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ORIGINAL PAPER

A combined GIS and remote sensing approach for monitoring climate change-related land degradation to support landscape preservation and planning tools: the Basilicata case study

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Abstract

Monitoring landscapes in times of climate change patterns is a crucial issue, moreover, in the analyzed Mediterranean area, one of the major global candidates to develop land degradation stresses and consequential desertification phenomena. The research presented here is developed in the Mediterranean Basin, specifically in the Basilicata Region (southern Italy). The region is characterized by a very long history of intensive anthropization endowed by the high diversity of relatively geologically young soil types that consequentially created a vastity of spatial mosaics, which contributed to the composition of its archeolandscapes and endorsed some specific characteristics of the Mediterranean region, that evolved to respond to the human impact, including grazing, cultivation, and fires. Those key elements lead to the crucial issues of the region investigated here as soil erosion, salinization, loss of organic carbon, loss of biodiversity, and landslides, which together with deforestations, depopulation, and wildfires, define the exact framework of degradation and marginality. The evaluation of the sensitivity to degradation was performed (i) firstly at the regional scale, through a MEDALUS (Kosmas et al. 1999) approach, by implementing 6 main indicators (Soil Quality Index, Climate Quality Index, Vegetation Quality Index, Management Quality Index, Landslide Risk Index, Water Availability Index), and (ii) secondly at the mid-regional scale, through remote sensing by evaluation of the NDVI differencing thresholds in time intervals, covering a 20 years' time span going from 2000 to 2020. The study helped to define the in-progress land degradation trends and scenarios of the region, which must be the evidence-based foundation of integrated landscape planning strategies in marginal territories, implemented through a Decision Support System (DSS) based both on ecological, climate-adaptive, and environmental indicators, and on social, cultural, and economic development co-creation strategies.

Keywords Desertification · Land degradation · Agricultural landscape · Remote sensing · Marginal areas · Landscape conservation and planning

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Introduction

Climate change in a globalized world

Human activities are at the core of global environmental change. Humans play a key role global warming, land degradation, air and water pollution, rising sea levels, eroding the ozone layer, extensive deforestation, and acidification of the oceans, which is driving Earth's sixth "mass extinction" (Crutzen 2002). The population of the Earth, now over 8 billion, is projected to increase to between 10 and 12 billion by the end of this century (Cherlet et al. 2018). This does not bode well for the future since the planet has a finite capacity to support humanity, especially in the face of continued resource depletion and environmental change.

Currently, humans appropriate 20 to 25% of the Earth's annual net primary production (NPP) from land, while representing less than 1% of the total global mass of organisms (Haberl et al. 2007). Through mining industries, humans move more sediment into the ocean than all the world's rivers combined (Crutzen 2002). About 45% of Earth's land surface is dedicated to livestock and livestock-feed production (Steinfeld et al. 2006). Increasingly, the Earth is transforming into an "urban planet": by 2050, over two-thirds of the world's population will reside in cities. The current rate of human consumption creates enormous pressures on the natural resources of the globe, and, within the context of Earth's finite boundaries, the current footprint of humankind is not sustainable (Hoekstra 2014). By 2050, the world's population will likely grow to more than 9 billion (Reynolds & Stafford 2002). Supporting 2 billion more people will require more agricultural production not only to satisfy demands for food but also to meet the need for fiber, biofuels, and chemicals to sustain the global economy. However, increasing food production will be one of humanity's greatest challenges since global agriculture is at the nexus of many complex and interconnected issues, including food production, preservation of biodiversity, energy and water systems, climate change, declining water resources, land and air pollution, floods, and land and soil degradation (Cherlet et al. 2018, Prince 2016).

Definition of land degradation (LD)

Soil is a nest of living organisms. It feeds us and we all depend on it even though it covers the earth in a thin layer that is only a few dozen centimeters thick. It is the site of intense activity and home to an extremely rich ecosystem. Insects, worms, and the billions of bacteria that live in soil digest mineral plant and animal matter like a huge stomach, then they convert this matter into the nutrients necessary for plant growth. These plants will in turn provide food for human beings and animals. But, the fine layer around the earth is delicate and in dry and arid environments, it is particularly vulnerable. It can take 500 years for 2.5 cm of soil to form, but only a few years to destroy it (Cherlet et al. 2018). This is called desertification. Desertification refers to land degradation resulting from climactic variations and human activities. It is not a natural process, but the result of mankind's actions today. What fosters the land degradation process, and the desertification process is the overexploitation of natural resources in vulnerable areas. It is a major threat to humanity and the environment (Vieira et al. 2015). The first authoritative approach to the topic was in the 1950s for UNESCO's Arid Zone Program, a crucial point for the international community to recognize that land degradation/desertification was a major economic, social, and environmental problem of concern to many countries in all regions of the world (Fig. 1).

The Arid Zone Program gave the background in 1977 for the United Nations Conference on Desertification (UNCOD) which was the first to adopt a Plan of Action to Combat Desertification (PACD), which indicated the desertification in "the reduction of the biological potential of the soil which can lead to desert conditions," a definition considered partial today, but which in fact captures the ultimate effect of desertification processes: a persistent and irreversible decline of the biological productivity of a given territory and therefore of its possibilities of use for agricultural, pastoral, or forestry purposes. After several years, the question of how to tackle desertification was still a major concern for the United Nations Conference on Environment and Development (UNCED), which was held in Rio de Janeiro in 1992. The Rio Conference solicited the United Nations General Assembly to form an Intergovernmental Negotiating Committee (INCD) to prepare, by June 1994, a Convention to Combat Desertification, particularly in Africa. The General Assembly agreed in December 1992, and adopted the resolution 47/188 on this matter. This resulted in the United Nations Convention to Combat Drought and Desertification (UNCCD) which ended in describing desertification as the "land degradation in arid, semi-arid and dry sub-humid areas, resulting from various factors, including climatic variations and human activities" (UNCCD 1996) (Fig. 2).

According to this definition, desertification is a form of land degradation in drylands with predisposing factors and anthropogenic causes contributing to the triggering of those processes of land degradation that lead to a decline in soil functions, in soil capacity to support biological or economic productivity, and a loss of diversity in croplands, pastures, or forests, with negative effects on human survival and ecosystems (Trotta et al. 2015) (Fig. 3).

Commensurate with the theme of human domination of the Earth, the modern paradigm of "desertification" and land degradation is based on interactions and feedbacks between social and ecological systems (Reynolds et al. 2007). The basic building blocks are coupled socioecological systems (SESs), which permit structured, interdisciplinary inquiry to assess the social (economics, culture, politics, etc.) and ecological (biotic, abiotic) dimensions of sustainable resource use, development, and management (Cherlet et al. 2018).

LD in Mediterranean Basin

The world's five Mediterranean-climate regions are renowned for huge levels of plant richness and endemism (Heywood 1993; Cowling et al. 1996). Despite of that, the Mediterranean is one of the most imperiled ecosystems, due to the undergone land use changes and so biodiversity losses, which are estimated to escalate by 2100 (Sala

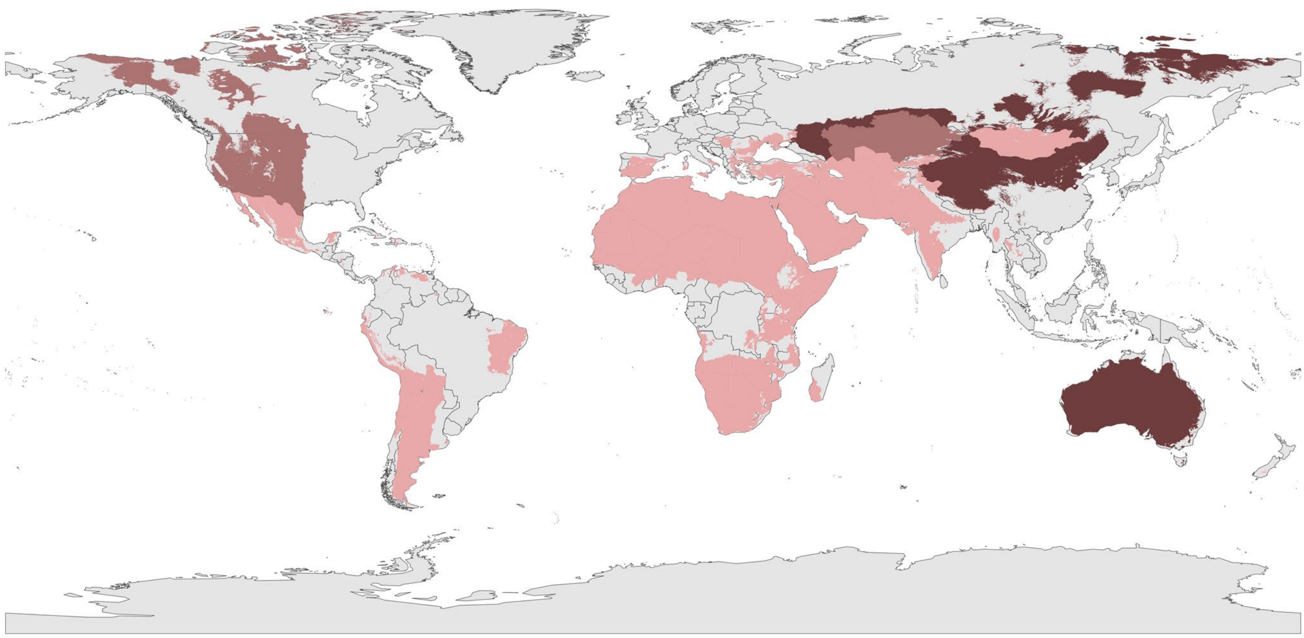

Fig. 1 Patterns of aridity 1981–2010. The observed global distribution of the climate classes over the periods from 1951 to 1980 and 1981 to 2010 (Spinoni et al. 2015)

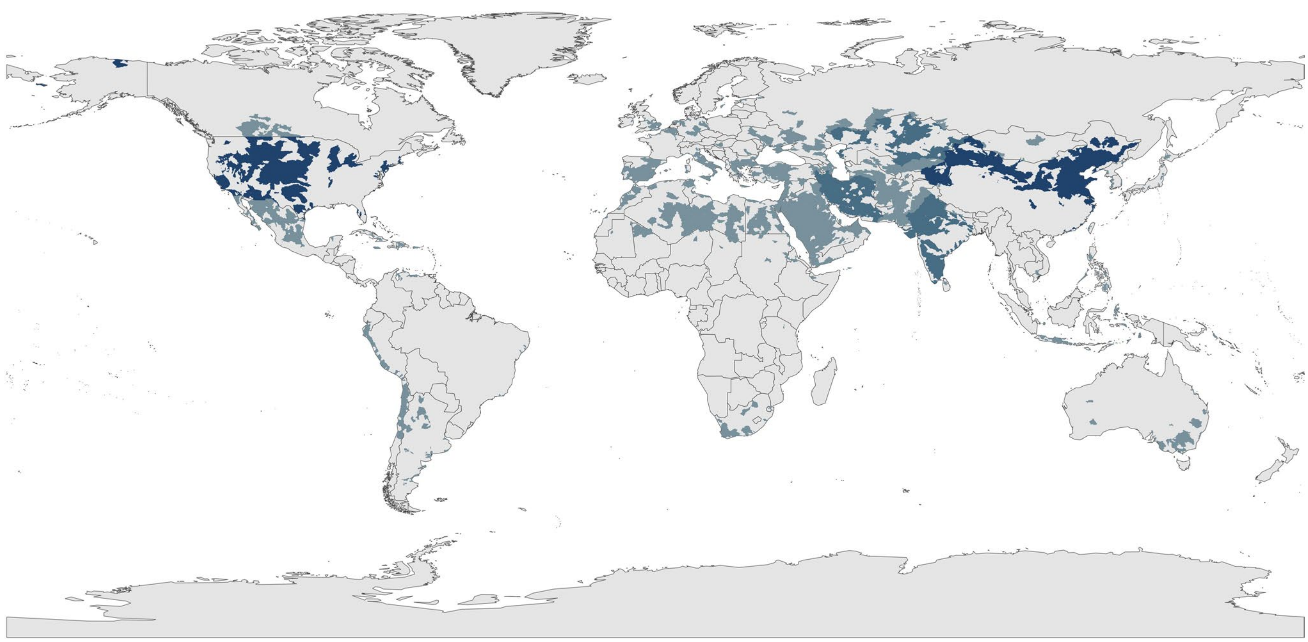

Fig. 2 The Water Stress Indicator is a measure of chronic human-induced stress deriving from the agriculture, domestic, and industrial sectors (Gassert et al. 2014)

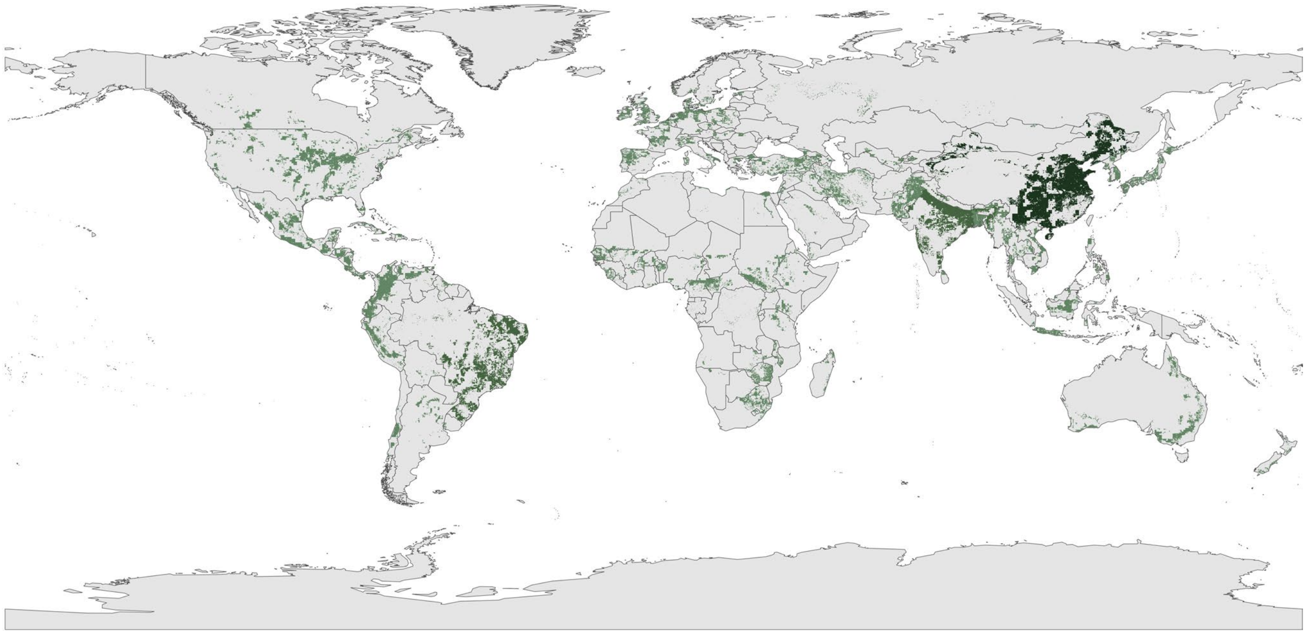

Fig. 3 Nitrogen surplus exists. Calculated based on the N balance level remained above the fourth quantile, meaning that there is more nitrogen than the crop needs (Latham et al. 2014)

et al. 2000). In the five Mediterranean regions research work provide evidence that these threats are also of concern to Mediterranean biodiversity: e.g., population density and growth of urban areas (Rouget et al. 2003; Schwartz et al. 2006), conversion to agriculture (Le Houérou 1981; Hobbs and Norton 1996), and conversion of natural areas for tourism-related development (Grenon & Batisse 1989; Paskoff & Manriquez 1999). The Mediterranean Basin of Europe is increasingly affected by desertification. Studies have reported these areas to be often impacted by soil erosion, salinization, loss of soil organic carbon, loss of biodiversity, and landslides (Montanarella & Tóth 2008). The extended period of elevated temperatures and low rainfall in Europe in the summer of 2018 reminded the pressing importance of this problem. The European Environment Agency (EEA) in 2008, carried out a 1.68 million km^2 desertification study in southern, central, and eastern Europe. In 2017, a follow-up study (Prăvălie et al. 2017a), based on the same methodology, was carried out. This research showed that the amount of territory with a high or remarkably high sensitivity to desertification had increased by 177.000 km^2, an area approximately equivalent to the size of Greece and Slovakia combined, in less than a decade. The Mediterranean Basin is tectonically active and subject to frequent earthquakes. Soils are young in geological terms and highly vulnerable to erosion, while the climate is characterized by an unequal annual distribution of rainfall which appears to be uneven, as 80% falls from October to March, in the torrential rain pattern. Summers are hot and dry, and the topography is often rugged, when one adds the extended periods of overgrazing, deforestation, and wildfires, one has the "perfect ingredients" for land degradation (Zdruli et al. 2017). In Mediterranean contexts, drivers of land degradation are usually classified as environmental factors and human pressures (Francaviglia 2011). Microclimate conditions related to the exposure of the slopes that are unfavorable to the regeneration of vegetation can be identified as relevant, indirect drivers of land degradation too (Salvati e al. 2008). Also, the soil structure is altered using unsuitable agricultural machinery which ends up enhancing soil compaction by reducing water infiltration capacity and increasing soil erosion. The irregular soil management fostered by heavy and inadequately applied mechanization leads to soil degradation, mostly due to the use of inadequate soil cultivation (e.g., plowing) in agricultural production. As in fact, the plowing result in soil compaction is a proof of the application of heavy machinery on clay soils. This process of soil degradation prevented water infiltration in deeper layers which leads to the stagnation of water in the surface layer (Colantoni et al. 2015; Zambon et al. 2017).

One of the principal determinants of LD in Mediterranean rural areas is the adoption of unsustainable production behaviors especially in agriculture (Mendelsohn & Dinar 2003). Farmers cultivating rented land show less propensity to invest money in land protection, e.g., by adopting agronomic techniques to preserve landscape and soil quality. They prefer to arrange crop production with the aim to maximize immediate profits, thus generating serious ecological consequences. This behavior was due to the last decades of European and country-specific subsidies and policies that have been based on the stimulation of intensive agriculture with the idea of overcoming the problem of food production, resulting in low profits and negative impacts on the environment. Because of low profitability, the areas are often abandoned when the subsidies stop, with consequent soil erosion. For the inland areas, this process leads to a feedback mechanism linked to rural depopulation and human desertification due to the lack of development possibilities.

Literature review

The cross-sectorial effects of desertification have attracted the interest of political institutions and research communities that progressively supported the development of different methods of analysis based on empirical approaches. In the field of environmental sciences, for the estimation of vulnerability, the understanding of the processes that can be fruitful to investigate in between the different typologies of land degradation (caused both by anthropic factors and natural processes) is possible by using multi-sourced data concerning vegetation, fauna, air, meteorology, hydrology, etc. (Trotta et al. 2015). The literature review had a specific focus on the Mediterranean area, covering approximately 20 years of studies, by using as searching engine widely accepted scientific repositories such as Google Scholar, Scopus, and Web-of-Science implementing research frameworks tackling some desertification-related keywords. The review wanted to frame an overall world-renowned scientific methodology for assessing regional desertification, inclusive of the peculiarity of the place taken into consideration, that could also be rigorous and guarantee an important feedback from the scientific community.

First literature review

A first evaluation defined that for the keyword "sensitivity," "land degradation," "desertification," and "UNCCD," the respective methodology used worldwide—with a specific interest for the ones used in Italy and in the Mediterranean area (as in the case of the national evaluation of the desertification risk indexes in Italy, Ceccarelli et al. 2006)—was the MEDALUS (MEditerranean Desertification And Land Use) methodology for assessing ESAs (Environmentally Sensitive Areas) in large-scale areas, belonging to the MEDALUS projects, financed by the European Commission from 1991 to 1999. Still, even after the project was concluded, the MEDALUS methodology proved to be one of the most used ones to monitor land sensitivity to degradation and desertification all over the world (Ferrara et al. 2020). The original methodology is based on the evaluation of 4 indexes: Climate Quality Index (CQI), Soil Quality Index (SQI), Vegetation Quality Index (VQI), and Management Quality Index (MQI) (Kosmas et al. 1999). Each index is scored and then its geometric mean value is used for assessing a classification of the LD prone areas, better known as the Environmentally Sensitive Area Index (ESAI). The method progressively found numerous applications, assuming the role of standard and uniformly shared methodology, while respecting the local peculiarities of the territory.

It is also important to mention other significative models which came up in this first literature review for the assessment of desertification or land degradation as The Global Assessment of Human-induced Soil Degradation (GLASOD) (Oldeman et al. 1993), and recently LADA (Tengberg 2002; Ponce Hernandez & Koohafkan 2004). GLASOD has been the most influential global appraisal of land quality in terms of environmental policy. However, its judgments were never tested for their consistency. GLASOD model is hardly reproduced and is not widely used in literature. The LADA model has been set up by FAO, UNEP-GEF, and various other partners to assess land degradation in dryland areas (Ponce Hernandez & Koohafkan 2004). Set in the larger context of the Driving Forces–Pressures–States–Impacts–Responses (DPSIR) framework, the LADA project was mainly a Decision Support for Mainstreaming and Scaling up of Sustainable Land Management (DS-SML) (2015–2018). In the Italian panorama, the DPSIR framework is found in the "National Atlas of Desertification in Italy" (Costantini et al. 2007), a study that was intended as a first step to creating an information system to analyze the phenomenon of desertification at national level (Costantini et al. 2007).

Fine tuning of the first literature review

After this first literature review, the methodology defined as the more suitable and valid was the MEDALUS (Kosmas et al. 1999). Its framework was then partially adjusted following the last 10 years of scientific innovations and implementation of this index in the Mediterranean research field, after reviewing the large-scale analysis of adjusted and innovated versions of MEDALUS methodology, taking into consideration scientifically valuable cases in Italy (Canora et al. 2015; Colantoni et al.

2015; Coluzzi et al. 2019; Ferrara et al. 2010; Ladisa et al. 2012; Trotta et al. 2015; Salvati & Bajocco 2011; Salvati et al. 2013), in Asia (Lee et al. 2019), in the rest of Europe (Karamesouti et al. 2018; Contador et al. 2009), in northern Africa (Lamqadem et al. 2018), and in the Middle East (Bakr et al. 2012). MEDALUS methodology also developed the Global-ESA project, a 3-year program (2017–2019) aimed to integrate the globally available datasets with the extensive knowledge on local-scale desertification processes, as developed over the last 20 years by the ESA (Environmental Sensitive Areas) methodology applications, into a comprehensive worldwide coherent framework. Those recent studies confirmed the adaptability and flexibility of the ESA framework to be suitable for the application in different worldwide areas, stressing the importance on the harmonization of regional/country level studies and applications, and the more efficient use of global level datasets (Ferrara et al. 2020).

Second literature review

The second literature review had the aim to find an indicator that could be efficient in rapidly evaluating the LD at a mid-regional scale, considering a time span of 20 years (2000–2020). The studies taken into consideration had the common line of enlightening a cause-effect correlation between the aggravation of desertification and the damage of the surface vegetation which could be seen using Vegetation Indexes (VIs) applied to Remote Sensing (RS) techniques. These elements mainly caused a biomass and surface vegetation reduction, resulting in a lower VI in the remote sensing image (Schlesinger et al. 1990; Zeng et al. 2006; Pan & Li 2013; Becerril-Pina et al. 2016). It is reasonable to say that, due to the complexity of different light spectra combinations, instrumentation, platforms, and resolutions used, there is not a unified mathematical expression that defines all VIs. Still, among the VIs, Normalized Difference Vegetation Index (NDVI) is one of the most extensively applied for its sensitivity to the presence, density, and condition of vegetation. It is a simple numerical indicator that can be used for remote sensing measurements. The NDVI, first suggested and demonstrated by Rouse et al. (1974) and Tucker (1979), has been the most used indicator to map spatial and temporal variation in vegetation. Thus, it has been additionally employed as an indicator of land cover change and desertification as an adequate proxy for vegetation productivity profitably used in various biogeographic regions and at different spatial scales (D'Emilio et al. 2018; Sulla-Menashe et al. 2018). Therefore, temporal analysis of satellite-based NDVI is one of the major remote sensing tools which can identify the depletion of vegetation cover (Kundu et al. 2017) and it is of considerable value as an indicator of environmental change (Eastman et al. 2013). In this case study, the NDVI has been used within the framework methodology of NDVI differencing threshold for land cover change detection, which is an immediate effective method for assessing LUCs, evaluated by comparing vegetation indices from satellite data among different dates (Lyon et al. 1998). This is a methodology that has been widely documented in change detection research and favored for its accuracy, simplicity in computation, and ease in interpretation (Singh 1986; Muchoney & Haack 1994; Green et al. 1994; Coppin & Bauer 1996; Macleod & Congalton 1998; Mancino et al. 2014).

Concluding, NDVI differencing and classification methods are the most common procedures for detecting and monitoring land use changes. In a process commonly called "change detection," image time series acquired from different dates are compared to analyze the spectral difference (change), caused by land use/land cover (LU/LC) change between the two dates while trying to normalize other conditions to similar levels during that period. In general, multidate remote sensing data can be used for this purpose (Coppin et al. 2004; Lu et al. 2004).

A dynamic archeolandscape: the Basilicata case study

Landscape as the result of the interaction between natural and cultural factors

Seventy years ago, the concept of landscape was an aesthetic perception of "Natural Beauty" and in various European countries, natural heritage preservation laws were issued in order to protect "panoramic beauty" and "beautiful areas" that could be admired from specific viewpoints.

The Landscape was an area where natural or manmade features created a beautiful picture with an aesthetic value. During the twentieth century, the concept of the landscape became the one of a territory interpreted by the human beings that had been building or modifying it over the centuries. Thus, this needs to be considered as the result of a succession of transformations, and layers of the signs and places where the history of mankind has left its traces, whether these might be major "monuments" or simply the land organization to cultivate and produce. The landscape is a widespread construction, often involving the entire population (especially peasants and farmers), using construction techniques that differ from area to area and using locally available materials. Furthermore, it consists of perishable or unstable materials (vegetation, water, soil, stones, etc.) that require ongoing management and maintenance.

These features particularly characterize the agricultural landscape more for their widespread nature (building materials, construction types, settlement systems) than for their specific stylistic and architectonic components.

Through this, over the last decades, the aesthetic criteria (beautiful place or panorama) have been replaced by a new criterion that considers the landscape as the link between the natural and historical aspects, as the result of the man and nature work, so including human activities.

The landscape is of course part of our history, which operates on natural environmental pictures through man interventions. A landscape is dynamic, and it is a space of various extension for a time of various duration. The lasting works of man, as structures and infrastructures necessary for his life, for his economic, cultural, and spiritual actions, overlap the natural substrate and fit into a historical legacy in the process of progressive enrichment.

The European Landscape Convention (ELC, Florence, October 2000) issued that landscape means "an area as perceived by people, whose character is the result of the action and interaction of natural and/or human factors" and it is "an essential component of people's surrounding, an expression of the diversity of their shared cultural and natural heritage, and a foundation of their identity," so "the landscape contributes to the formation of local cultures and that it is a basic component of the European natural and cultural heritage, contributing to human well-being and consolidation of the European identity" (ELC, 2000).

For landscape-related issues, the ELC is an essential cultural benchmark both in terms of method and practices, highlighting the need to develop exchange and cooperation between centralized and local bodies, universities, research centers, and cultural associations in European countries. It also underscores how landscapes present cultural, ecological, environmental, and social significance. It is a resource that aids business and, if suitably protected, managed, and planned, can even help create employment.

The Convention emphasizes the need for governments to consider and plan the entire territory and all landscapes, not only those of special importance but also those seen as ordinary or degraded, "acknowledging that the landscape is an important part of the quality of life for people everywhere: in urban areas and in the countryside, in degraded areas as well as in areas of high quality, in areas recognised as being of outstanding beauty as well as everyday areas" (ELC, 2000).

The complex of natural and cultural features must be analyzed to manage, valorize, and rehabilitate outstanding and ordinary landscapes in their dynamic changing.

In this regard, Roberto Gambino considers that "the ELC suggests a shift from the concept of cultural landscape to the concept of the cultural significance of every landscape. Every landscape, even if "ordinary" or "common" or also degraded or partially destroyed, express a specific cultural meaning and witnesses the past or ongoing processes of civilization. In this sense each landscape is a cultural landscape, or more precisely a place of cultural mediation" (Gambino 2010).

The landscape in fact is the result of the collective transformation of nature and it is the cultural projection of a society in a specific area. This does not refer only to the tangible side but also to the spiritual and symbolic ones. Human societies, through their cultures, transform the original natural landscapes not only with the material aspects they bring (methods and types of construction) but also by transferring their values and sentiments onto the landscape. The landscape is the place that contains the experiences and aspirations of the people, with a wealth of meanings and symbols that express a range of thinking, ideas, and emotions.

The Landscape is a heritage and it is dynamic, it can assimilate and integrate natural and cultural changes and transformations, but if the changes are too intense and fast, they cause an impact that the landscape cannot absorb. The problem is not the transformation of the landscape, but the type and meaning of transformation: in the last decades, too often urban expansion, industrial development, commercial and tourist settlements, infrastructures, and intensive agriculture, associated with climate and socioeconomic changes have caused a severe alteration of the landscape and its often irreversible decay. Some areas are marginalized, and others are made uniform, erasing the historical identity. The respect for natural values and cultural traditions should not be considered as a limit or a brake for development and innovation. It must be the necessary starting point for creating an awareness that determines the correct insertion and connection of new anthropic elements. These will gradually implement the stratification of the landscape, yet been shaped and designed in the last millennia by the interaction between man and the environment, for the purpose of mutual survival.

It is now absolutely necessary to consider the landscape for its systemic characteristic, a set of anthropic and natural elements that represent its founding components in order to re-establish the complexity of its values, as a complex process of interactions and reciprocal adaptations (Jakob 2009).

In addition to what has already been indicated, it is necessary to note that seeing the landscape merely as a composition of the various architectural and natural elements is limiting if one does not consider not only the immaterial heritage but also the relationship with "Mother Earth." The landscape needs to be seen as the outcome of a sustainable, community design/plan that is implemented by respecting the places and resources that are present.

This means recognizing the value of the landscape as a concrete expression of the informed and sustainable transformation of natural resources and, consequently, it means understanding that, in this, the balance between human needs and available resources is fundamental to the continued vitality of a specific territory.

In this regard, again Roberto Gambino underlines: "Over the past three decades, the landscape has gained a growing importance in the territory management and planning processes and in the contemporary society perceptions, expectations, hopes and fears. The landscape matter reflects the necessity of redefining the relations between man and Earth.

The landscape matter seems designated to worsen and to become more and more complex concerning:

- The "scaling up" of many environmental problems, such as those directly linked to "global change," which are facing increasing difficulties in monitoring, regulation and government;
- The growing interference of the environmental issues with the economic and social ones, such as those concerning poverty, access to water and to the primary resources, access to information and culture" (Gambino 2010).

All this considered, it is therefore important to support the knowledge of cultural and traditional landscapes as a tool to strengthen the identity of communities and to better valorize fragile and deteriorated areas.

The Basilicata historic agriculture landscape

The landscape of Basilicata has very ancient origins that date back to the Mesolithic period. Important Greek colonies were founded from in seventh century BC, defining the landscape settlement. The subsequent Roman conquest from the third century BC continued a complex and articulated work of anthropization that is still legible.

In this regard, Emilio Sereni, in his famous book dedicated to the history of the Italian agricultural landscape, describes a document of inestimable value, the Table of Eraclea which "allows us to understand exactly the features of this agricultural landscape, as it appeared towards the end of the 4th Century BC on the lands around the temple of Athena Poliade, in Eraclea of Lucania." The document demonstrates the regular shape of the fields, served by a complex network of roads and smaller plots intended for the vineyard. In the Greek period, the cultivated areas are in fact precisely designed and delimited from those uncultivated or destined for grazing with the construction of roads, walls, canals, edges, and the fields assume regular geometric shapes (Sereni 1961).

The Roman intervention represents a further moment of profound transformation of the Basilicata landscape, especially due to a new road and water network linked to the plot limitation (limit) to be assigned to the settlers and the construction of many new rural buildings. As a consequence, inevitable changes happened in the crop kind and production system, with the development of the centuriation settlement and the creation of important road and water works that have left evident traces on the landscape.

Historical cartography between the sixteenth and eighteenth centuries documents a territory rich in wooded areas, still referring to the ancient one compared to the current one, transformed in the last century. The landscape represented by the historic cartographers was complex: in the mountain and hilly areas, it was rich in spring waters and valleys, covered with various vegetation: woods, vineyards, and olive groves and near the villages orchards and gardens. In the flatter areas, there was a uniform and slightly undulating landscape, with cereal cultivation associated with sheep grazing characterized by numerous caves used as shelters by shepherds. This landscape demonstrates the permanence of the Roman Era settlement and management: only the Modern age has radically changed it, with extensive deforestation and land transformation.

Currently, the arable land areas extend over a third of the regional territory and constitute not only one of the main components of the Basilicata landscape system but also the most fragile one. The open-field structure (openness) of these landscapes has a significant aesthetic-perceptive value and makes us recognize the atmosphere and the sense of places, the perception of a long-lasting history of adaptation, survival, and landscape anthropization. At the same time, all this is extremely fragile: openess is often understood and perceived as an empty space, without particular ecological and landscape values, that can therefore be occupied, filled with various development proposals (photovoltaic and wind power plants, tourist facilities, intensive crops), increased by the market difficulties that are weakening the traditional cereal productive economies at the base of these vast landscapes.

All this considered, it is evident that pastoralism practiced by transhumance and agriculture in Basilicata has very ancient origins. Traditional agricultural activities include well-known dairy products, cereal crops in the flat areas, e.g., wheat to produce the famous pasta, vineyards and olive groves along the slopes of the hills, and pastures and woods in the mountain areas. Over the centuries, this agricultural landscape has stratified, linking with rural buildings, urban centers, and infrastructures and connecting with the natural landscape forming a complex system of historic relationships between the work of man and the work of nature.

In this regard, it is important to remember that Basilicata presents agricultural landscapes of particular historical-cultural and productive value, included in the National Register of Traditional Rural Landscapes (Agnoletti 2010) that still show ancient settlements and represent significant archeolandscapes. They are specifically:

– The chestnut groves of Vulture-Melfese of both considerable perceptive-landscape value and high historical-identity value, considering that already the Constitution of Melfi (1231) issued regulations aimed at protecting the chestnut groves.
– The pastures of the Murgia Materana: the anthropic presence in the area is documented from the Paleolithic, and

archeological finds from the Greek and Roman period emerge in various locations. In ancient times, this landscape was managed by shepherds and herdsmen who lived in small villages obtained from the adaptation of natural caves connected to dry stone sheepfolds. The archeological importance of the area is also linked to its numerous rural churches that dot the area, dating back from the early Middle Ages to the nineteenth century.
- The olive groves of Ferrandina: the value of tradition is here linked to the permanence of the terraced cultivation of olive trees, whose origins in the area date back to the period of Magna Graecia. The landscape is strongly characterized by olive trees alternating with arable land, vegetable gardens, and woods. The historical value of the olive groves of Ferrandina is documented by the presence of monumental ancient trees. The abandonment of the countryside and the interruption of traditional cultivation practices represent a significant risk factor for the terraced olive growing around Ferrandina.
- The Aglianico vineyards in the Volture: of both considerable aesthetic-landscape value and historic significance. The cultivation of the vine grapes and the culture of wine date back to the VII-VI century BC. The origin of the name of this vine seems perhaps to derive from Ellenico, which became Aglianico around the sixteenth century. One of the greatest current strengths is the high qualitative value of Aglianico del Vulture, a wine appreciated all over the world and already recognized by the DOCG certification. From the landscape settlement point of view, the vineyards represent small tiles within a heterogeneous landscape characterized by chestnut groves, woods, arable land, and olive groves.

The intensive deforestation, depopulation, and the marked signs during the nineteenth–twentieth century

As previously demonstrated, the Basilicata landscape is the result of multiple human–environment-climate interactions that have driven its ecological dynamics throughout the Holocene. Still, southern Italy remained essentially peripheral to the process of integration between agriculture and livestock which, by the spread of fodder crops and the intensification of bovine breeding of stallion character, defined the Northern Italy economy. In Basilicata, transhumant sheep-farming was the prevalent component and there was limited supply even for cattle, apart from a few restricted areas, with the predominance of the wild breeding system. This condition of absolute insufficiency and weak relationship—almost of separate coexistence—with the agricultural practice worsened during the transition from the late nineteenth to the early twentieth century, shaping the agricultural landscape of the region by two related phenomena, (i) the defeat of feudalism and the sale of the huge ecclesiastical patrimony confiscated after the establishment of the Unitary State; (ii) the new land structure that derived from it, which accelerated the deforestation of the region, radically transforming the landscape. So, the agrarian landscape of Basilicata faced the new century substantially transformed and the most relevant element was the deforestation. The first forest law of 1877 (law n. 3917 of 20 June 1877), promoted by Salvatore Maiorana Calatabiano, laid the legal basis for massive deforestation, as observed (Lacava 1903), from 1861 the clearing of the state-municipal property was accentuated without regulatory rules. The precise data on the phenomenon are not precisely known due to some discrepancies in the data collection systems in the various decades; however, two estimates were made to get an idea of the size of the aggression suffered by the forest heritage of the region. In 1860, there were about 380,000 hectares of forests in Lucania while in 1930, there were just 130,000 hectares, reduced to 150,000 in the 1950s (Fontana 2004). This transformation had a significant impact on the landscape. A completely desolate landscape began to emerge, with the blackening of the fallow plots, the fences, the hedges, and the ditches closing the land owned properties (Sereni 1961). This is the "agrarian landscape" of Basilicata which manifests itself to the Prime Minister Zanardelli during his journey of 1902: the phenomenon of deforestation, which in just 50 years halved the Lucanian forests, is reported in all its evidence and in all the danger showed in his technical analysis. Here, the livestock production was completely incapable—due to size, composition of species, and breeding systems—to satisfy the needs of organic fertilizer in agriculture, dominated by cereal crops. The problematics exacerbated between the two wars, due to the agrarian policy of fascism, a reform that should have been carried out in the eighteenth century and pursued a just and necessary, but anachronistic reform goal, achieved late, when peasant society was now about to be absorbed and dissolved in industrial society. The reform worsened the implications related to the degradation of the soils and to the pressure of its water bodies: in fact, the complete realization of the irrigation works triggered that specialization process towards an intense irrigated agriculture with a higher rate of profitability, entailing a whole series of negative externalities in environmental terms; specifically, the availability of water resources, increased by canalization and adduction works, paved the way for intensive cultivation, with heavy loads on the soil quality and its degradation patterns. In the second half of the twentieth century, the development of industrial agriculture, with the growing mechanization of production processes and the strong expansion of chemical fertilization together with the parallel intensification and production specialization of livestock farming, determined also in the South of Italy a radical transformation of the landscape, characterized by recurring patterns of high-value ecosystems in contexts of depauperated, prone to desertification areas.

Today's regional LD pressures and trends

Land degradation in the Basilicata Region is caused by a variety of complex and interrelated processes, besides the climate, and geomorphological and socioeconomic issues. These processes can be ascribed to soil erosion, vegetation degradation, land use changes, and climate variability (Piccarreta et al. 2006; Rendell 1986; Salvati & Carlucci 2010). The main factors affecting environmental sensitivity to degradation in the region are by their intrinsic characteristics soil, vegetation, climate, and management fostered by their interaction with the landscape. European and national policies, together with technological development and commercial strategies, led to a production based on monoculture and soil intensive exploitation. Moreover, the inappropriate use of production means for intense agricultural systems and improper forest management have initiated land degradation in many regions (INEA 1999), including Basilicata. Agricultural soils in Basilicata underwent continuous degradation during the last century, with acceleration in the last 30 years due to the introduction of Common Agricultural Policy (CAP) measures (Rendell 1986; Sonnino et al. 1998), such as Reg. CEE 1765/92 concerning the subsidies to cultivate durum wheat (first on production and the uncultivated areas) and Reg. CEE 2078/92 regarding the F measure (20 years—set-aside) (Piccarreta et al. 2006). In Basilicata, the first CAP measure favored the reclamation of bushy lands and badlands for durum wheat cultivation owing to the great economic advantages. Reclamation of badlands is known as "remodeling" and implies the flattening of the landforms, reduction of slope angles (~20°), and breaking up of the soil surface. The exposed larger surface area results in more rapid wetting, increased slaking, and an increased tendency for soils to chemically disperse (Phillips 1998). Subsequently, the second measure has determined the abandonment of several remodeled areas, especially of badlands, which are characterized by low productivity. The seasonal cultivation of durum wheat and cereals and the frequent abandonment of some of these areas deeply increased the erosion effectiveness of natural processes over these lands, causing degradation conditions, as in other Mediterranean areas (Kosmas et al. 2000; Dunjó et al. 2003).

Former regional studies framing LD

The National Action Plan to Combat Drought and Desertification (PAN) was the main instrument identified by the United Nations Convention to Combat Desertification (UNCCD 1994) in order to identify the factors that contribute to desertification and outline actions and useful measures to counter back the phenomenon. The PALs (Local Action Plans), drawn up in various Italian regions, converged and contributed to the drafting of the PAN. It is important to take into consideration the Basilicata PAL, as it was the first instrument that arose awareness concerning the land degradation and desertification issues in the region. During its elaboration, the PAL benefited from the new Rural Development Plan for 2007–2013. This favorable situation made it possible for the definition of territorial policies and actions to contrast degradation. The Basilicata PAL developed the true analysis with specific indicators on a well-defined area of the region, identified as potentially vulnerable within the MEDALUS framework (Kosmas et al. 1999). The PAL analysis focused on the regional territory of "Montagna Materana" which presented areas with a very marked land deterioration situation, in some cases irreversible, particularly in the eastern portion of the area. Measures were defined, related to territorial planning, to establish management policies aimed at soil protection, sustainable management of water resources, and territorial rebalancing, in line with the main territorial vocations and community activism. This methodology was a good starting point for addressing marginalities and degradation, unfortunately slightly abandoned over the years.

Materials and methods

MEDALUS methodology applied to Basilicata context

MEDALUS methodology in its original framework relies on the evaluation of four main indicators that then are used to compute the final ESAI, and are CQI, SQI, VQI, and MQI (Kosmas et al. 1999).

To obtain these indicators, it is necessary to process a series of variables or sub-indicators that represent the parameters from which to evaluate both the environmental and anthropogenic aspects of one studied area. Those are the direct or indirect responsibity of land sensitivity to degradation phenomena and are determined by climate, soil, and vegetation conditions, together within the land management specificities. Essentially, each indicator is obtained by integrating and processing geographic variable data (as geometric mean), used as thematic raster layers in a GIS environment. The entire susceptibility procedure is then applied by grouping the environmental parameters/variables in several sensitivity classes, according to the original MEDALUS methodological scheme (Kosmas et al. 1999). Then, each sub-indicator is scored in classes that have a certain score value (ranging from 1, which indicates a low land degradation sensitivity, to 2, which indicates a high sensitivity to degradation). Then, to obtain the main quality indicators, the sub-indicators are processed by their geometric mean. To evaluate the ESAI final indicator, the weighted classes of the main quality indicators are processed using the same averaging procedure. For this case study, the weight factors to score the sub-indicators relied, where possible, on previous literature studies dealing with similar geomorphological situations (Kosmas et al. 2014; Prăvălie et al. 2017b; Salvati et al. 2013; Vieira et al. 2015; Tavares et al. 2015; Salvati & Bajocco 2011). Other added sub-indicators and consequential new main indicators, which were more related to the Basilicata case study, have then been implemented, scored, and calibrated on the area characteristics, by the quality and quantity of the input data and on the characteristics of the study area, deriving a final more accurate ESAI sensitivity map. One of the final goals of the work was to adjust and implement, with the aforementioned regional characteristics-driven methodology, the previous ESAIs quality index indicators presented in Gabriele et al. 2020) taking into consideration main aspects strongly related to the inner traits of the Basilicata Region (i.e., Landslide Risk Index and Water Availability Index), for assessing in a more precise way its desertification sensitivity, in order to preserve land resources, and so to be able to implement more appropriate measures for a future DSS, to prevent or slow down the process of land degradation. In addition to the four main environmental indicators, this approach also considered other indicators to help assessing land sensitivity to degradation, such as the Landslide Risk Index (LRI) and the Water Availability Index (WAI). These indicators, added to the ones featured in the original methodological scheme, were useful for a more accurate assessment of land sensitivity to degradation. On one hand, LRI assesses one of the historical LD treat of the Basilicata Region, which strongly defined its geomorphology, enhanced by the deforestation operations. On the other hand, WAI assesses the water availability in a region that has undergone a huge water stress due to the water control activities for the agricultural purposes, while suffering from aridity and water scarcity. By these two indicators, MEDALUS methodology was implemented with new variables added to the basic indicators CQI, SQI, VQI, and MQI, considering the methodology's adaptability and flexibility according to local and national conditions (Contador et al. 2009; Bakr et al. 2012; Prăvălie et al. 2017b). Finally, using GIS tools (GQIS 3.8 software), the six indicators were processed. All indicators and sub-indicators were analyzed based on raster data and processed according to the best available spatial resolution. Also, this research outlined mask areas, consisting of artificialized areas and water surfaces, considering the fact these areas cannot be interpreted/investigated in terms of land susceptibility to degradation with this index (Prăvălie et al. 2017b). More specifically the masking was done, by using the CORINE Land Cover (CLC) database (2018 edition), highly anthropized land use classes (continuous urban fabric, discontinuous urban fabric, industrial or commercial units, road and rail networks, and associated land, port areas, airports, dump sites, construction sites, green urban areas, sport, and leisure facilities), as well as water-covered areas (water courses, water bodies, coastal lagoons, sea, and ocean) (Fig. 4).

Landslide Risk Index

The LRI was implemented from the geometric average of two sub-indexes as landslide risk and distance from faults, and calculated as the following Eq. (1):

$$LRI_{ij} = (Landslide\ Risk_{ij} \times Distance\ from\ Faults_{ij})^{1/2} \quad (1)$$

The knowledge of the spatial distribution of landslide phenomena is crucial to investigating many issues of landscape evolution and its relationships with human activities and land management. The Italian territory is largely affected by landslide phenomena, which caused victims and damage to infrastructures as well as cultural heritage. In the Basilicata Region, mass movement processes are mainly related to the intrinsic fragility of the landscape, which is featured by high relief and widespread outcrops of clay-rich deposits. Historically, Basilicata has been described as "the most degraded region of southern Italy" as a result of the widespread soil erosion and landslides that it experiences (Kayser 1958). The situation of the region becomes worse during the twentieth century, when the municipality had become almost completely deforested. These events, combined with the undercapitalized cereal farming started during the 20's and finalized in the 50's with the Agrarian Reform, accelerated erosion and with it, the danger of landslides. For that reasons, the landslide phenomena were taken into consideration in the current plan for the defense against hydrogeological risk (PAI Basilicata). The plan determines the risk classes based on the elements and relationships intercurrent between the mapped landslide element and the elements within its perimeter. The landslide risk is in this way defined as the expected degree of loss (in terms of loss of life, people injured, damage to properties, and disruption of economic activities) due to a landslide in each area and for a defined timespan. The risk classes from the plan were used for scoring the risk classes in the MEDALUS classification, keeping the same values (Table 1). Assignment of the risk class (R4, R3, R2, R1, and P) was defined as extracted from the Hydrological Authority Plan:

R4 = area in which it is possible to establish phenomena such as to cause the loss of human lives and/or serious injuries to people, severe damage to buildings and infra-

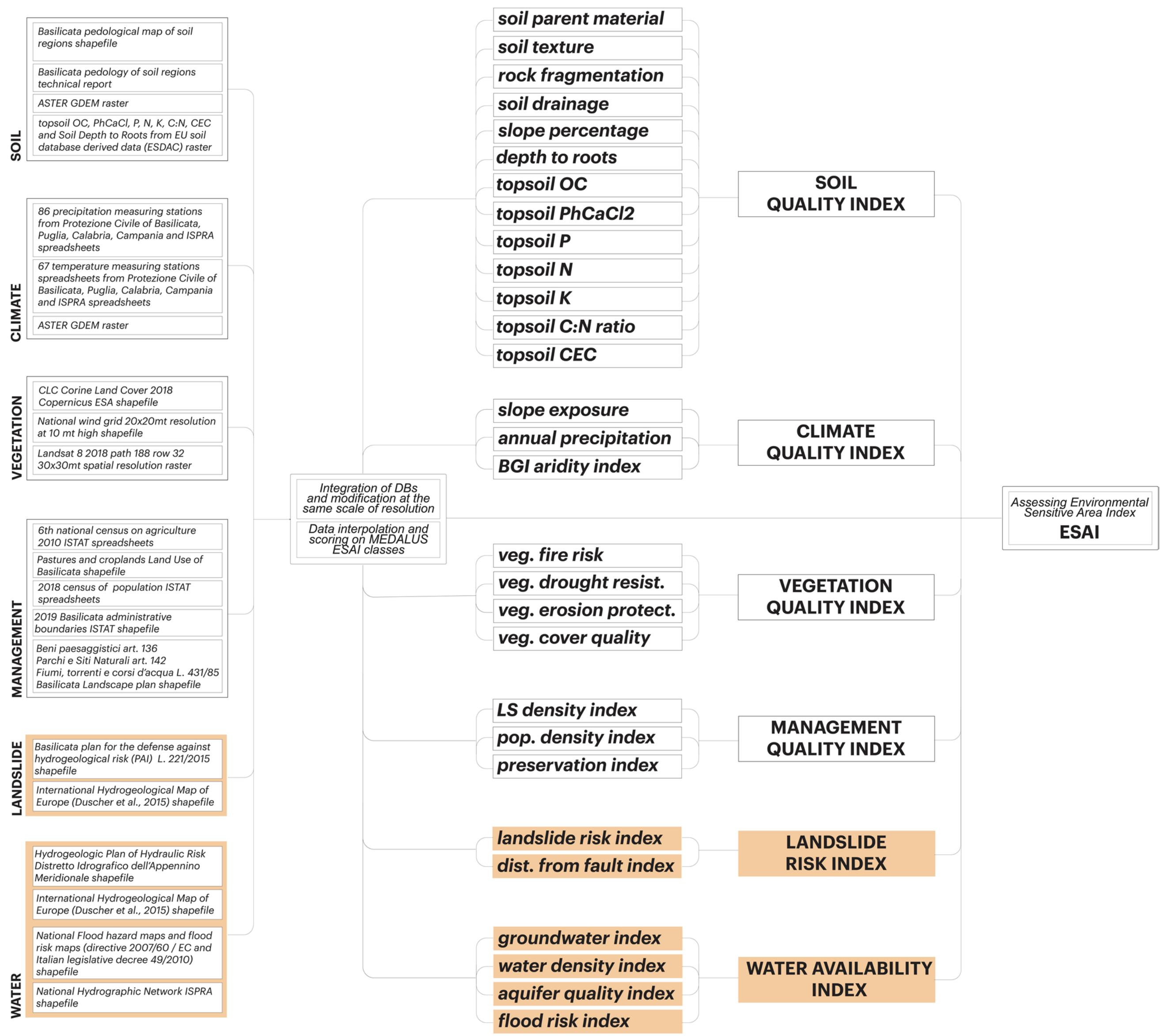

Fig. 4 Proposed workflow for the evaluation of the Environmental Sensitive Area Index

structures, damage to the environmental and cultural heritage, the destruction of socioeconomic activities;
R3 = area where it is possible to establish phenomena involving risks for the safety of people, functional damage to buildings and infrastructures with consequent inaccessibility of the same, the interruption of socioeconomic activities, damage to the environmental and cultural heritage;
R2 = area where it is possible to establish phenomena involving minor damage to buildings, infrastructure and environmental heritage, which do not affect the economic activities and the usability of the buildings;
R1 = area where it is possible to establish phenomena involving marginal social and economic damage to the environmental and cultural heritage;
P = area which, although presenting conditions of instability or propensity for instability, affects areas that are not populated and almost always without exposed goods and, therefore, do not directly threaten the safety of people and do not directly cause damage to goods and infrastructure;
ASV = (areas subject to hydrogeological verification) areas in which there are phenomena of instability and instability, active or quiescent, to be subjected to specific recognition and verification.

Table 1 Landslide Risk Index (LRI) scores

Description	Value	Scoring
Landslide risk (LRI sub-indicator)		
Risk ASV	Areas subject to hydrogeological verification	1.2
Risk P	Areas that are not populated and mostly without exposed goods	1.2
Risk R1	Marginal social and economic damage	1.4
Risk R2	Minor damage to buildings, infrastructure and environment	1.5
Risk R3	Risks for the safety of people, functional damage to buildings and infrastructures	1.8
Risk R4	Loss of human lives and/or serious injuries to people, severe damage to buildings and infrastructures	2.0
Distance	Tipology	Scoring
Distance from faults (LRI sub-indicator)		
100 mt	Fault	2.0
100 mt	Overthrust	1.9
100 mt	Supposed overthrust	1.8
200 mt	Fault	1.9
200 mt	Overthrust	1.8
200 mt	Supposed overthrust	1.7
300 mt	Fault	1.8
300 mt	Overthrust	1.7
300 mt	Supposed overthrust	1.6
400 mt	Fault	1.7
400 mt	Overthrust	1.6
400 mt	Supposed overthrust	1.5
500 mt	Fault	1.6
500 mt	Overthrust	1.5
500 mt	Supposed overthrust	1.4
600 mt	Fault	1.5
600 mt	Overthrust	1.4
600 mt	Supposed overthrust	1.3
700 mt	Fault	1.4
700 mt	Overthrust	1.3
700 mt	Supposed overthrust	1.2
800 mt	Fault	1.3
800 mt	Overthrust	1.2
800 mt	Supposed overthrust	1.2
900–1000 mt	Fault	1.2
900–1000 mt	Overthrust	1.1
900–1000 mt	Supposed overthrust	1.1
Description	Value	Scoring
Landslide Risk Index (LRI indicator)		
Low risk	Low	< 1.25
Medium risk	Moderate	1.25–1.50
High risk	High	> 1.51

For the distance from faults sub-index, the faults database was extracted from the International Hydrogeological Map of Europe (Duscher et al. 2015) and then scored within a MEDALUS framework. The linear data was firstly buffered for 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 mt. Then the symmetrical difference intersection of the distances was carried out between intervals of 100 mt. Buffers were used for two reasons: (1) faults weaken surrounding rocks and material, and (2) when referring to larger scale geologic maps, it is evident that there are numerous smaller faults dispersed outward from the major faults illustrated in the large-scale map at distances over 1 000 m (Wachal & Hudak 2000). Generally, as the distance from faults increases, landslide frequency decreases (Sarkar et al. 1995; Gökceoglu & Aksoy 1996; Pachauri et al. 1998), so the scores were firstly given based on distance and then on the typology of fault (fault, overthrust, supposed overthrust). The result of the LRI is presented in Fig. 5.

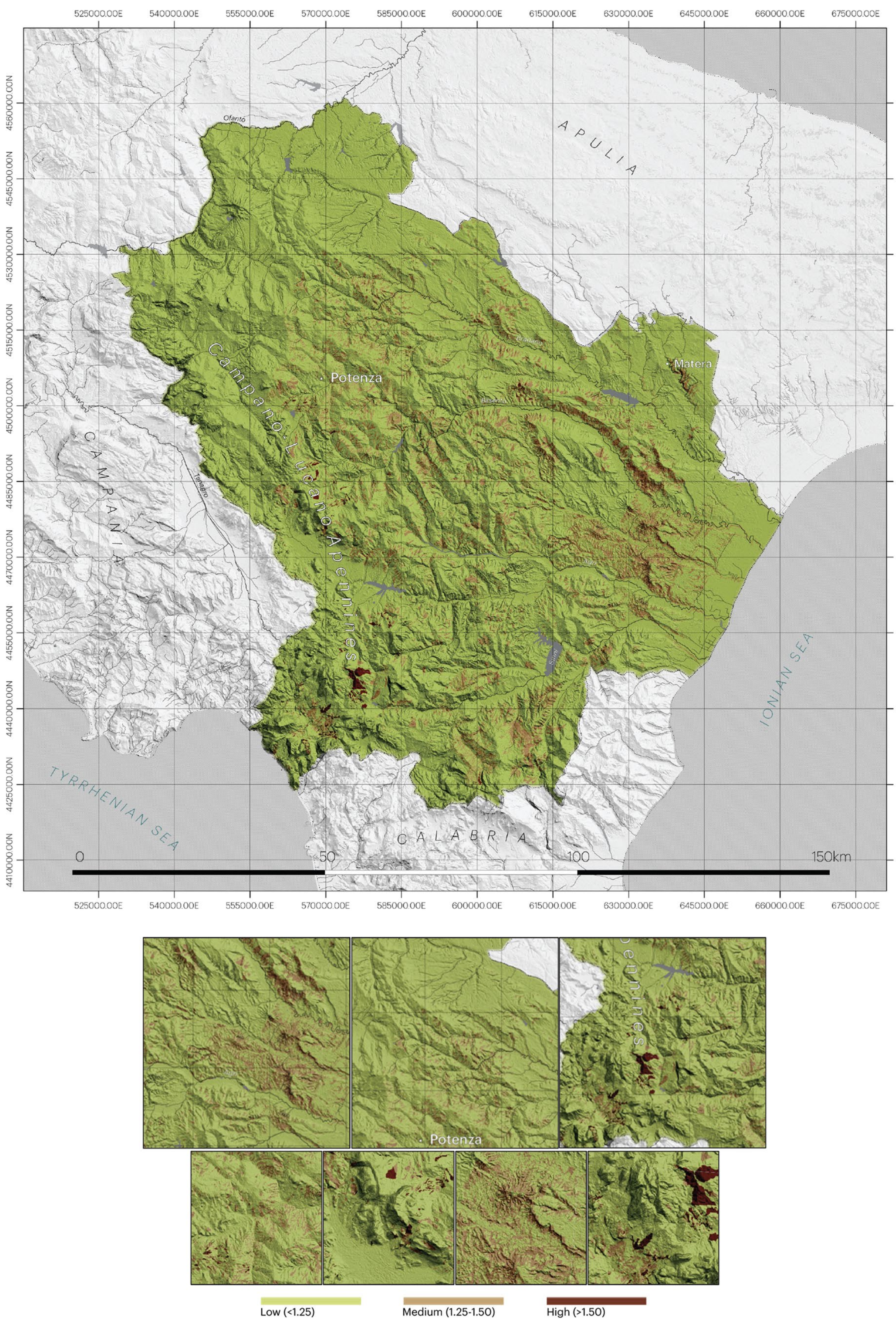

Fig. 5 Reclassified Landslide Risk Index

Water Availability Index

The WAI was implemented from the geometric average of four sub-indexes as water density, groundwater bodies quality, flood risk, and aquifer productivity, and calculated as in Eq. (2):

$$WAIij = (Water\ Densityij \times Groundwater\ Bodies\ Qualityij \times Flood\ Riskij \times Aquifer\ Productivityij)^{1/4} \quad (2)$$

Water density was obtained by classifying the shape file of water streams extracted from the drainage basin authority into rule classes based on the official national classification. National classification is based on the following typologies of water courses as "ALVEO ANTICO", "CANALE", "FIUMARA", "FIUMARELLA", "FIUME", "FOSSO", "PANTANO", "RIO", "TORRENTE", "VALLE", "VALLONE," each one defined by an "order" going between 1 and 9, stating its hierarchical importance and its waterflow. The Shapefile was firstly buffered in a QGIS environment, with a buffer of 100 mt, to obtain a new areal file for the following geoprocessing. Then, a chainage of the watercourse with a fixed distance point-to-point of 10 mt was carried out in the QGIS environment with the QChainage plugin, to get a point file containing the values of each water stream with a 10 mt interval. Point density per square kilometer was then determined in a Surfer environment with the gridding function. The resulting spatial distribution was adjusted in the QGIS environment with a kernel function with GRASS useful to smooth the spatial variation, to obtain a natural data distribution. The water streams were grouped into 5 classes by equal intervals and then scored within a MEDALUS framework classification as the following: from 0.3 to 2.5 the assigned value with the assigned value of 2.0; from 2.5 to 4.7 with the assigned value of 1.6; from 4.7 to 6.9 with the assigned value of 1.3; from 6.9 to 9.2 with the assigned value of 1.0 (Table 2).

The different hydrologic structures of the regional aquifers were taken into consideration to study the groundwater bodies quality. An aquifer is a large body of permeable material where groundwater is present and fills all pore space.

Table 2 Water Availability Index (WAI) scores

Description	Value	Scoring
Groundwater bodies quality (WAI sub-indicator)		
Alluvial aquifer	Moderate/low permeability	1.5
Carbonate aquifer	High permeability	1.0
Karst aquifer	High permeability	1.0
Coastal-alluvial aquifer	Moderate/low permeability	1.5
Marly limestone hydrostructure	Low or no permeability	2.0
Sandy-conglomerate aquifer	Low or no permeability	2.0
Volcanic aquifer	Low or no permeability	2.0
Carbonate hydrostructure	High permeability	1.0
Sandy-conglomeratic hydrostructure	Low or no permeability	2.0
Water density (WAI sub-indicator)		
Low density	0.3 to 2.5	2.0
Medium–low density	2.5 to 4.7	1.6
Medium–high density	4.7 to 6.9	1.3
High density	6.9 to 9.2	1.0
Flood risk (WAI sub-indicator)		
R2–R3 risk	Medium risk	1.5
R4	Elevated risk	1.0
Aquifer productivity (WAI sub-indicator)		
Highly productive porous aquifers	Good	1.0
Inland water	Good	1.0
Locally aquiferous rocks, porous, or fissured	Good	1.0
Low and moderately productive fissured aquifers	Medium	1.5
(including karstified rocks)	Medium	1.5
Low and moderately productive porous aquifers	Low	2.0
Practically non-aquiferous rocks, porous, or fissured		
Water quality index (WAI indicator)		
High water availability	High	< 1.2
Moderate water availability	Moderate	1.2–1.4
Low water availability	Low	> 1.4

Aquifers must not only be permeable but must also be porous and are found to include rock types such as sandstones, conglomerates, fractured limestone and unconsolidated sand, gravels, and fractured volcanic rocks (columnar basalts). While some aquifers have high porosity and low permeability, others have high porosity and high productivity. Those with high porosity and low permeability are referred to as poor aquifers and include rocks or geological formation such as granites and schist while those with high porosity and high permeability are regarded as excellent aquifers and include rocks like fractured volcanic rocks (Martínez-Austria & Bandala 2018). Good aquifers are those with high permeability such as poorly cemented sands, gravels, or highly fractured rock. A cross-check between the national level studies as the Management Plan of the Hydrographic District of the Southern Apennines shows the high-water potential of the hydrogeological structures and flat areas that are close to the regional borders, with aquifers of national and regional importance, that are the main conspicuous sources for drinking, irrigation, and industrial use. They aim at satisfying the needs of the most populated areas of the Regions and the portions of lands belonging to the Hydrographic District, but also of regional territories outside the Hydrographic District. In this regard, the major aquifers of national and regional importance are the carbonate hydrostructures, characterized by high permeability due to fracturing and karst. The transboundary aquifers dataset used for collecting information regarding groundwater bodies was requested from UNESCO-IHP (International Hydrogeological Programme) (IGRAC 2015) and then MEDALUS-scored according to the local aquifers definitions and descriptions found in the Southern Apennine District's report on "Update and revision of the maps of danger and flood risk drawn up in pursuant to art. 6 of Legislative Decree. 49/2010 implementation of Dir. 2007/60/EC-II management cycle."

Flood risk was calculated from the National Flood hazard maps and flood risk maps (directive 2007/60/EC and Italian legislative decree 49/2010), for the area of Distretto dell' Appennino Meridionale (Southern Apennine District). Datasets covered the regional basins of Basento, Cavone, Agri, and Bradano. The Italian Legislative Decree 49/2010 provides that risk maps must represent 4 risk classes, covering from R1 (minimal risk) to R4 (elevated risk). Risk classes refer to the Prime Ministerial Decree of 29 September 1998 and are expressed in terms of:

a) Indicative number of potentially affected inhabitants;
b) Infrastructures and strategic structures (motorways, railways, hospitals, schools, etc.);
c) Environmental, historical, and cultural assets of significant interest potentially present in the area interested;
d) Distribution and typology of economic activities persisting in the potentially affected area;
e) Plants referred to in Annex I of Legislative Decree 59/2005 which could cause accidental pollution in case of flood and protected areas referred to in Annex 9 to Part III of Legislative Decree 152/2006;
f) Other information deemed useful by district authorities, such as flood-prone areas with high volume of solid transport and debris flows or information on relevant sources of pollution.

The risk classes where scored based on MEDALUS framework, giving 1.5 to the medium risk classes (R2–R3) and 2.0 to the high-risk classes (R4). The symmetrical difference of the area of the region that resulted not invested by flooding risk was classified as 1.0 and then rasterized within a resolution of 30×30 mt.

The aquifer productivity data were extracted from the International Hydrogeological Map of Europe, which is the digitalization of a series of approximately 30 general hydrogeological maps covering nearly the whole European continent and parts of the Near East, financially supported by the Government of the Federal Republic of Germany through the Federal Institute for Geosciences and Natural Resources (BGR) and by the United Nations Educational, Scientific and Cultural Organization (UNESCO) (Duscher et al. 2015). The productivity of the aquifers in the Basilicata Region is defined by 5 categories, such as highly productive fissured aquifers (including karstified rocks); highly productive porous aquifers; inland water; locally aquiferous rocks, porous or fissured; low and moderately productive fissured aquifers (including karstified rocks); low and moderately productive porous aquifers; and practically non-aquiferous rocks, porous, or fissured. This dataset was also scored within a MEDALUS approach, crossing the (Duscher et al. 2015) European aquifers classification within the local peculiarities of the aquifers found in the Southern Apennine District's report on "Update and revision of the maps of danger and flood risk drawn up in according to art. 6 of Legislative Decree. 49/2010 implementation of Dir. 2007/60/EC-II management cycle," and then rasterized within a resolution of 30×30 mt (Fig. 6).

Final ESAI evaluation in the Basilicata Region and observations

The first MEDALUS method identified the areas of the region more likely to be sensible to desertification through the ESAs index. Starting with the described methodology (Kosmas et al. 1999), the model parameters were implemented and then processed with a GIS-based approach, to evaluate soil, climate, management, and vegetation quality factors (Gabriele et al. 2020), which represented the

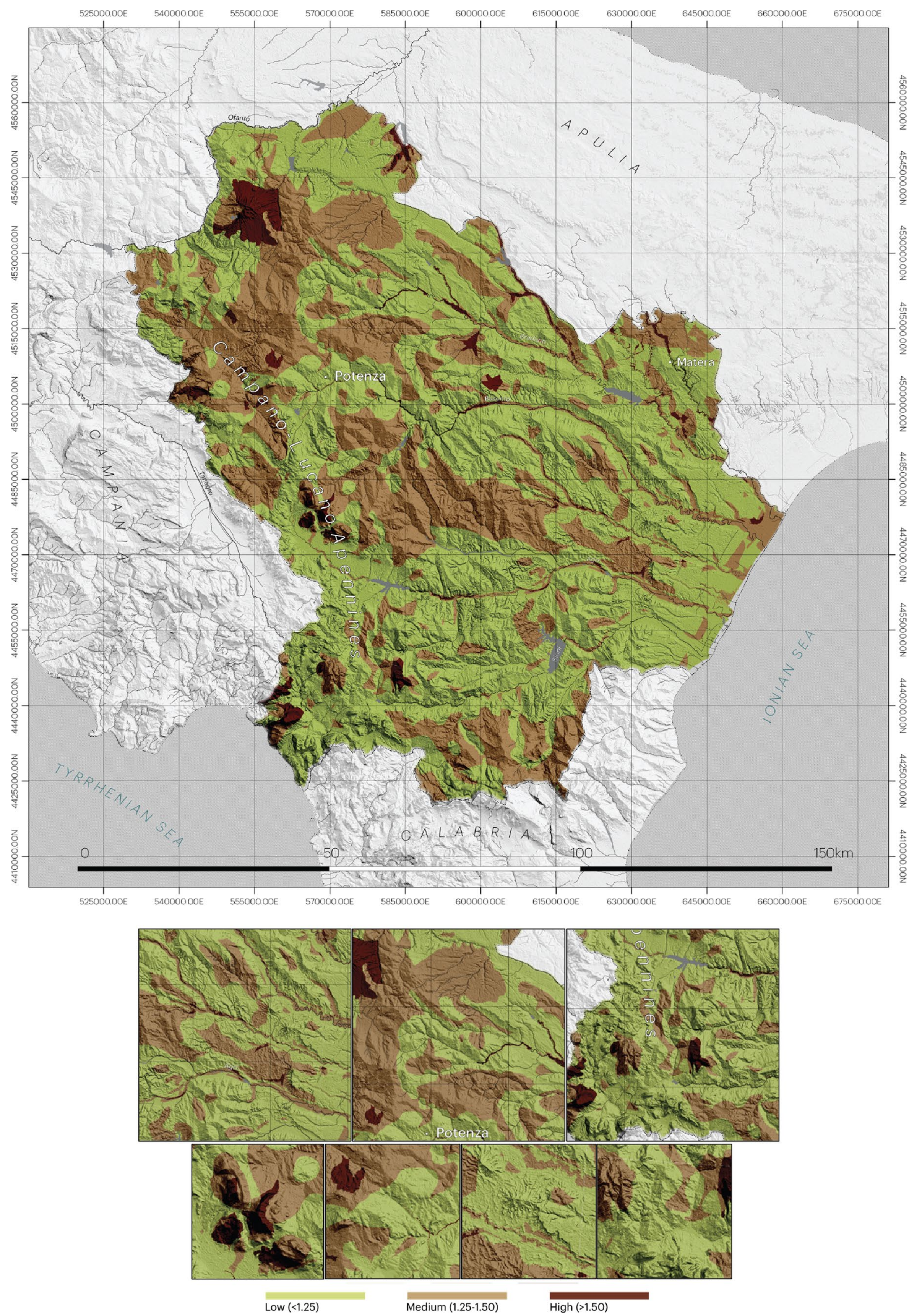

Fig. 6 Reclassified Landslide Risk Index

necessary input for assessing ESAs. The abovementioned previous study showed that the accessibility to the datasets was not immediate. This issue, which was a huge constraint, revealed the possibility to partly innovate the consulted literature, finding new methods to analyze and implement the available data; moreover, it motivated both the addiction of the LRI and of the WAI, developed within the context of this new study. This contributed to defining with more precision the land degradation risk. The approach based on the MEDALUS methodology essentially highlights not only the threat of land degradation but also, to a certain extent, that of desertification. As previously mentioned, desertification represents any form of land degradation that occurs in drylands, i.e., the degradation of lands that are constantly subjected to aridity conditions corresponds, in fact, to desertification. The six quality indices were mapped to identify the spatial distribution in Basilicata. The final ESAI was evaluated as the geometric mean of the quality assessment based on the original methodology (Kosmas et al. 1999) (soil, climate, vegetation, and management quality indexes), together with landslide risk and water availability, classifying the area into four main classes (not affected (N), potentially affected (P), fragile (F), and critical (C)) and 8 sub-classes (N, P, F1, F2, F3; C1, C2, C3). ESAI, see Fig. 7, is expressed in Eq. (3):

$$ESAIij = (SQIij \times VQIij \times CQIij \times MQIij \times LRIij \times WAIij)^{1/6} \quad (3)$$

The spatial distribution of the ESAI defines 1317.560 km^2 for the non-affected areas (N sub-class); 2989.038 km^2 for the potential areas (P sub-class); 2843.366 km^2 for the first band fragile areas (F1); 2016.629 km^2 for the second band fragile areas (F2); 351.303 km^2 for the third band fragile areas (F3); 24.104 km^2 for the first band critical areas (C1); 1.589 km^2 for the second band critical areas (C2); there are no third band critical areas (C3).

The final calculation of the ESAI scores shows how much this region has a potential high-rate desertification, especially in the southern-eastern area, where agriculture, livestock, and soil degradation processes are concentrated. Furthermore, the results even imply that there is not a coherent strategic policy from the authorities for facing the future of the region and the consequences that will derive from the bad management, carrying huge losses from the economic, social, and ecologic point. It is therefore to be expected that these major hotspots with a high degradation potential will be affected by certain severe environmental issues such as declining agricultural productivity, decreases in the natural resilience of lands, soil infertility, or reduced water quality. These issues have already been highlighted in a broader land degradation context at the continental level (Cherlet et al. 2018). The detailed assessment of ESAIs is crucial to evaluate the combined effects of environmental and socioeconomic policies and to monitor human pressures that may lead to environmental degradation. Climate change conditions impact the landscape by worsening, stabilizing, or improving the environmental conditions that cause LD (Symeonakis et al. 2016). The Mediterranean landscape is rarely able to experience disturbances and preserve its environmental quality while changing (Tanrivermis 2003). Regularly updated data on ESAIs, with reliable indicators of land vulnerability to desertification, are critical information for regional management, planning, and conservation (Prenzel 2004; Freire et al. 2009).

NDVI differencing threshold and vegetation change detection

Image differencing is simply the subtraction of the pixel digital values of an image recorded at one date from the corresponding pixel values of the second date (Hayes & Sader 2001), the histogram of the resulting image depicts a range of pixel values from negative to positive numbers, where those clustered around zero represent no change and those at either tail represent reflectance changes from one image date to the next (Jensen 1996). In the land cover change detection with NDVI image differencing, ideally, if there exists a land cover change somewhere between two dates, the NDVI differencing image should have a pixel value greater than or small than 0. However, in reality, a threshold value based on the mean and standard deviation (SD) of NDVI differencing image is required in determining real change occurrence. The most crucial step for vegetation change detection analysis is discrimination between real changes and seasonal or inter-annual variability, represented by a threshold between these factors, which is generally determined by applying the SD from the NDVI differencing image (Hayes & Sader 2001; Coppin et al. 2004, Desclee et al. 2006; Pu et al. 2008). One difficulty encountered in employing image differencing for change detection is the selection of the appropriate threshold values in the histogram that separates real and spurious change. The subjectivity of threshold placement may be further improved by the analyst's familiarity with the study area as well as access to ancillary data such as field information, GIS data, and/or matching dates of aerial photography (Hayes & Sader 2001), and also it is important to mention the UAV (Unmanned Aerial Vehicles) validation on the data, not developed in this case.

As previously mentioned, the NDVI differencing method employs NDVI to differentiate images for mapping change/no-change pixels of land cover types. Among the Vegetation Index (VI) differencing methodologies for change detection the NDVI differencing method is widely quoted. Six Landsat TM cloud free images (path 188, row 32) with 30 × 30 m spatial resolution were analyzed. The images were acquired during the period in between 13 June and 16 August, for the following years: 2000 and 2019.

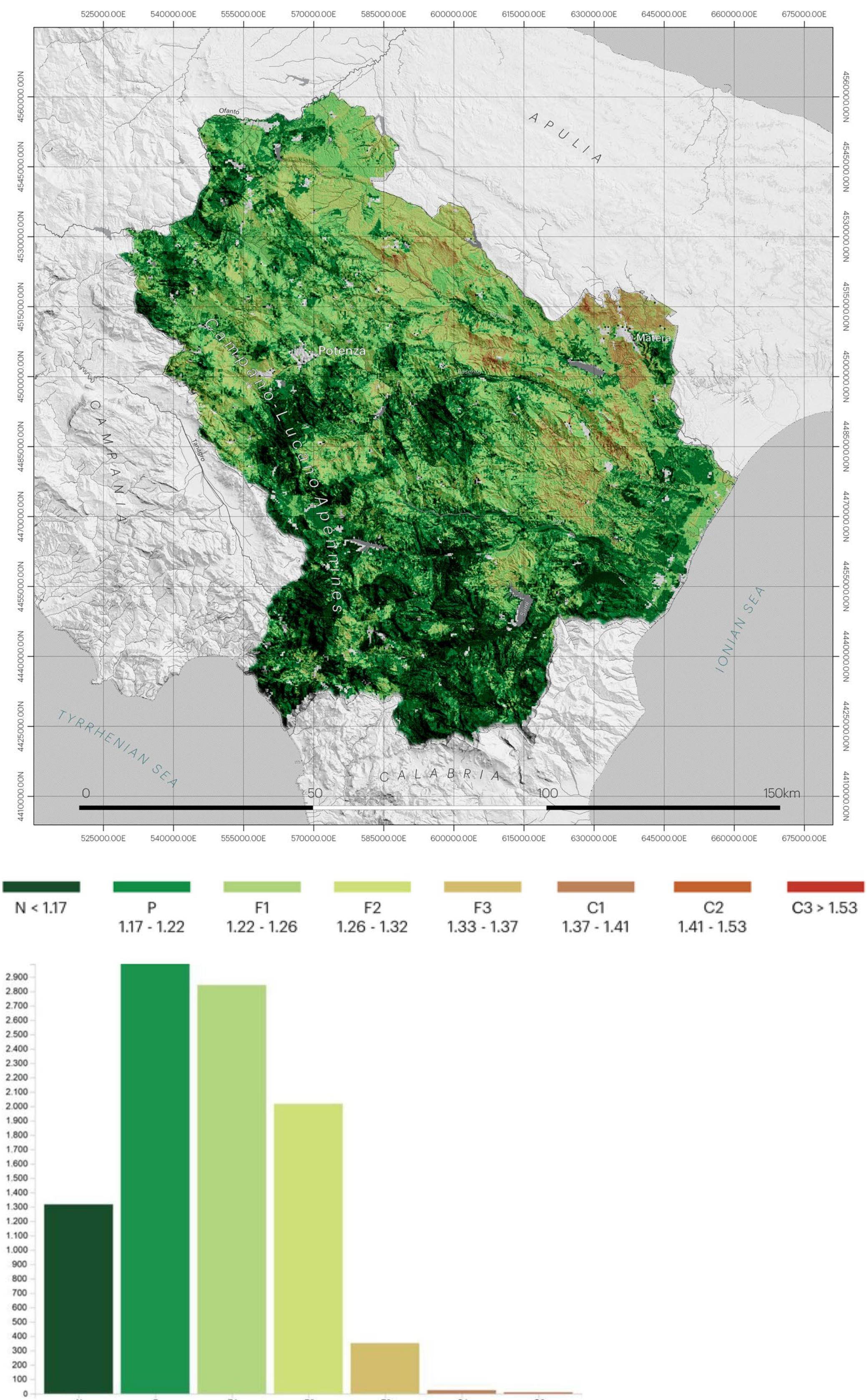

Fig. 7 ESAI in the Basilicata Region: spatialization of the index (top) and histogram of frequencies of different classes (bottom)

For the NDVI differencing method, an NDVI image for each of the studied years was first calculated with an NIR band and a RED band. Due to differences in atmospheric and land surface conditions, solar position, imaging geometry, and phenological stages, the images of the same area acquired from different dates exhibit differences (in digital number or radiance). That is why before analyzing the data, some processing was performed to normalize the data (to allow quantitative comparison between images) and remove atmospheric effects and noise in SCP (semi-automatic classification plugin in QGIS 3.8). Atmospheric correction removes the scattering and absorption effects from the atmosphere and allows to remove the effects of atmospheric scattering caused by light scattered by water vapor and aerosols, particularly at lower wavelengths in the blue part of the electro-magnetic spectrum. Dark Object Subtraction (DOS1 correction in SCP) is a common technique used for correcting atmospheric disturbances. It assumes that reflectance from dark objects includes a substantial component of atmospheric scattering. Hence, it measures the reflectance from a dark object, such as a deep lake, and subtracts that value from the image (Fig. 7, bottom).

Then, for each of the ΔNDVI images, was calculated its mean and standard deviation, with SAGA zonal statistics in QGIS 3.8. This was a necessary operation in order to get the key values for calculating the ΔNDVI difference.

The difference image ΔNDVI was then reclassified using a threshold value calculated as in Eq. (4)

$$\Delta NDVI = \mu \pm n \cdot \sigma \tag{4}$$

where μ represents the ΔNDVI pixels digital number mean, and σ the standard deviation. The threshold identifies three ranges in the normal distribution: (a) the left tail ($\Delta\text{NDVI} < \mu - n\cdot\sigma$); (b) the right tail ($\Delta\text{NDVI} > \mu + n\cdot\sigma$); and (c) the central region of the normal distribution ($\mu - n\cdot\sigma < \Delta\text{NDVI} < \mu + n\cdot\sigma$). Pixels within the two tails of the distribution are characterized by significant vegetation changes, while pixels in the central region represent no change. The n factor defines the range of dispersion around the mean. This study considered only the negative variation in vegetation cover defined as the area of probable land degradation.

Threshold identification for the detection of vegetation changes represents a key issue in the NDVI differencing method. The standard deviation (σ) is one of the most widely applied threshold identification approaches for different natural environments based on different remotely sensed imagery (Singh 1986; Jensen 1996; Coppin et al. 2004; Lu et al. 2004).

Generally, the threshold value is identified by $n\cdot\sigma$ of the NDVI difference image average, where the n value is identified by the trial and test method, and σ is the standard deviation of the pixel values density function in the change image. This approach exhibited viable results, and reliability for different forest ecosystems under both human-induced and natural land use changes, with threshold values between $1\cdot\sigma$ and $2\cdot\sigma$ supported in the literature (Mas 1999).

In the present study, the final identification of the best-fitting $n\cdot\sigma$ threshold value was based on visual analysis on the visual comparison of digital aerial orthophotos Ortofoto Italia 2000 MAATM and 2017 Ortofoto Basilicata datasets. In particular, a visual analysis based on three different threshold values ($1\cdot\sigma$, $1.5\cdot\sigma$, and $2\cdot\sigma$) was conducted using different thresholds over random points, within areas of detected agricultural LD processes. The chosen threshold value used for the NDVI image differencing classification was 1.5 and it is expressed with the following Eq. (5):

$$\Delta NDVI < \mu - 1.5 \cdot \sigma. \tag{5}$$

The chosen high-risk area

The chosen high-risk area for the study of NDVI differencing assessment is the Fossa Bradanica and a portion of Montagna Materana (Figs. 8 and 9). The area falls in the badland area of the Basilicata Region. Badlands are characterized by their steep, unvegetated slopes, high drainage densities, high rates of erosion, and a tendency for the formation of a regolith profile with desiccation cracks in the top 1–5 cm, creating a "popcorn" surface (Howard 1994). These are lands particularly prone to land degradation issues as their erosional features are formed from the Pleo-Pleistocene clay parent material. The high erodibility of these clays is a consequence of their tendency to disperse both chemically and physically.

Historically, as previously mentioned, in the post-reform period, intensive agriculture was concentrated in the valleys. The draining of the lowlands allowed industry and intensive, irrigated agriculture to develop in these areas. The economic benefits of the reforms, were restricted to the lowland valleys, which did not present badland formations. The uplands remained characterized by dry subsistence farming carried out by an aging population (King 1990), even though nowadays exposed to a market economy. In 1990, the CAP set-aside schemes halted any remodeling in Basilicata aimed at exploiting the increasing prices of durum wheat. Farmers then claimed the badlands as part of their set-aside land. Subsequently, reclamation of the badlands has been driven by CAP subsidies for durum wheat, again encouraging farmers to bring all their land into production. Remodeling of badlands is now a knowable proposition as the badlands of Basilicata are not vanishing. In fact, their reclamation goes through the manipulation of the environment. This is partly

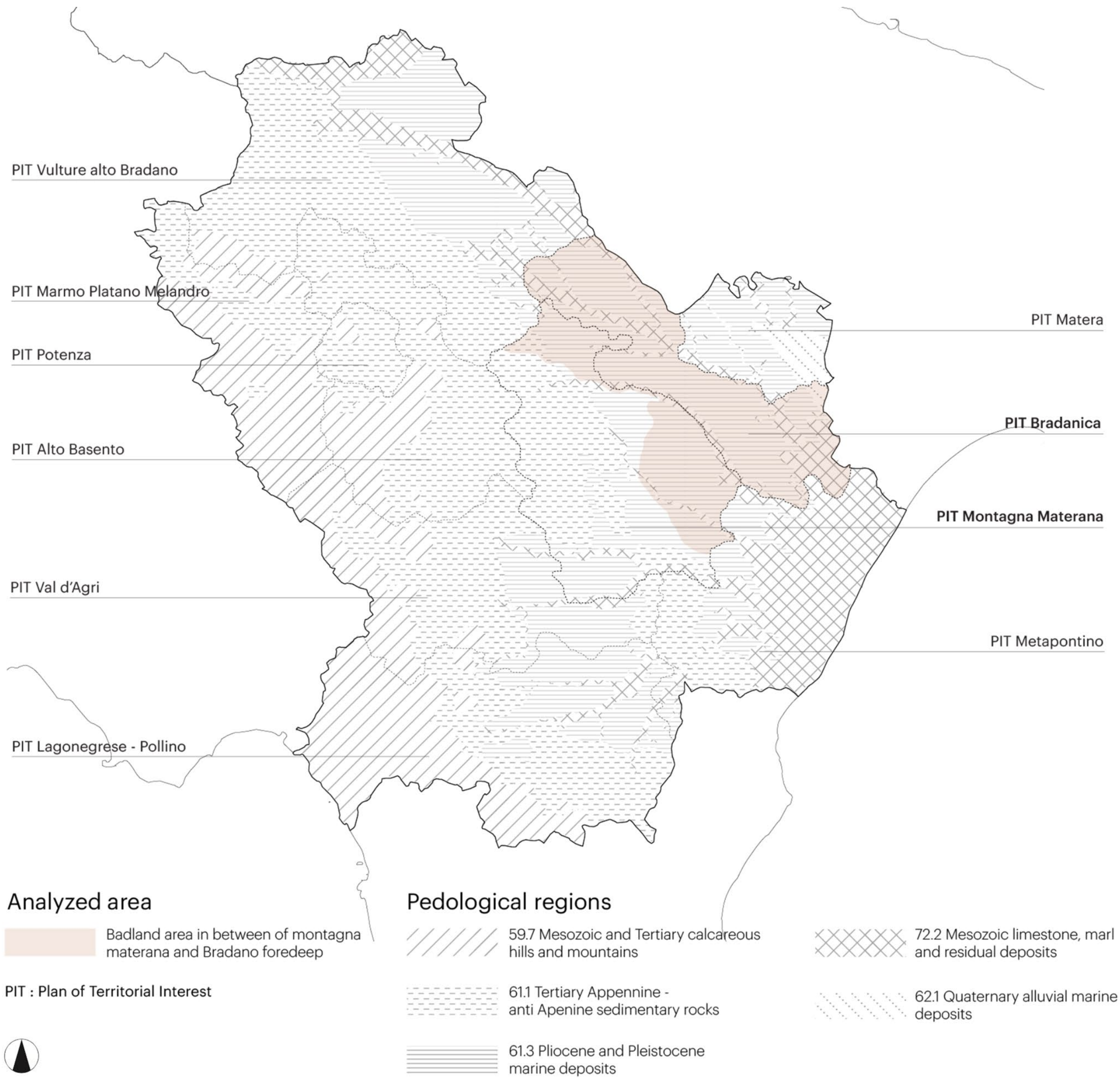

Fig. 8 Study area highlighted as elevated risk from ESAI evaluation (Fossa Bradanica and a portion of Montagna Materana)

because they have not experienced the same pressures to farm intensively, exemplified by extensive wheat cultivation or modelled areas. Erosive climate, in addition to the lack of manure additions, militates against the build-up of organic matter. As a result, the badlands remain active, and if left alone are likely to become re-established in these remodeled areas. Remodeling of the badlands for agriculture flattens the landforms, reduces slope angles, and breaks up the surface. The larger surface area exposed results in more rapid wetting, increased slaking, and an increased tendency for the clays to disperse chemically (Phillips 1998).

The releases of large volumes of sediment through erosion, accelerated by the remodeling process, had significant economic implications. These are not necessarily directly associated with agriculture because many occur off-farm. The increased pressure to farm marginal lands and reclaim badlands has been the result of a rapidly developing agricultural system. These developments have their roots in the agrarian reforms of the 1950s which stimulated a more intensive and mechanized form of agriculture, together with the exposure of the agricultural community to a market-based economy and subsequent world price fluctuations (Phillips,

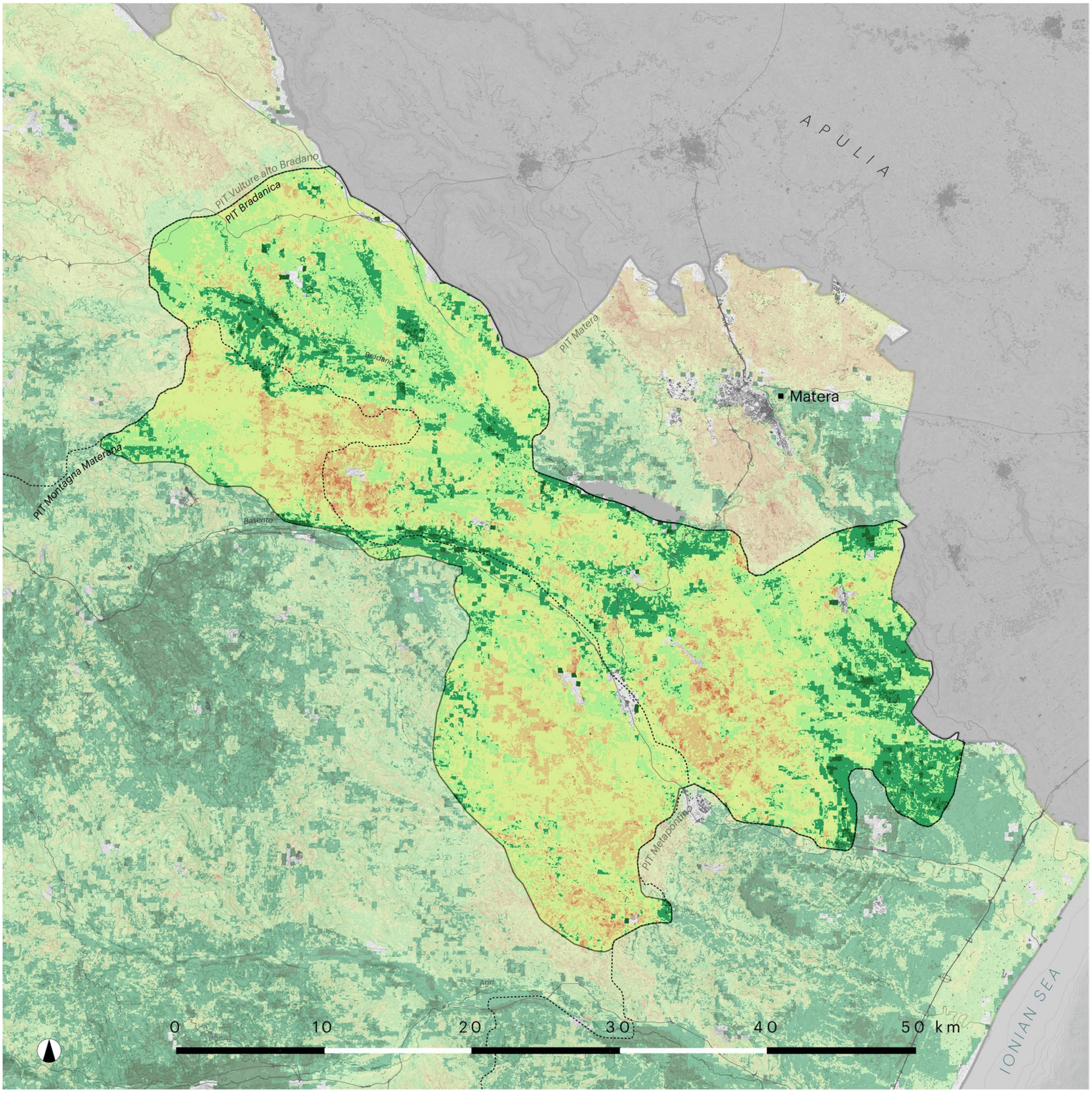

Fig. 9 ESAI in the study area (Fossa Bradanica and a portion of Montagna Materana)

1998). In addition, the EU CAP continues to play a key role in triggering the reclamation of these badland environments.

Sampled areas and LUCs observation

The two Landsat images from 2000 and 2019 were processed (ref. par. 4.2) and classified with a chosen threshold value of 1.5, resulting in a change detection image differencing (ΔNDVI). To validate the methodology after the calculation of the ΔNDVI (Fig. 10), 35 randomly chosen areas were sampled from it to spot effective changes in the landscape, by comparing them both to the National Orthophoto from 2000 and to the Basilicata Orthophoto from 2017. These two orthophotos were chosen for (i) closeness in terms of time reference to the ΔNDVI and (ii) availability of open data. The result registered 29 True Positives and 6 False Positives. So, the validation with sample points evidenced valuable feedback in the evaluation of land degradation with a precision of 0.828. In fact,

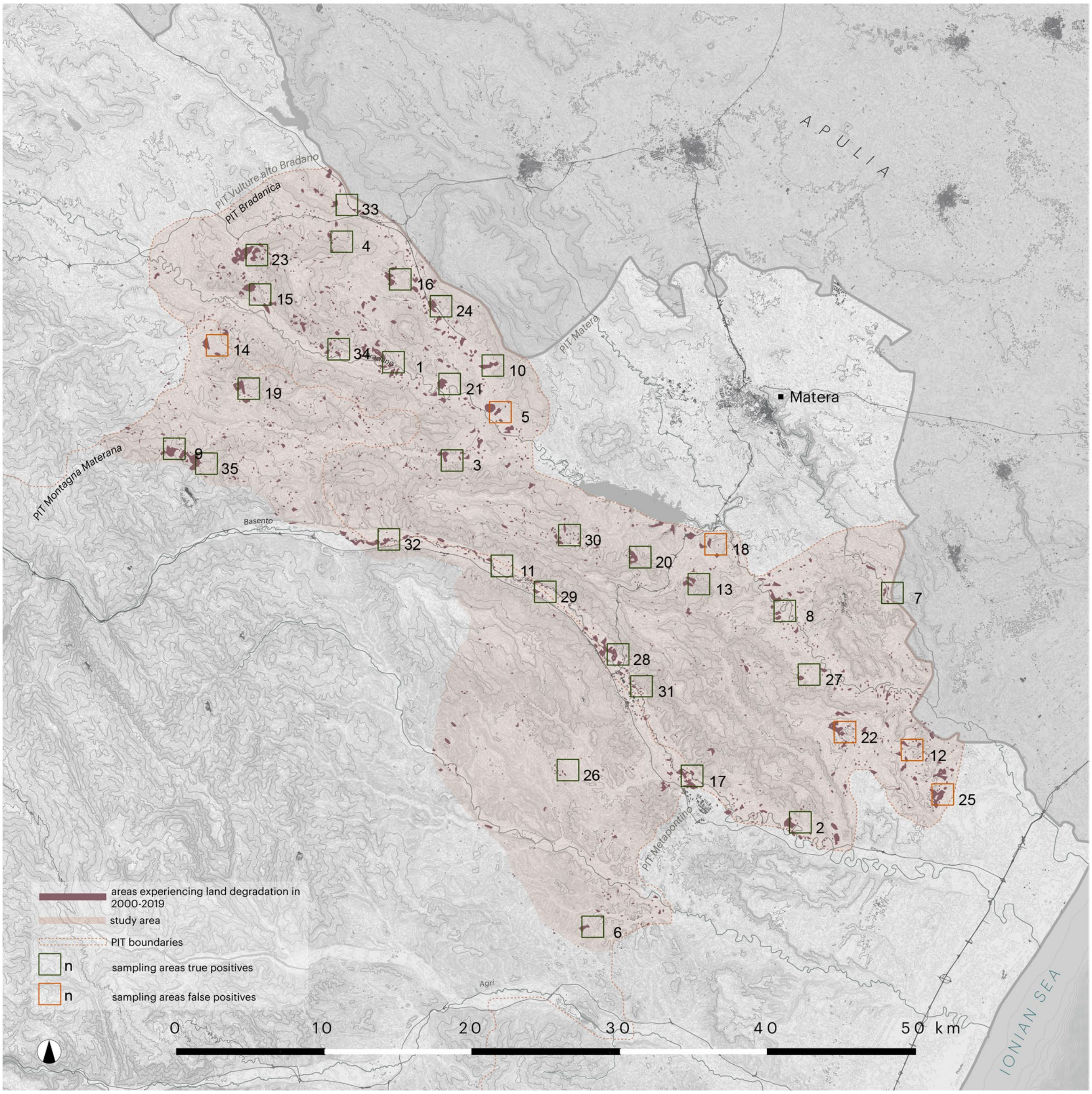

Fig. 10 Sample areas identified as degradation used for method validation

in most of the areas detected with the NDVI threshold method, there is a tangible change in the landscape composition to be referred to as a manifested phenomenon of LD (Fig. 11a, b).

The cluster that registered more errors fell in the southern area, where the repetitive pattern of crops affected the index by causing less precision in determining the phenomena. Here showed false positive agricultural patterns, that in the effective validation did not show any kind of LD issue (Fig. 12).

The index on a mid-regional scale, as in this case, spotted the macro-areas that had experienced changes and enlightened a consequential LD to be referred to as phenomena of land abandonment, overgrazing, soil erosion, soil sealing, and overexploitation of natural resources. The southern cluster of agricultural areas that did not experience LD was included in the threshold due to a change due to a different crop composition and not for an effective LD issue. Another validation was carried out to study the areas that did not fall within the ΔNDVI boundaries. Even in this case, 35

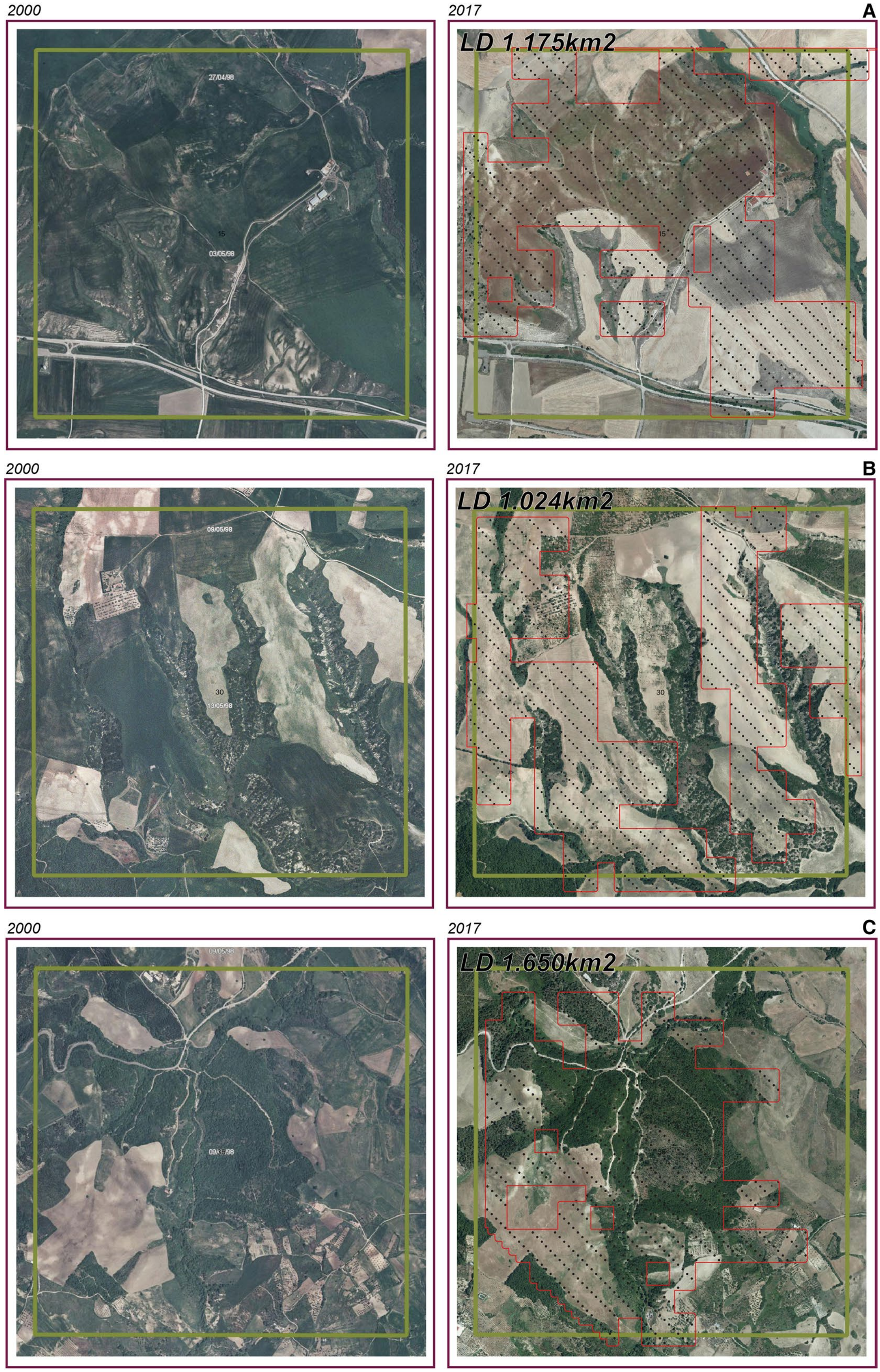

Fig. 11 **A.** Erodedslopes in the natural grasslands and reduced complexity of non-irrigable arableland. **B**. Recurring formation of badlands andimpoverishment of sparsely vegetated mixed forest areas. **C**. Changed agricultural patterns due to landabandonment and presence of huge burnt forest areas.

Fig. 12 Pattern of areas showing false positive

randomly chosen areas were investigated, with a result of 17 False Negatives and 18 True Negatives (Fig. 13). This is a crucial issue for the index, reporting clusters not spotted by the ΔNDVI, even if showing a modest or important LD, e.g., a cluster in internal areas characterized by a less alike-agricultural landscape (Fig. 14), which tended to affect the overall index accuracy (Table 3).

As a deepened LD study deriving from the ESAI macro-scale, the NDVI threshold evaluation defined, at mid- scale, which agricultural areas were much more affected and by which specificity of the phenomenon. It made it possible to understand samples of the real problem and how it had evolved during the years, progressively affecting the landscape and its composition.

On one hand, the NDVI threshold perfectly identifies the LD processes affecting the agricultural landscape (which was the main aim of this part of the research), permitting to rapidly assess a mid-regional scale and within a good precision, of the LD of agricultural landscapes.

On the other hand, it is better to define other thresholds for the NDVI differencing index when dealing with other patterns or detailed scale issues, considering implementing the index with other frameworks.

Results and future developments

The present study demonstrates how implemented methodologies within the framework of GIS and RS can provide reliable results in the assessment of land degradation dynamics affecting cultural and agricultural landscapes and by doing so, be a support for the future decision and land management policies. The implementation of the previous study (Gabriele et al. 2020) defined a better ESA Index, implemented two formally new indexes in the MEDALUS framework, the Water Availability Index and the Landslide Risk Index. Moreover, the second part of the study, carried on within the NDVI differencing threshold, allowed a high-precision identification of LD issues concerning the agrarian landscapes during a 20-year time span. It is important to mention the relative simplicity of the methodology and the free availability of time series Landsat TM images, but it would be desirable a further integration with more recent data provided by Copernicus Sentinel 2. Landsat TM in this case was used mainly for the long-time span covered, allowing a comparison between 2000 and 2019. Implementing Copernicus in the presented methodology for detecting short-time changes is a fundamental element to be investigated in our future work. Indeed, the higher spatial resolution of Sentinel 2 data compared to Landsat 8 will allow a better monitoring of NDVI changes in small agricultural and forest patches that proved being problematic with Landsat data. In particular, the investigation of Sentinel 2 time series will allow a prompt identification of anomalies and trends in NDVI values that may be the result of continuous land degradation or connected to localized phenomena (e.g., fires).

The fossa Bradanica (Bradanic foredeep) area was chosen as paradigmatic among the high risk areas, because historically affected by episodes of colonization, deforestation, and strict

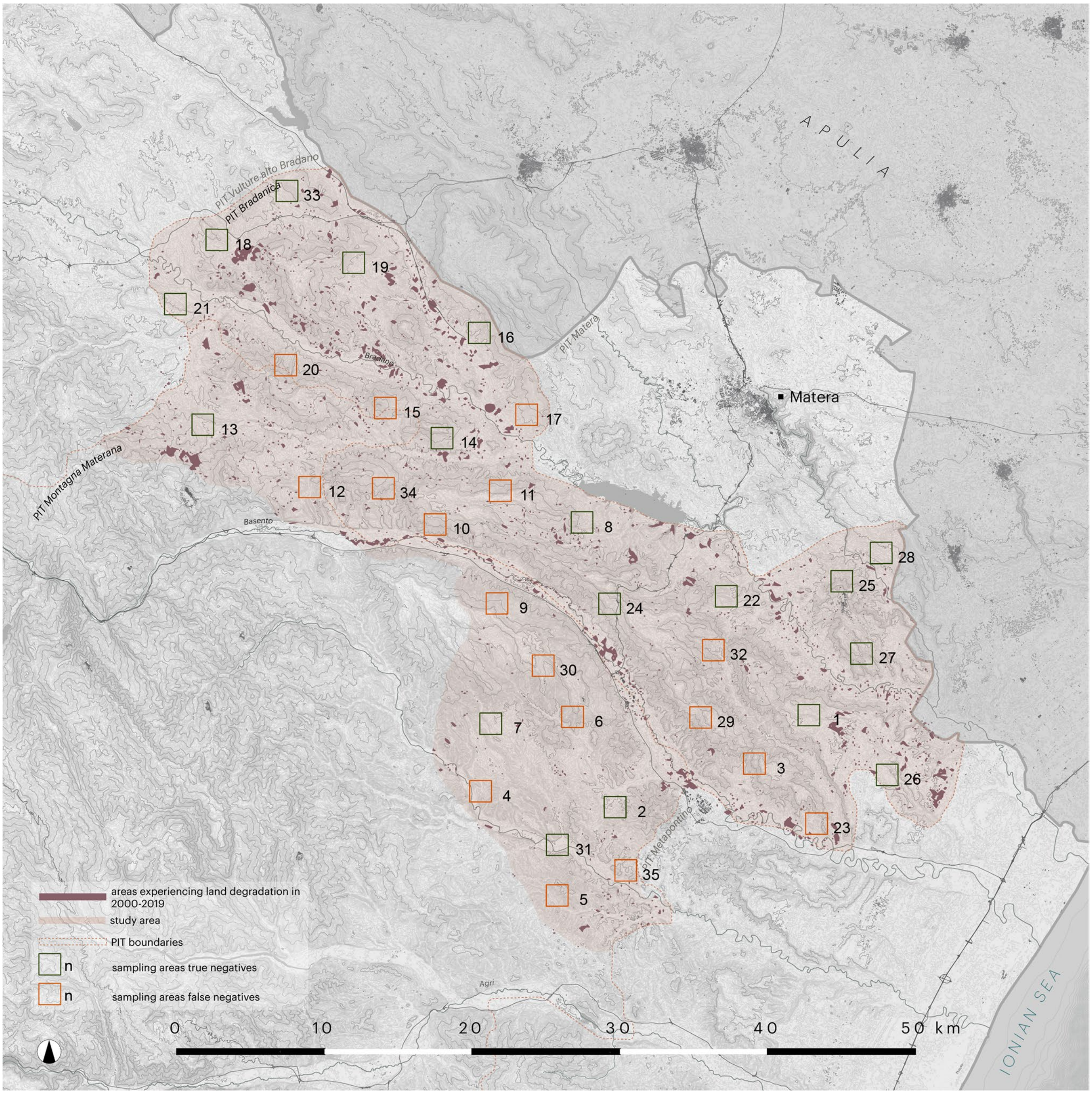

Fig. 13 Sample areas identified as non-degradation used for method validation

agricultural procedures that progressively, together with the depopulation and the natural disasters, such as landslides, led to a process of land degradation. This area was firstly enlightened in the ESAI macroscale, as formally "high prone to desertification," then, with the NDVI differencing threshold evaluation, was better understood in its LD dynamics, defining, within the help of the orthophotos, a range of the characters of a degraded agricultural landscape at a mid-regional scale. It is important to consider that knowing in detail the current situation of marginal-fragile areas helps to define planning tools and policies to set new agricultural systems and groves. In fact agri-rural landscapes represent an added value to the local products and an important economic resource, in particular for the marginal areas where traditional products and tourism can constitute the main resources for improving the quality of life of the local communities. These landscapes are also important for the preservation of biocultural diversity (UNEP-UNESCO, 2016), as they have a great biological and cultural value (Naveh 1990). These landscapes are a complex system that maintains different habitats characterized by different animal and plant species. Considering all these distinct aspects,

Fig. 14 Pattern of areas showing false negatives

it is clear that rural landscapes have an important multifunctional role, not only related to productive and economic functions but also related to cultural and environmental ones (Wilson 2005).

Table 3 Precision, recall, and accuracy

Description	*Value*
precision $\frac{TP}{TP+FP}$	0.828
recall $\frac{TP}{TP+FN}$	0.630
accuracy $\frac{TP+TN}{TP+TN+FP+FN}$	0.671

Integration of vulnerability studies in regional DSS

One of the most important tools for landscape management, conservation, and valorization is the development of a monitoring system, suited to control not only dynamics but also the effectiveness of the policies affecting the rural landscape. Establishing a monitoring system means primarily assess of the level of integrity as well as the main vulnerabilities of rural landscapes (Agnoletti et al. 2019). To monitor the evolution of the landscape, associated with changing climate

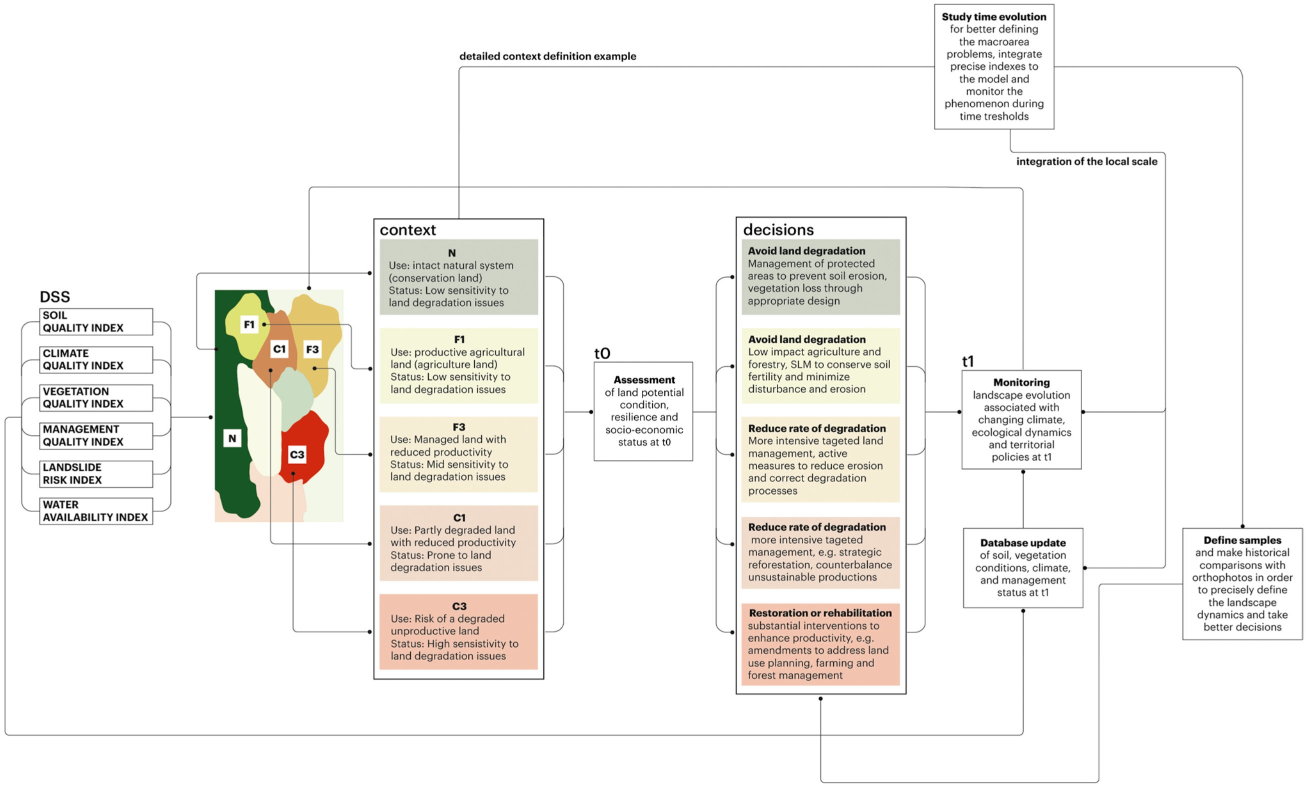

Fig. 15 Workflow of the proposed Decision Support System (DSS)

and its internal ecological dynamics, which are potentially subjected to external forces, such as land use changes leading to a progressive land degradation, the ESAI model can be a good Decision Support System, integrated into the WEB-GIS portal as an informational system supporting multiscale territorial organizational decision-making (Fig. 15).

As aforementioned, when describing the MEDALUS model and subsequently, the ESAI deriving model, it is evident that the methodology, integrating multidimensional aspects, determines with a good resolution scale the sensitivity to land use changes and the possibilities for the land to be affected by land degradation and desertification issues. This can be a great resource when managing a territory such as Basilicata which proved to be affected by the previously mentioned problems. The 6 different thematic layers that were chosen to study the phenomenon, derived from both literature and historic studies, estimated the soil, climate, vegetation, landslide, and management qualities thanks to a work of implementation of Big Datasets for the whole region. These layers can concur to build an integrated multiscale Decision Support System, progressively upgraded with properly new available datasets, implementing the existing layers of the database, defining the problematics of a territory constantly changing. This can help in spotting the inevitable landscape transformations and also evaluates how severe these transformations are in contributing to modify the landscape. After this, these must be consciously guided and managed by appropriate planning policies. When implemented in a Decision Support System (DSS), the ESAI model can provide the necessary integration between the six indexes through a spatial query procedure meeting the user's needs (Salvia et al. 2019). The user's types acquiring information from the implementation of such a tool can be, i.e., country-level and regional-level political actors, local administrators, and regional/local planners; managers of local production activities, including reclamation consortia, farmers' associations, cooperatives, and large producers. In this phase, the absence of a bottom-up participatory process to adopt the essential information among local communities and other actors will be filled up in the subsequent phase of local-scale implementation with local mitigation policies, with calls for locally embedded, bottom-up initiatives and community projects which focus on the local population as key actors for change. As previously said, multidimensional DSS definitely benefits from continuous update and improvements in the available databases (Serra et al. 2014). Regarding the Climate Quality Index, continuous updating and re-analysis of data from regional (or national) weather databases and improvement of regionalized estimates for specific variables (e.g., precipitation, average temperature, and evapotranspiration) are finally needed to implement new indicators of climate aridity, drought, and water balance relevant for the analysis of land degradation neutrality (Salvati et al. 2008). Instead, the Soil Quality Index, implementation of a soil data warehouse at a supra-national scale, continuing to integrate different data sources and environmental statistics can be a particularly appropriate knowledge base when defining new indicators of soil degradation, especially in less investigated fields such as soil salinization, compaction, contamination, and sealing, representing emerging (but relevant) phenomena of land degradation in the Mediterranean Basin. In the Management Quality Index, comprehensive analysis of human pressures requires a refined integration of data sources and available indicators from official statistics. The main processes of degradation triggered by management anthropogenic factors (population density) and agricultural practices should focus on the relationship between agricultural policy, economic dynamics, and environmental sustainability. These aspects are nowadays lacking in the Management Quality Index for the fact that there are no actual measures of regional-scale land management (except for the areas under constrains). Concerning the Vegetation Quality, it should be updated each year with the yearly NDVI calculation defining the actual conditions of the vegetation quality and the CLC defining the land use changes in the vegetation cover, this should be done in order to monitor and check the vegetation status. Concerning the Landslide Susceptibility Assessment, it should be updated from the competent regional authority data warehouse, and if this is not possible, it should be calculated from available satellite data and updated annually. Regarding the WAI, it could be future implemented in the interconnections with the reservoir systems, especially for local communities, in order to achieve a good water storage for drought periods, framing those areas that suffer much more from water availability, in order to immediate satisfy their future demands within a territorial water network.

It is important to stress the need to integrate studies concerning land degradation in the DSS in order to support planning policies, and so in this way, highlighting the areas that, falling out of the “legal constrains” of the valuable heritage, are invested by a problem. In particular, speaking about the case study, we have seen that the index provides a framework in which to operate, defining localized areas that have been invested by centuries of evolutions and extremely complex phenomena that are not easy reversible. What is needed at time 0, it is to create adaptive management, aimed at trying to recover the past people–place relationship and the functional value of a semi-arid environment.

In the context of public policies and land management, it is fundamental to mention that Basilicata Region is yet a member of the Network of European Regions Using Space Technologies (NEREUS) European platform. NEREUS offers a dynamic platform to all Regions aiming at making a better use of space applications for the delivery of efficient public policies benefiting citizens. As Europe’s flagship space program, Copernicus provide data and signals which can be transformed into useful information for Regions across Europe. The Copernicus4Regions initiative explores how other regions in Europe have managed to tackle common challenges, showing the benefits of the Copernicus program, and therefore invites more regions to be involved in the Copernicus ecosystem. Among the showcases 99 user stories describing how public administrations across Europe are using Copernicus data and information to address their challenges and how this is positively impacting the lives of citizens, the landscape degradation monitoring is not still present as an adopted continuous service. This experience can be a starting point aiming to undertake a service available to the different actor at the regional level.

A digital twin to dynamically involve co-working multi actors within 15th SDGs on desertification and land degradation

Digital twins have been born to manage the complex process through a digital replica of physical assets connecting people, places, systems, and devices throughout its life cycle. A digital twin is a digital copy of an actual physical product, process, or ecosystem that can be used to run virtual simulations, using data to update and change the digital copy to reflect any changes in the real world. Digital twins applications are extensively boosting remote maintenance-driven processes in the manufacturing industry with the help of mixed reality (virtual reality and augmented reality) and IOTs (Revetria 2019), including workers training purposes.

The term “digital twin” has been coined in 2002 even if NASA (National Aeronautics and Space Administration) pioneered the concept of working with digital models of real-world data and systems during its Apollo missions to create accurate simulations. In the Earth Observation domain, they could foster innovative potentials to simulate hazards pressures, and addressed to find out mitigation solutions supporting real-time responders as well as medium long-term active solutions. Even if this research is still at the beginning, it is demonstrating that such a platform able to dynamically follow the trends connected to the landscape transformation could represent an added value and an opportunity to let the different operators cooperating all together: PAs (i.e., the Regional Administration) responsible of the policy planning, land owners involved within a bottom-up process finalized to find out sustainable solutions, citizen involvement within climate change issues rising awareness, production industries progressively changing the food chain with sustainable cultivation, and smart technologies and start up enterprises interacting to deliver innovative service and solutions through IoT sensors network applications capable to follow the daily evolution and pushing adaptive AI-based actions.

Sustainable Development Goal 15 of the 2030 Agenda aims to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss." Deserts are among the "fragile ecosystems" addressed by Agenda 21, and "combating desertification and drought" is the subject of Chapter 12 of the Agenda. Desertification includes land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities. Desertification affects as much as one-sixth of the world's population, 70% of all drylands, and one-quarter of the total land area of the world. It results in widespread poverty as well as in the degradation of billion hectares of rangeland and cropland.

The research here developed implements the desertification subjects of the Chapter 12 under many aspects on landscape degradations issues: the necessity to relate the abandoning trends of the mountains and settlement affected by land degradation represent an important aspect within the desertification and land degradation in semi-arid and dry sub-humid areas, and need to be further addressed to promote activities able to reverse such phenomena and attract innovative sustainable socioeconomic policies.

Particularly, future developments could move ahead to deploy researches towards crosscutting edge such as recent NanoClay studies carried out within outstanding research groups (EIT Climate-KIC, Knowledge and Innovation Community) working to accelerate the transition to a zero-carbon, climate-resilient society, in the desert areas of the middle east: it could open interesting fields of application in the landscape degradation of the Mediterranean areas such as the one of the Basilicata here focused by adopting a systemic approach. Turning desert into green land to cultivate desert into farmland normally takes 7–15 years: the research project Desert Control found a way to convert sandy soil into fertile land in 7 h. Desert Control produces Liquid NanoClay (LNC) by combining clay and water in a patented mixing process. The mix sinks into the soil, creating a 40–60 cm deep layer, which retains the water like a sponge. This layer stops water from evaporating and ensures optimal growing conditions for anything you plant in it. One application of LNC lasts a minimum of 5 years. NanoClay is completely organic and does not use any chemicals. Tests have shown a significant yield increase on anything planted in soil treated with LNC and fertilizer. Turning desert to green land lowers the surface temperature around 15 °C and reduces CO_2 emissions by 15–25 tons per hectare.

Policies and innovation technologies boosting tanks collectors for saving water, or underground droplet irrigation, need to be involved within the digital twin dynamic monitoring and managing. The capability to digitize, aggregate, query/visualize, and analyze disparate behavior models can be empowered by ground segment data collection with IoT devices optimized for sensor data acquisition. As it is the case of water raining indicators in the different areas connected to the regional indicators and open data already made available.

The main objective of this research — as underlined by chapter 10 of Agenda 21 — is to work in the direction to boost an integrated planning and management of land resources, dealing with the cross-sectoral aspects of decision-making for the sustainable use and development of natural resources, including the soils, water, and biota that land comprises. This broad integrative view of land resources, which are essential for life-support systems and the productive capacity of the environment, is the common basis of Agenda 21's and the Commission on Sustainable Development's consideration of land issues.

Digital twins monitoring potentials here explained together with the actions highlighted within the proposal of a systemic regional policy planning including fragile areas issues intend to use the results coming from the continuous monitoring from the Satellite data (Landsat and Copernicus programme) together with the local indicators within a circular economy approach.

Network of European Regions Using Space Technologies, NEREUS offers a dynamic platform to all Regions aiming at making a better use of space applications for the delivery of efficient public policies benefiting citizens.

Landscape preservation as an active planning tool

The already mentioned ELC (2000) refers to some fundamental terms for the study, conservation, and management of the landscape considered as a complex and dynamic system. Particularly, "Landscape protection means actions to conserve and maintain the significant or characteristic features of a landscape, justified by its heritage value derived from its natural configuration and/or from human activity; Landscape management means action, from a perspective of sustainable development, to ensure the regular upkeep of a landscape, so as to guide and harmonize changes which are brought about by social, economic and environmental processes; and Landscape planning means strong forward-looking action to enhance, restore or create landscapes." It is evident that for the ELC, landscape preservation and landscape planning must be linked as part of the same process. Only by recognizing the historic-cultural, natural-environmental, and perceptive values, problems, and opportunities, connected with socioeconomic aspects of the landscape, it will be possible to define management and preservation plans to conserve and enhance the strengths, to solve or reduce weaknesses, and to rehabilitate and regenerate problematic situations, involving the communities in order to set a better and more sustainable landscape for the future generations.

In this regard, one of the most effective tools for the preservation and conservation of the landscape is its knowledge, with the awareness that only through the historical and environmental analysis of ancient landscapes, it is possible to obtain a correct planning for the current landscape and above all the design of that of the future.

The current landscape, as already highlighted, is the result of the continuous relationship between man and the environment. Landscapes are great containers of becoming and of man's relationship with them; studying the complex history of ancient landscapes also means "listening" to landscapes that tell us stories of identity.

The landscape is not only the structural and perceptive one, but certainly it is the result of transformations of the communities that have lived it and through an accurate process that studies and reconstructs this becoming it is possible to understand the history of our territories and propose a project to build the landscape of the future.

Studying the landscape in its entirety and integrity, first of all, involves a knowledge of the cultural identities stratified over time and of the relationship between human settlements and environmental components through multiple interdisciplinary analyzes, involving historical, geographical, anthropological, archeological, geo-archeological, surveying, agricultural, architectural, ecological, and aesthetic issues. It is a long and arduous process that analyzes features, practices, and structural, cultural, and perceptive changes of the landscape in order to identify the essential constitutive characters and types that need to be preserved and valorized, setting specific projects and plans.

Any landscape project and plan need to relate to global targets, even if the project is linked to the nature and problems of each of the areas being analyzed. The already mentioned ELC (2000) is a fundamental reference since it is the major international tool in this sector and it sets out the following targets:

- To preserve the landscape as an essential component of people's surroundings, an expression of the diversity of their shared cultural, natural, social, and economic heritage, and a foundation of their identity.
- To establish and implement policies aimed at landscape conservation, management, and planning through the adoption of specific measures.
- To establish procedures for the participation of communities, local and regional authorities, and other parties with an interest in the definition and implementation of landscape policies.
- To consider regional and town plans and the cultural, environmental, agricultural, social, and economic policies with a possible direct or indirect impact on the landscape.

To reach these targets, it is necessary to take concrete steps, at least in the following: knowledge, awareness, education and training, identification and assessment of local landscapes, and the definition of policies to achieve social awareness, to increase landscape consideration, and to improve a better and more sustainable landscape management.

In this perspective, "the landscape planning can play a particularly key role, with three main missions:

- The cognitive and evaluative mission, is designed to enable the decision makers and all stakeholders to become aware of the values and challenges, the risks and threats, the opportunities and potentials, the mobilizable resources, the involved interests: basically, of all the factors that can influence the planning choices.
- The regulatory mission, to define constraints, limitations, specific measures of discipline and governance of territorial transformation processes, according to the undertaken objectives.
- The strategic orientation mission, to propose visions, ideas and strategic guidelines, to be discussed and shared with a plurality of parties, institutions and stakeholders, in order to promote coordinated or converging policies" (Gambino 1997).

Landscape requires an interpretation of the territorial context, pointing out the values to be protected, as well as the pressures and critical factors threatening them. In this direction, two main steps must be considered:

- Identifying the landscapes like areas where specific systems of environmental and cultural relationships create a recognizable identity and a unitary image;
- Identifying the environmental networks connecting the different natural and cultural resources which are relevant for management planning.

Both steps are based on the structural interpretation, highlighting constructive features, perceptive elements, and natural-environmental characteristics to guide the policies of conservation, management, and planning.

The review of the Basilicata Regional Landscape Plan now in progress sets as one of its mail goals the necessity to define a landscape preservation linked to the landscape and local planning. The aim is to coordinate the management of protected areas, binding actions, and preservation tools to establish criteria for an active safeguard and a sustainable management (PPR, 2011–2021).

With particular reference to the agricultural landscape, it is important to underline that — at the European Community level — the rural space represents a public good, regardless of ownership structures and management criteria. The focus is on the multifunctionality of the rural and open territory, on its ability to produce a flow of goods and services useful to the community, related not only to primary production (energy, food, wood) but also to the recovery of fundamental resources (air, water, soil); to the conservation of ecosystems, biodiversity, and landscape; to the development of eco-tourism and recreational activities; and to the protection and valorization of lifestyles, cultures, and local traditions.

In Europe as in Basilicata, the rural territory can perform all these functions because it constitutes the prevalent portion of hydrographic basins, ecosystems, and landscapes, i.e., the environmental infrastructures that support, directly or indirectly, the life of communities, with their economic, social, and cultural activities.

To define a strategy for the conservation and recovery of the rural territory of Basilicata, the new Regional Landscape Plan aims to address in an integrated way the processes that are rapidly changing the regional landscape. First, the continuous expansion of urbanized areas raises the need to contain the land consumption, settlement dispersion, and fragmentation of the rural space, with its trivialization and the rapid decline of its multifunctionality. In addition, agricultural recovery must be planned, in order to avoid an increasingly marked differentiation of agricultural systems on a territorial scale, with a complex mosaic of areas of intensification, diversification, and abandonment of crops, with the consequent marginalization of many areas. Still to be considered — as highlighted in the previous paragraphs — are the problems of land degradation.

All these processes produce rapid transformations of the cultural landscapes of Basilicata that must be evaluated, addressed, and managed to preserve the fundamental common goods of the Lucanian community: lands, ecosystems and landscapes.

Conclusions

The integration of both evaluations contributed to achieving the final goal of the research, which mainly consisted in identifying the phenomena that generate degradation in the landscape, therefore outlining the future management possibilities and implications concerning to this critical issue, in order to maintain or restore the pre-existing values, or to support the creation of new coherent and integrated landscape strategies. This objective derives from recognizing the landscape as defined in the already mentioned European Landscape Convention, which designates it as "a specific part of the territory, whose character derives from the action of natural and/or human factors and their interrelations" (ELC, 2000). Landscape, performs crucial functions of community interest, from the cultural, ecological, environmental, and social point of view, and is also a resource for economic development, without forgetting that it is a fundamental component of cultural and natural heritage too.

European Landscape Convention underlines that in some cases, the need for conservation may or must prevail over the prospects of transformation; however, it presupposes that "conservation is a choice and not an inevitable and eternal destiny of certain places" (ELC, 2000). Evidently, the theme of management is of fundamental importance as it well expresses the need for constant interventions, in order for the landscape to maintain its dynamic balance meanwhile facing the changes brought by the rapid and continuous alterations that characterize our era. According to Ferrara (2010), "the underlying problem, that must be put under control, is the transformation: we either learn to transform, or we are lost. In the research for a good balance between the protection, management and planning of a landscape, it must be recognized that landscapes have always undergone changes and they will continue to change, both because of natural processes and of human actions; consequently it is impossible to preserve the landscape during a certain stage of its evolution. The goal to be pursued, therefore, should be to guide the future changes by recognizing the great diversity and quality of the landscapes that we have inherited from the past, trying to enrich this diversity and this quality."

In conclusion, the research wants to stress the potential benefits that could derive from integrating evidence-based studies concerning land degradation in the landscape planning policies, giving the possibility to retrieve information finalized on pointing out which areas that, falling out of the preservation or planning binding actions, are being affected by the LD problem. Speaking about the case study, the indexes provide a framework in which to operate, defining localized areas that have been subjected to centuries of evolutions and extreme complex phenomena that are not easy reversible. This is because territories constantly change, and so, the landscape transformations are inevitable. What is needed now in time 0, it is to use the GIS and RS science to monitor site-specific indicators, from which to foster an adaptive management, aiming to recover the past people–place relationship and the functional value of a semi-arid environment. The biophysical conditions, such as those in the arid, semi-arid, and dry sub-humid regions of Mediterranean Europe, are unfavorable, and the resource-depleting practices, such as agricultural intensification, monocultures, abandonment of traditional practices, overgrazing, deforestation, forest fires, surface, and groundwater over-drafting, are the core drivers of the problem. There is the need to reverse the trend. Adaptation to climate change involves anticipating and monitoring change and assuming actions to prevent the negative consequences, and to take advantage of the potential benefits of those changes. Monitoring means learning by doing, as planning policies strictly derive from the progressive development of phenomena. Protecting and enhancing the agricultural landscape and promoting eco-sustainable agriculture creates coherent and integrated landscape values, and involves citizens in the restoration and conservation of degraded agroecosystems through bottom-up and co-creation actions. The local-scale process will significantly impact at global level, enhancing the major influence and autonomy of communities to address socioeconomic and land degradation issues, meanwhile building resilience and thus, fostering new possibilities for cultural and eco-sustainable development.

Author contribution The present work was conceived and written jointly by the four authors. MG developed "Literature review," "The intensive deforestation, depopulation, and the marked signs during the nineteenth–twentieth century," "Today's regional LD pressures and trends," and "Former regional studies framing LD" sections; MG, MP, and RB developed "Materials and methods," "Integration of vulnerability studies in regional DSS," and "A digital twin to dynamically involve co-working multi actors within 15th SDGs on desertification and land degradation" sections; AC developed "Landscape as the result of the interaction between natural and cultural factors," "The Basilicata historic agriculture landscape," and "Landscape preservation as an active planning tool" sections. The authors collaborated in the writing of the "Abstract," "Introduction," and "Conclusions," and for the final revision of the manuscript.

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