

## Chapter 17

# Recovery of Terraced Landscapes as a Distinctive Sign of Land Culture and Protection from Hydrogeological Risk



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**Abstract** Terraced landscapes are ancient agricultural systems that demonstrate human skill and respect for the environment. They are often found in challenging terrains and utilize techniques to safeguard biodiversity and prevent erosion. However, climate change threatens these landscapes, increasing the risk of extreme weather events. To protect these valuable systems, efforts are being made to preserve traditional knowledge, such as dry-stone wall construction, which is now recognized as a UNESCO Intangible Cultural Heritage. This paper examines three specific regions to develop strategies for the restoration and sustainable management of terraced landscapes, focusing on techniques to mitigate impacts of climate change and preserve cultural heritage.

**Keywords** Terraced landscape · Climate change · Dry stone walls · Historical landscapes · Aeolian archipelago · Lamole Valley · Lucretili mountains · Hydrogeological risk

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## 17.1 Introduction

Generally located in inhospitable land, terraced landscapes represent an ancient agricultural and ecological system created by the adaptability and inventiveness of the human kind since ancient times. They express a long and intimate relationship between peoples and their natural environment and reflect specific techniques of land use that guarantee and sustain biodiversity development and safeguarding of the landscape towards hydrogeological risks. Spread all around the world, traditional terracing shows common techniques of farming, utilizing dry stone walls to realize the terraces.

It is widely demonstrated that in recent decades, changes in climate have caused impacts on natural and human systems and are expected to increase in the future. Moreover, climate change is contributing towards increased intensity and frequency of hydro-meteorological events, such as heavy rainfall, wind-storm, heat waves and droughts (IPCC, 2023). Landscape is consequently put at risk not only by impending disasters, but very often also by emergency and post disaster recovery actions with consequently jeopardization and even global loss of biodiversity, as highlighted by the Convention on Biological Diversity (CBD)<sup>1</sup> and the United Nation Convention to Combat Desertification (UNCCD)<sup>2</sup>.

The regeneration and protection of the terraced landscape is therefore extremely important, since it triggers a chain process of conservation of socio-cultural aspects distinctive of the way of life of the local community, as well as of protection of the surrounding environment (i.e. preventing landslides and floods, combating desertification and erosion). In particular, the awareness of the pivotal role played by the knowledge of the traditional construction technique of dry-stone walls motivated its inclusion in the UNESCO's Intangible Cultural Heritage list in 2018 (UNESCO, 2018b).

This contribution feeds into WP4 "Restoration and sustainable strategies for Heritage preservation against risks and climate change" of the project PNRR CHANGES by providing the state of progress of interdisciplinary activities addressed to the protection of terraced landscape performed by the University of Florence, University of Roma Tre, and two Institutes of the National Research Council of Italy (1 - Institute of Atmospheric Sciences and Climate; 2 - Institute of Heritage Science).

Specifically, we here illustrate the methodology applied and the preliminary results obtained so far on three Italian case studies representative of terraced landscape selected in the framework of the project:

- Aeolian Archipelago, Sicily.
- Lamole Valley, Tuscany.
- The Natural Regional Park of Lucretili Mountains, Lazio.

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<sup>1</sup><https://www.cbd.int/doc/legal/cbd-en.pdf>

<sup>2</sup><http://www.unccd.int/en/Pages/default.aspx>

## 17.2 The Aeolian Archipelago and Its Terraced Landscape

Located in the Southern Tyrrhenian Sea at the North of Sicily, the Aeolian Archipelago consists of seven main Islands (Lipari, Vulcano, Filicudi, Alicudi, Salina, Stromboli and Panarea) and its landscape is the result of volcanic activity over 250,000 years.

The historical terraced landscape of the Aeolian Islands reflects the environmental and geological characteristics of the territory and is fully integrated with the natural landscape. The predominant material used for the construction of the dry-stone walls that delimit the agricultural terraces, *lenze* in local dialect, is the volcanic stone obtained from the solidified lavas (Fig. 17.1). The natural color of the stones and their biological cover generally give a homogeneous appearance that gives uniformity to the landscape.

The Aeolian Archipelago is a particularly fragile ecosystem. Located in the Mediterranean Sea, a hot spot of climate change, it is increasingly affected by drought and heavy rainfall. Catastrophic floods and increasingly prolonged drought periods are the main “water” challenges facing the islands of the archipelago, where current water management practices may not be robust enough to cope with the impacts of climate change. Among the various consequences of these catastrophic



**Fig. 17.1** Picture illustrating characteristic dry-stone walls of one terraced area in the island of Panarea (Photo by Alessandro Sardella)

events can be the increase in soil erosion, which in a terraced landscape can be considerable.

Densely inhabited and cultivated until the mid-1900s, the Aeolian Islands are among the smaller islands of Sicily, those with the highest percentage of terraces abandoned (90%) (Barbera et al., 2009). Alicudi, Filicudi, Salina and Panarea are almost entirely terraced, while Lipari presents a random distribution of terraces and Vulcano is characterized by their total absence due to the last eruption in 1888–1890, which determined the abandonment of large parts of cultivated terraces.

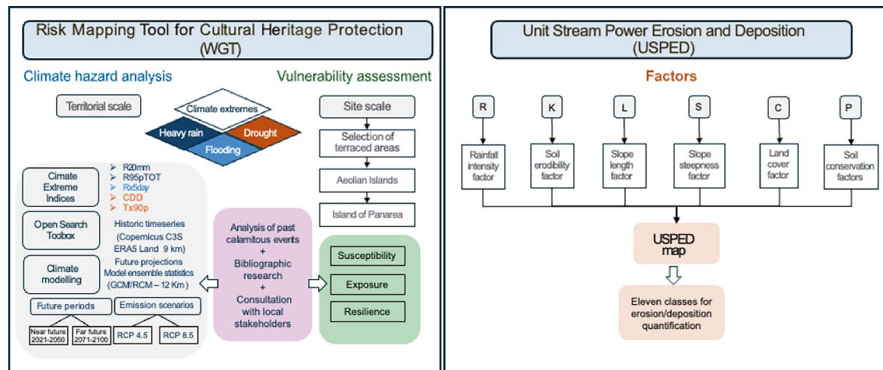
In general, the state of conservation of dry-stone walls is good in still cultivated areas where maintenance is constant. In the case of abandoned land, on the other hand, conservation is very variable, ranging from occasional or extended collapses to areas in good structural condition, but characterized by degradation due to colonization by spontaneous vegetation causing structural problems in dry stone walls that are already in poor stability. Animals grazing and the effect of the increasing frequency of summer fires and heavy rainfall are undoubtedly additional factors of damage, as well as the implementation of inadequate interventions of maintenance. As a result, the landscape is degrading gradually. Soil erosion is decreasing in some areas that have been abandoned totally and allowed to revert to nature (Camera et al., 2018). Soil erosion in such cases is more gradual than on recently abandoned or badly maintained land, as seen in other terraced (Brandolini et al., 2017) and non-terraced locations (Nasta et al., 2017) around the Mediterranean Region.

The present contribution is addressed to: (i) an increase understanding of the potential impacts of extreme hydrometeorological events (heavy rain, flooding and drought) on the terraced landscape of the Aeolian Islands in climate change conditions by performing a hazard analysis at regional scale of the likelihood of increase/decrease of climate induced extreme events including fires linked to prolonged drought periods; (ii) understand and quantify soil erosion and deposition at a local scale for Panarea, making use of an empirical model.

### ***17.2.1 Methodological Approach***

The two sections of this work are as follows (Fig. 17.2): (i) developing risk maps for the entire Aeolian islands archipelago to study the effects and evaluate the vulnerability associated with heavy rainfall and flood events; (ii) using the Unit Stream Power Erosion and Deposition (USPED) model to evaluate soil erosion on Panarea Island.

The investigation of future projections of hazards at territorial level covering the Aeolian Archipelago is performed by applying the Risk Mapping Tool for Cultural Heritage Protection (WGT). This platform, implemented within the Interreg Central Europe projects ProteCHt2save and STRENCH and currently under further development in the framework of the Interreg Central Europe project INACO, aims to support private and public authorities in the safeguarding of cultural heritage in Europe and in the Mediterranean Basin from climate induced events (<https://www.>



**Fig. 17.2** Overview of the applied methodological approaches illustrating the two sections of the work: on the left, the procedure for the risk assessment by climate mapping and vulnerability ranking associated with heavy rainfall and flood events; on the right, the application of the Unit Stream Power Erosion and Deposition (USPED) model to evaluate soil erosion

protecht2save-wgt.eu.). First of all, among the climate variables and climate extreme standard indices defined by the Expert Team on Climate Change Detection Indices (ETCCDI) and available in the WGT, the following ones are selected and used: R20mm (very heavy precipitation days), R95pTOT (precipitation due to extremely wet days), Rx5day (highest 5-day precipitation amount), CDD (consecutive wet days) and Tx90p (extremely warm days). The selected indices are widely employed for the elaboration of future climate projections at global and regional level (Bonazza et al., 2021). The “Climate Modelling” tool of the WGT was then used for elaborating climate hazard maps covering the areas under investigation (Aeolian Archipelago). The WGT can provide maps developed by using 12 different combinations of 6 forcing global models (GCM) driving 5 regional models (RCM) under two emission scenarios: RCP4.5 (stabilization scenario) and RCP 8.5 (high pathway scenario), outlined in the AR5 Intergovernmental Panel on Climate Change (IPCC) assessment report (Sardella et al., 2020; IPCC, 2013). Maps of the minimum, mean, and maximum values of the model ensembles are also available.

For the current study, maps of future changes in R20mm, Rx5day, R95pTOT, CDD and Tx90p are investigated (~12 km resolution). The maps show the differences between the periods 2021–2050 and 1976–2005 (near future projection) and between the periods 2071–2100 and 1976–2005 (far future projection), under both RCP 4.5 and 8.5 scenarios.

The island of Panarea was selected to analyze how soil erosion affects an abandoned terraced landscape. The average soil loss (A) was calculated by the 2-dimensional USPED erosion-deposition model using the structure of the empirical Revised Universal Soil Loss Equation (RUSLE). Modelling was carried out based on the assumption that erosion and deposition predominantly depend on the sediment transport capacity of surface runoff, in contrast to the 1-dimensional RUSLE model (Mitasova et al., 1996). In particular, the formula that allows to estimate the annual soil loss is:

$$A = R \cdot K \cdot LS \cdot C \cdot P$$

where A is the annual average soil loss ( $\text{Mg ha}^{-1} \text{ year}^{-1}$ ), R is the rainfall intensity factor ( $\text{MJ mm h}^{-1} \text{ ha}^{-1} \text{ year}^{-1}$ ), K is the soil erodibility factor ( $\text{Mg h MJ}^{-1} \text{ mm}^{-1}$ ), L is the slope length factor (dimensionless), S is the slope steepness factor (dimensionless). C is the land cover factor (dimensionless) and P is the soil conservation or prevention practice factors (dimensionless).

The R factor was computed using the empirical equation developed by Capolongo et al. (2008), which was previously utilized in Gioia et al. (2021). The K factor was estimated using a conventional Wischmeier erosion plot (Renard et al., 1997). The formula present in Minervino Amodio et al. (2023) was used to evaluate the K-factor.

The LS factor was generated using the same workflow present in Gioia et al. (2021). The C factor, which shows how crops and management practices affect soil erosion rates, was computed taking advance of literature data (Wischmeier & Smith, 1978; Renard & Foster, 1983). The resulting three land-use types were given C values based on the literature. Considering there are no noteworthy supporting practices in the research domain, the P factor's value is regarded as 1. Table 17.1 describes the types of data, the acquisition periods and the sources used for the different factors.

For the application of the USPED model we fixed the R-factor and K-factor in the following way. The R-factor was based on the use of rainfall data from the station on the island of Salina, located about 20 km from the island of Panarea. This choice was made considering that the Salina station was the only active rainfall gauge with a time series of at least 10 years. Regarding the K-factor, the features of the geological map described in Table 17.1 was used, which was merged to obtain a lithology map (as described and already used by Gioia et al., 2021 and Minervino Amodio et al., 2023).

**Table 17.1** Table summarizes required and acquired data to compute the average soil loss (A) calculated by the USPED model

	Data	Period	Source
R-factor	Daily precipitation	2014–2023	SIAS—Servizio Informativo Agrometeorologico Siciliano
K-factor	Lithological data	1999	Geological map of the island of Panarea and Basiluzzo (Aeolian Islands) by Calanchi et al. (1999)
LS-factor	2 metres Lidar data	2012–2013	Geoportale Regione Siciliana
C-factor	Land uses data	2018	Corine Land Cover Dataset

## 17.2.2 Results and Discussion

### 17.2.2.1 Future Projections of Climate Hazards Impacting the Aeolian Islands

The complete set of maps of future changes of R20mm (very heavy precipitation days), R95pTOT (precipitation due to extremely wet days), and Rx5day (highest 5-day precipitation amount), produced with the model ensemble statistics (minimum, mean, and maximum) in the near (2021–2050) and far future (2071–2100) under RCP 4.5 (stabilization scenario) and RCP 8.5 (high pathway scenario), were analyzed and the outcomes are reported in Table 17.2. The maps illustrated in Fig. 17.3 represent an example of the maps obtained by using the Maps toolbox of the Risk Mapping Tool for Cultural Heritage Protection.

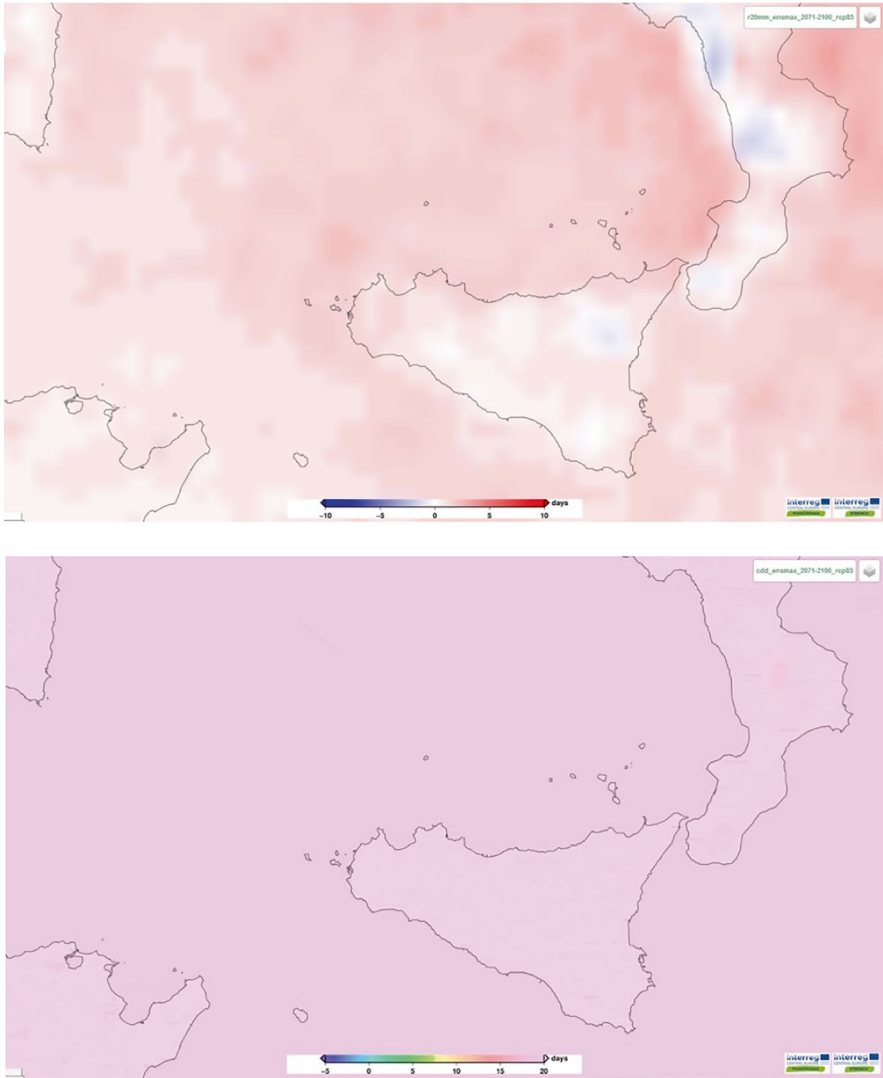
#### 17.2.2.2 USPED Model

The rainfall intensity factor (R factor) calculated for the Panarea Island using daily rainfall data is  $949 \text{ MJ mm ha}^{-1} \text{ h}^{-1} \text{ year}^{-1}$ . The land use and management factor (C factor) (Fig. 17.4a) ranges from 0 to a maximum of 0.025, here using the CLC classes the following values were assigned: 0 for class 523; 0.001 for class 112; 0.01 for class 332; 0.025 for class 323.

**Table 17.2** Data acquired from the future (near and far) projections hazard maps of 5 climate extreme indices: R20mm, Rx5day, R95pTOT, CDD and Tx90p

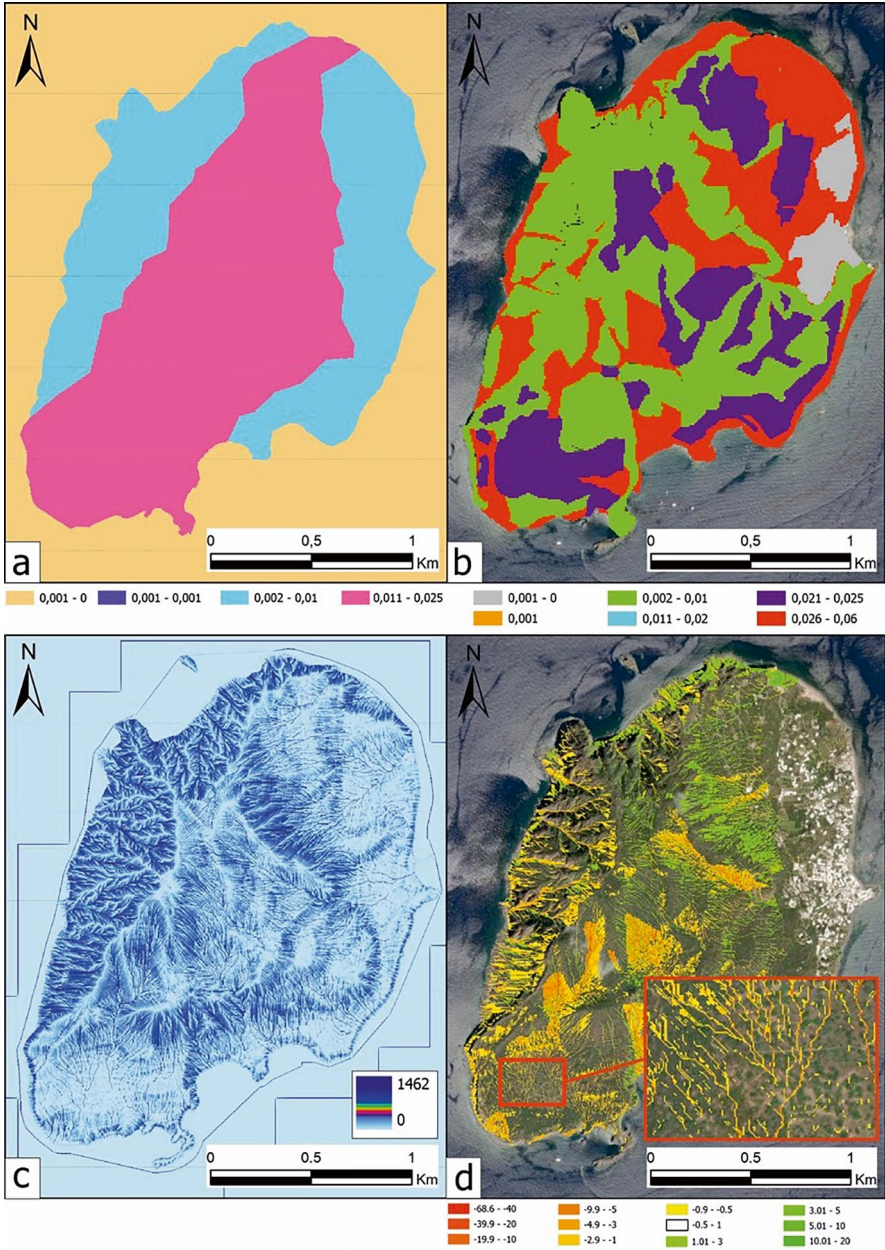
Index (measurement)	Projection	Ensmin RCP4.5	Ensmin RCP8.5	Ensmean RCP4.5	Ensmean RCP8.5	Ensmax RCP4.5	Ensmax RCP8.5
R20mm (days)	Near future	-2/-1	-2/-1	-1/0	0/1	1/2	2/3
	Far future	-1/0	-1/0	0/1	0/1	2/3	3/4
Rx5day	Near future	-14/-12	-15/-13	-3/-1	-2/0	10/12	12/14
	Far future	-12/-10	-13/-11	0/2	0/2	10/12	20/22
R95pTOT (mm)	Near future	-40/-30	-40/-30	0/10	0/10	40/50	40/50
	Far future	-40/-30	-40/-30	10/20	20/30	50/60	70/80
CDD (days)	Near future	-7/-6	-6/-5	0/2	2/4	10/12	13/15
	Far future	-7/-6	0/2	3/5	13/15	13/15	16/18
TX90p (%)	Near future	0/2	4/6	8/10	10/12	30/32	40/42
	Far future	10/12	38/40	28/30	40/42	48/50	78/80

In the table the minimum, mean and maximum variations of the indexes in relation to RCPs 4.5 and 8.5 are reported



**Fig. 17.3** Maps showing the climate projection simulation (ensemble maximum “ENSMAX”) of the indices R20mm (top) and CDD (bottom) for the far future (2071–2100) under RCP 8.5. Focus Area: Southern Italy and Aeolian Islands (~12 km resolution)

The soil erodibility factor (K-factor, Fig. 17.4b) was derived from the lithological information of the geological map (Calanchi et al., 1999) and it shows a range between 0 and 0.06. A value of 0 was attributed to the presence of the urban area, while a value of 0.06 was attributed to unstable areas prone to erosion, such as landslide areas and debris fan deposits. The map of slope length and steepness factor (LS factor, Fig. 17.4c) shows values between 0 and 1462. High value of the LS



**Fig. 17.4** Factors considered for building the USPED model (a: C factor; b: K-factor; c: LS factor) and model output (d: A values) (see text)

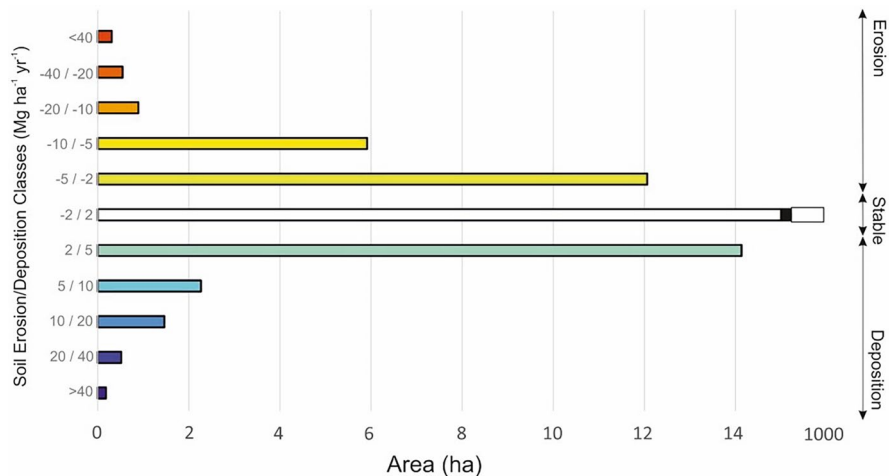
factor can be found in the north-western part of the island, where the particular topographic conditions have not allowed man to build terraced areas for the farming activities; in fact this area is mostly characterized by landslides, and linear erosion.

By combining all the factors, we obtained the results of the USPED model, as Fig. 17.4d shows. In the figure, each pixel was categorised using the 11 erosion/deposition classes listed below:

- Extreme erosion ( $<-40 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- High erosion ( $-40/-20 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- Moderate erosion ( $-20/-10 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- Low erosion ( $-10/-5 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- Very low erosion ( $-5/-2 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- Stable ( $-2/2 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- Very low deposition ( $2/5 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- Low deposition ( $5/10 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- Moderate deposition ( $10/20 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- High deposition ( $20/40 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )
- Extreme deposition ( $>40 \text{ Mg ha}^{-1} \text{ year}^{-1}$ )

Both erosion and deposition areas emerge from the processing, but stable areas clearly prevail. Furthermore, making a focus on an area with high density of terraces (red rectangle in Fig. 17.4d), it can be seen how the erosion/deposition.

The distribution of classes in the USPED model (Fig. 17.5) shows that most of the analyzed area is stable (about 96%), while the area in erosion is about 2% and the area characterized by deposition is 1.9%. This small difference between erosion/deposition translates into 1.25 ha in favor of erosion, probably this net loss of material is due to the north-west area of the island characterized by large linear incisions and landslides that remove material depositing it directly into the sea.



**Fig. 17.5** Histograms show the USPED model's area distribution

### **17.2.3 Future Work**

As a further step the analysis of historic time series of climate extreme indices suitable for investigating past climate extreme events on the area will be conducted by using the “Open search Tool Box” of the WGT which allows the exploration of selected climate indices recomputed following the full time series products of Copernicus C3S ERA5 Land (~9 km resolution, from 1981), Copernicus C3S ERA5 (~31 km resolution, from 1981), and NASA GPM IMERG (~10 km resolution, from 2000). Parallely, an analysis of the past calamitous events affecting the area will be conducted based on bibliographic research, data available in the literature and consultation with local stakeholders, with the objective of collecting information on the areal distribution of the episode, the impacts and recovery or preventive measures put in place by local authorities.

Further investigations will be devoted at improving the USPED model by making use of more refined input spatial data, such as knowledge of soil characteristics (e.g., typology, thickness) and their use at a more detailed scale. This will allow us to define in a more detailed way those terraced areas where erosion rates are higher, and which therefore no longer play the role of risk mitigation. The results will be useful in defining priority areas for intervention and restoration of dry-stone walls.

## **17.3 The Terraced Landscape of the Lamole Valley (Chianti)**

### **17.3.1 Description of the Study Area**

The landscape of Lamole (see Fig. 17.6) is a product of centuries of human adaptation to its high-hill environment, situated at a medium altitude of around 600 m above sea level. Communities in this region have long transformed the natural terrain to make it suitable for agriculture. Historical records show settlements in Lamole dating back to the Etruscan period, and by the medieval era, its steep slopes were utilized to build dry-stone terraces. These terraces not only levelled the land for farming but also created a unique microclimate that enhanced crop quality and yield. Over time, these terraces became a distinctive feature of Lamole’s agricultural landscape, contributing to its productivity and its cultural and historical heritage (Ministerial Decree, 2018).

Agriculture has always been fundamental to Lamole’s economy, with diverse crops forming a distinctive mosaic of terraced landscapes. The area has largely maintained traditional practices, focusing on the mixed cultivation of vines, olive trees, and other crops. Efforts by local farmers, such as Fattoria di Lamole, have restored and preserved traditional terraces, counteracting trends in the wider Chianti region where many terraces have been destroyed to accommodate industrial-scale farming. These efforts earned Lamole recognition in 2018 when it was added to the National Register of Historic Rural Landscapes by the Italian Ministry of



**Fig. 17.6** The Lamole Valley, point cloud from the airborne survey of 2020

Agricultural, Food, and Forestry Policies (Ministerial Decree, 2018). Its terraced vineyards were later acknowledged also as heroic and historical vineyards in 2020 (Inter-ministerial Decree, 2020).

Terraces and dry-stone walls in Lamole provide a wide range of environmental benefits, including managing water runoff, preventing soil erosion, enhancing soil fertility and productivity, improving food security, promoting agrobiodiversity, and addressing climate change impacts. When maintained, terraces mitigate natural hazards such as landslides and floods (Agnoletti et al., 2023). However, many terraces have deteriorated due to abandonment and insufficient maintenance, leading to increased hydrogeological risks like erosion and slope instability. The lack of unified regulations on terrace recovery, inadequate education in dry-stone wall construction, and insufficient economic incentives for farmers contribute to this decline. Recent efforts aim to recover and preserve the knowledge of this practice, the art of dry-stone walling, recognized by UNESCO as intangible cultural heritage, to safeguard traditional viticulture techniques and ensure the enduring cultural and historical significance of the region (UNESCO, 2018a).

In recent years, Lamole has become a hub for research integrating historic preservation with modern scientific methodologies to enhance agricultural practices (Preti et al., 2013, 2018; Tarolli et al., 2014; Agnoletti et al., 2015; Tucci et al., 2019; Parisi & Tyc, 2021, Tyc et al., 2022). Since 2016, collaboration with Fattoria di Lamole has expanded access to several vineyards, enabling long-term monitoring of terraced vineyards like Grospoli and Le Stinche (see Table 17.3). This has facilitated continuous spatial and temporal data collection to better understand terrace dynamics.

In the context of broader framework of the research conducted in Lamole, the focus during the CHANGES project has been primarily the accurate assessment of temperature from thermal imaging and its role in terraced vineyards dynamics on a multi-temporal and multi-spatial scale. In fact, the study of traditional

**Table 17.3** Detailed information about the vineyards considered in the Lamole case study area

Area of study	Terraced Vineyards of Lamole (Greve in Chianti, Florence, Italy)	
Scale of reference	Territory and landscape	
Location	Lamole Valley	
Owner	Fattoria di Lamole, property of Paolo Socci	
Vineyard	Grospoli II	Le Stinche
Geographic coordinates	43°32'32"N 11°21'37"E	43°31'49"N 11°21'27"E
Type of terracing	Terraces with dry-stone walls and soil embankments	Terraced portion with soil embankments
Vineyard exposure	E-O	O-E
Years of monitoring	2017, 2019, 2020, 2022, 2024	2022
Vineyards' terraced area	~1.3 ha	~1.9 ha
Vine variety	Sangiovetto 100%	Sauvignon blanc 50% Chardonnay 50%
Cultivation method	The vines are cultivated by the traditional "alberello" method	

agro-hydraulic systems, such as terraces, has been performed on different scales, from the entire valley (airborne survey) to the single vineyards (UAV-based survey), to the single vine or dry-stone wall (ground-based measurements) to understand how mitigation strategies for climate change affect the quality and characteristic of the wine production despite the environmental shifts. In this context, geo-spatial technologies provide a shared substrate for different disciplines in terms of spatial data and thematic information for documenting the geometry, for modelling and simulation of hydrogeological phenomena and for monitoring through time and space the evolution in terms of geometry and thermal behaviour of such complex systems to ensure that this ancient landscape remains resilient and productive facing the challenges of a changing climate.

### ***17.3.2 Methodological Approach***

A key aspect of the research is the use of geospatial technologies to collect high-resolution spatial and temporal data, combining both aerial and ground-based data. Unmanned Aerial Vehicles (UAVs) equipped with visible (VIS) and Thermal Infrared (TIR) sensors are used as advanced thermal monitoring techniques to create 3D models of the morphology and thematic maps of the thermal behavior of the selected vineyards. The UAV photogrammetry, in conjunction with ground-based thermal imaging, allows for precise spatial reconstructions and detailed monitoring of temperature fluctuations at the local vineyard scale on different time spans (from daily variation to multi-year monitoring).

This study focuses on monitoring vineyard temperature using advanced tools to enhance vine health, optimize grape ripening, and support sustainable water use.

Technologies such as thermal imaging and infrared sensors help assessing temperature variations, detect water stress, and design smart irrigation strategies. By analyzing temperature fluctuations due to evapotranspiration and stomatal activity, farmers can better allocate water resources, leading to healthier vines and higher-quality grapes. Another important consideration, where monitoring temperature variations plays a crucial role, is the increasing use of terracing as an adaptation strategy to climate change and rising temperatures, allowing for the effective utilization of steep slopes and facilitating the shift of vine cultivation to higher latitudes and altitudes.

The research utilizes a structured approach for data collection and analysis:

1. **Thermal Imaging and Temperature Estimation:** Precise temperature estimation via thermal imaging requires attention to parameters such as emissivity, reflected temperature, and ambient conditions like relative humidity and temperature. By refining field data collection methods, the study aims to track vineyard daily temperature behavior over multiple years and compare patterns across various vineyards.
2. **Sensor Selection and UAV Integration:** After testing different sensor-platform setups for data acquisition, the DJI Matrice 300 RTK UAV and the Zenmuse H20T thermal sensor have been selected as the optimal combination for geospatial imaging and thermal data collection.
3. **Ground-Based Control Network:** To validate drone-collected temperatures, a ground-based control network has been set up using contact sensors like thermocouples, providing essential reference data (ground-truth) for validation, calibration, and accuracy enhancement.
4. **Combined Ground and Aerial Measurements:** Thermal data was captured from both ground and UAV-mounted sensors, allowing cross-validation. Ground-based cameras provided high-resolution data for single vines or sections, while UAVs delivered thermal maps of entire vineyards, to visualize temperature variation throughout the day.
5. **Enhanced Data Collection Techniques:** Improvements in data collection were made by using high-resolution contact sensors and onsite weather stations, ensuring higher accuracy in measuring environmental conditions like ambient temperature and relative humidity.
6. **Periodic Thermal Surveys:** Regular thermal surveys monitored daily and yearly temperature variations across different vineyards, evaluating the thermal behavior of various vineyard layouts, terrains, and altitudes, crucial for design and management.
7. **UAV-Based Photogrammetry for Thermal Mapping:** UAV photogrammetry enabled the creation of detailed thermal maps (orthomosaics) for vineyards, capturing temperature distribution and daily effects such as shadowing and differing responses from materials like stones, soil and vegetation.
8. **Geometric Validation and Calibration:** Increasing the geometric accuracy of UAV-based 3D thermal maps obtained from photogrammetry through

procedures such as partial camera pre-calibration, aimed at producing more spatially reliable 3D representations of vineyard terrains.

9. Radiometric Validation and Calibration: Validating the accuracy of thermal data by analyzing the sensitivity of temperature measurements to influencing parameters (e.g., emissivity, ambient conditions) and verifying their reliability for precise temperature readings.
10. Controlled and Real-World Testing: Tests in controlled and real environments validated the accuracy of the geometric and radiometric data, ensuring method reliability under diverse conditions.

### ***17.3.3 Results and Discussion***

The mentioned methodology allowed to obtain thematic maps for each vineyard representing the thermal distribution of temperature. This is possible thanks to a 3D reconstruction by using photogrammetry and by a radiometric conversion of the thermal data to obtain temperature values for each pixel.

The results of two selected vineyards are reported in Figs. 17.7 and 17.8, where the visual information related to the temperature distribution allowed to identify different thermal behaviors, induced by the sun position and by the different characteristics of the materials along the day (e.g. dry-stone walls).

This method allows for high temporal and spatial resolution mapping and monitoring of selected vineyards, to identify specific process affecting plant yield, growth and health.

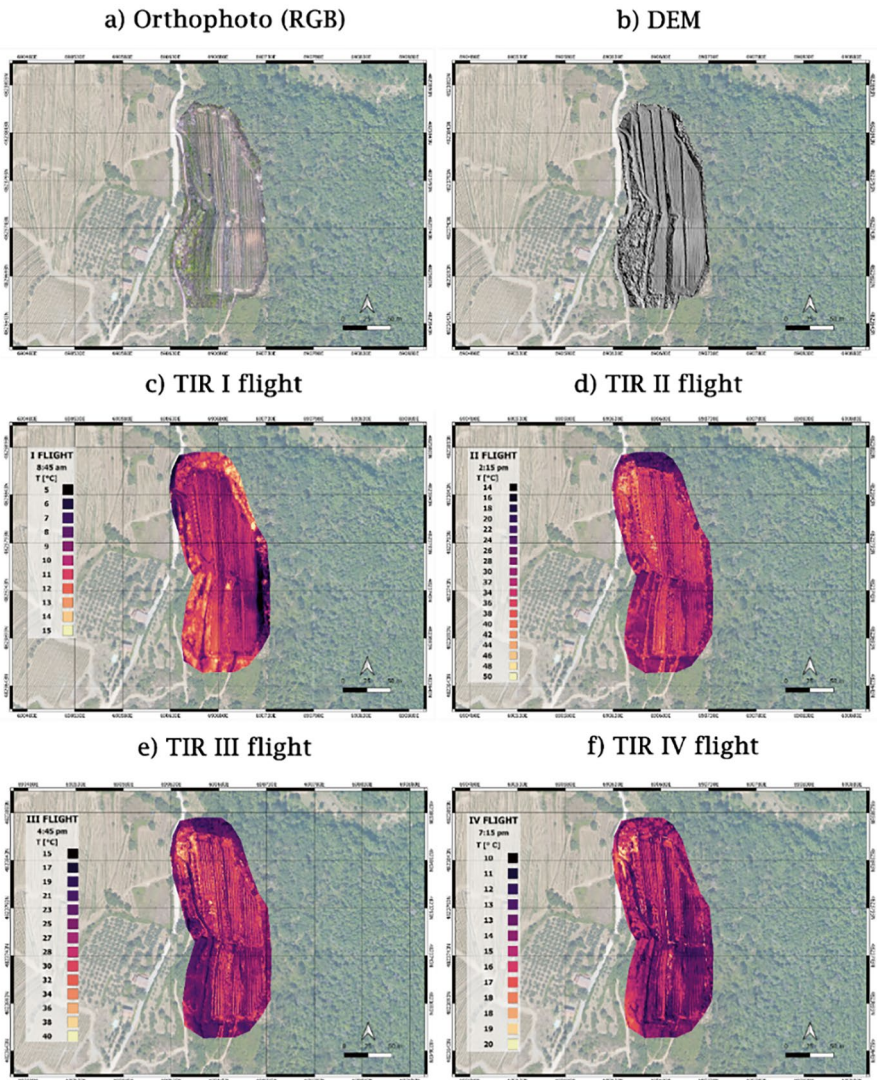
Furthermore, it is possible to analyze the radiometric data to produce GIS-based statistical information for each terrace extracting the temperature values trend acquired for each terrace, at selected distances, to identify micro-variation within the vineyard area, like dominant influence of solar exposure and shadowing on temperature fluctuations, which provided a foundation for further research.

These outputs may be used for the design of specific management and mitigation strategies although it is necessary to assess their reliability from both the geometric and radiometric point of view.

For this reason, the latest research focused on these topics:

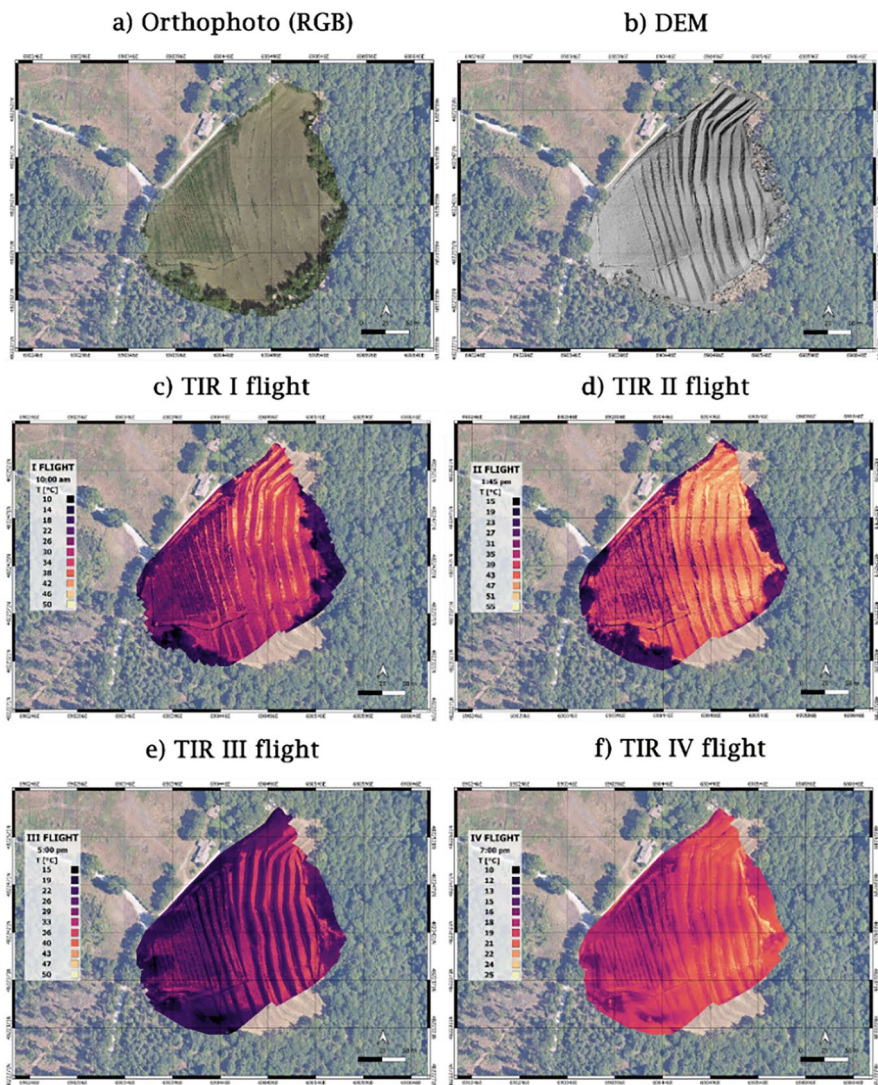
- preliminary analysis on the effects of GNSS measurements on the geometric self-camera calibration and how they affect the obtained photogrammetric 3d models (Parisi et al., 2022).
- preliminary analysis on the precision and accuracy of absolute temperature values obtained from thermal imaging radiometric conversion in different contexts (Parisi et al., 2024, publication in progress).

### GROSPOLI II VINEYARD



**Fig. 17.7** Grospoli II vineyard: geospatial morphological data (orthophoto and digital elevation model) and thematic information (thermal orthomosaics) for spatial and temporal monitoring of the thermal behaviour with visual information and absolute temperature values

### LE STINCHE VINEYARD



**Fig. 17.8** “Le Stinche” vineyard: geospatial morphological data (orthophoto and digital elevation model) and thematic information (thermal orthomosaics) for spatial and temporal monitoring of the thermal behaviour with visual information and absolute temperature values

### ***17.3.4 Future Works***

Future work will explore customized methodologies for assessing the impact of terracing as traditional agro-hydraulic systems. These studies will consider the multi-dimensional benefits and challenges of terracing, particularly its role in enhancing climate resilience. Emphasis will be placed on evaluating terracing from various perspectives, integrating environmental, agricultural, and socio-economic factors to inform adaptation strategies that respond to shifting climate patterns.

Efforts will include the development of robust and reliable methodologies for monitoring intra- and inter-specific parameters of terraced vineyards. By using advanced geospatial techniques, future research will aim to improve the qualitative and quantitative measurement of key factors such as temperature. This approach will facilitate a deeper understanding of microclimatic variations and the overall health of vineyard ecosystems, supporting targeted management and optimization practices.

The research will also prioritize collaboration with experts within the Spoke 7 of the CHANGES project. This interdisciplinary approach will contribute to the creation of shared practices and strategies that ensure the long-term preservation of terraced landscapes. By leveraging diverse expertise, future work will develop best practices and workflows aimed at balancing productivity with conservation, thereby safeguarding the cultural and environmental value of terraced vineyards.

## **17.4 The Terraced Landscape of the Lucretili Mountains**

### ***17.4.1 The Research Group***

The research group is affiliated with the Department of Humanities at Roma Tre University and is composed of an interdisciplinary team that combines the expertise of geographers (Carla Masetti and Sara Carallo) and landscape archaeologists (Emeri Farinetti), with the support of specialists from other disciplines (geomorphologists, plant ecologists, and experts in geotechnologies).

This integrated and multidisciplinary approach allows for the study of terracing from multiple perspectives, ensuring a critical, comprehensive, and in-depth analysis. The study of interactions between humans and the environment, traceable over time through phases of territorialization and the identification of cognitive and material sediments, has been fundamental in fully understanding the transformation of these structures in the long term.

The employed methodology is based on a detailed “regressive reading” of the territory, aimed at reconstructing the historical stratification process of these structures. Key steps include a critical analysis of geo-historical sources preserved in archives. These investigations are followed by field surveys, which involved direct and participatory observations, as well as the collection of oral sources.

\* Although the work can be attributed to a common discussion and project, it should be specified that the following paragraphs are assigned as follows: Carla Masetti is responsible for the sections “Research Group” and “Study Area”; Emeri Farinetti for the sections “Methodological Framework” and “Terraced Slopes”; Sara Carallo for the section “Some Preliminary Results of the Participatory Investigations” and “Best Practices”. The “Conclusions” are the result of joint collaboration. The archaeological investigations and participatory archaeology activities are conducted as part of the MoLuLaP (Monti Lucretili Landscape Project), a comprehensive archaeological project active in the study area of the Monti Lucretili (Bernardi & Farinetti, 2023; Bernardi et al., 2024). Analyses of soil samples for micromorphological and paleobotanical analyses are currently underway, thanks to collaboration with teams of international specialists.

### ***17.4.2 The Theoretical-Methodological Framework***

Through a bottom-up approach (multidisciplinary, multiscale, and diachronic), the research also involved the participation of local communities and aimed to investigate the level of social perception regarding the significance and characteristics of the landscape heritage under study, as well as the degree of awareness of the environmental risks to which the historical landscape is subjected.

The aim is to identify traces of material culture related to terraced areas and to promote participatory protection of the cultural heritage of the local community, encouraging forms of active participation and citizen science (Calandra, 2018; Burini & Ghisalberti, 2020; Masetti, 2019; Masetti & Spadafora, 2024). The dialogues initiated with the communities, in the form of participatory workshops or one-on-one meetings, aim to stimulate and revive local historical memory, promote co-production of knowledge, and foster greater territorial awareness and sense of place among the communities (Becattini, 2015; Farinetti, 2020, 2021).

The research aims to move beyond the point-focused logic of merely preserving individual monuments or contexts, instead promoting the protection of a widespread heritage, of which the rural landscape is a testament (Carallo & De Pasquale, 2018; Farinetti, 2012, 2021).

The fieldwork and integrated methodology will generate content for the creation of a community map (Baratti, 2012; Burini, 2016). This cartography will reflect the community’s self-perception and its landscape, presenting itself as a dynamic product, just like the landscape itself. Participatory workshops, organized in collaboration between academics, experts, and community members, provide the ideal setting to promote the shared creation of spatial and geo-historical content through real-time digital cartography. This encourages engagement and awareness, making the map a visual form of shared knowledge and increasing territorial consciousness (Belotti et al., 2024).

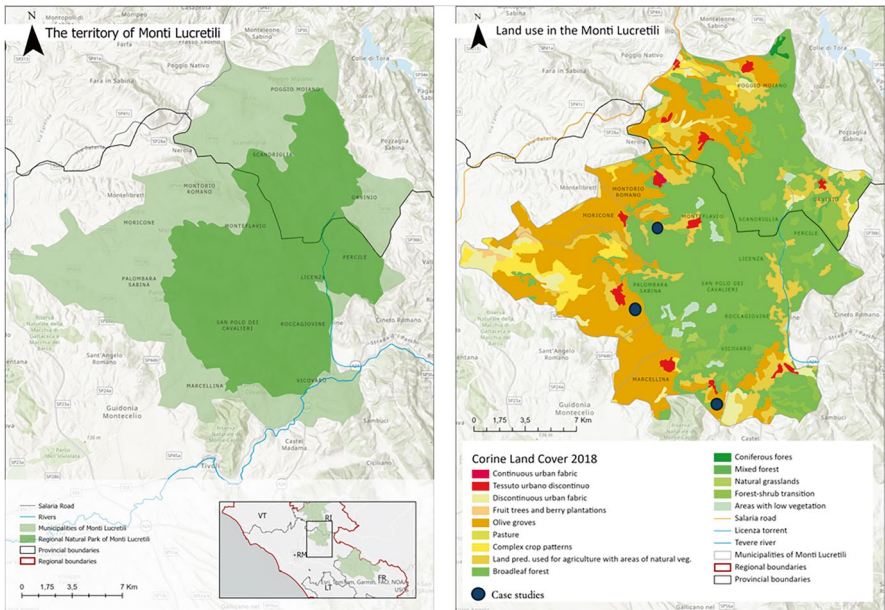
### 17.4.3 The Study Area

The Lucretili Mountains are located in the Lazio region, northeast of Tivoli, and extend between the Metropolitan City of Rome and the province of Rieti. This mountain range, composed primarily of limestone, runs in a northeast/southwest direction, situated to the left of the Tiber River, between the Sabine Mountains and the Rieti plain to the east, and the Aniene River valley and the Tiburtini Mountains to the south.

The area is extremely diverse, characterized by a predominantly mountainous environment typical of the Apennines, consisting mainly of narrow and steep mountain gorges, plateaus, and a lesser presence of low-gradient areas, interspersed with hilly and flat regions (De Angelis, 1995; Bernardi et al., 2024).

The Lucretili Mountains are part of the Regional Natural Park of the Lucretili Mountains, a protected area established by Regional Law No. 41 on June 26, 1989, to preserve local flora and fauna, as well as to promote awareness, environmental education, and recreational activities (Fig. 17.9).

The area features a great variety and richness of landscapes and biodiversity, including oak and beech forests, meadows, and limestone formations, such as the karst depressions of the “Pratone” on Monte Gennaro and “Prato Favale”. These locations have been engaged in transhumant pastoralism for millennia.



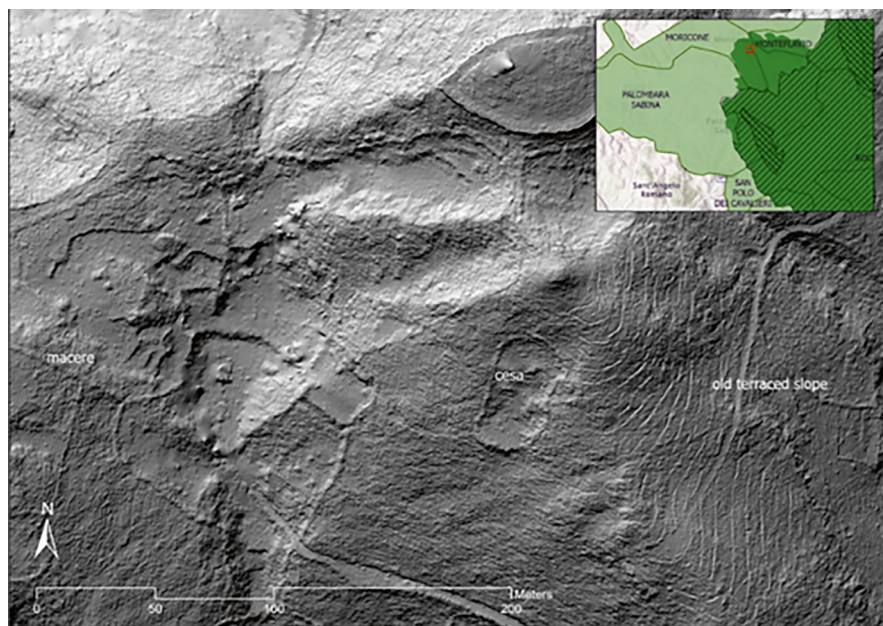
**Fig. 17.9** Left: The territory of the Lucretili Mountains. Right: Corine Land Cover of Lucretili Mountains and case studies marked with black dots. Authors Sara Carallo and Francesco Atanasio Carolei

### 17.4.4 *The Terraced Slopes*

The most significant material signs of the relationship between local communities and the environment are represented by the terraced olive groves, which remain a distinctive feature of the Monti Lucretili landscape (Fig. 17.9). This practice has left evident tangible and intangible traces in the memory of the populations, as well as in the archaeological heritage and local toponyms, constituting a substantial immaterial wealth of great cultural value (Scaramellini & Trischitta, 2006; Agnoletti, 2011).

The terraced slopes, supported by dry stone walls, are largely disused today. These rural structures, locally known as “macère,” are made from small-sized stone materials, primarily erratic or waste stones collected from the surrounding area. They are usually of limited height and, in addition to supporting terraces, are still used to delineate spaces and organize the land and resources available to local communities. They can define property boundaries, agricultural areas, enclosures for livestock, or paths. One example is the “cese” (as they are called in the local dialect), which are semi-circular enclosures designed to keep wild or domestic animals out of agricultural areas, thus protecting the crops (Bernardi & Farinetti, 2023) (Fig. 17.10).

In the study area, various types of structures can be found, constructed using different building techniques. Together with the diversity of the land, these create very distinct landscapes, ranging from terraced areas to flat steps extending over several



**Fig. 17.10** LIDAR survey with a drone of the old, terraced area south of Monteflavio (south slope of Monte Calvario), now covered by forest vegetation. Author Federico Fasson

dozen meters (organized in altitudinal bands with pure row crops) to steep slopes with small crescent-shaped steps, where each plant is surrounded by a dry-stone wall.

The origins, chronologies, and functions of these terraces are still a topic of debate. The MoLuLaP archaeological project, following recent research lines, is conducting excavation tests and diagnostic sampling on “macère” that serve as terraces. The aim is to establish relative chronologies for these structures and to analyse soil sliding and accumulation processes. The periods of most intensive economic exploitation may have seen an increase in dry stone terraces on the slopes for agricultural and/or pastoral purposes, such as during the Roman Republic (third to first centuries BC) along the river valleys, or in the medieval period and the sixteenth to seventeenth centuries in the more inland areas (Bernardi, 2021; De Coste, 2024). The nineteenth century experienced intensive use of the mountainous land (with charcoal production, livestock farming, and the cultivation of fruit trees and olives), a trend that ultimately led to abandonment following the depopulation of these areas in the post-World War II period.

In the 1930s, deforestation efforts, followed by the construction of road infrastructures and land subdivision in the 1970s, led to significant damage and deterioration, and in some cases even the destruction of numerous dry-stone walls, particularly those located in the foothill areas (Parco dei Monti Lucretili, 2018). The risks associated with climate change for these structures are high, primarily due to the acceleration of karst processes, erosion, and landslides, likely resulting from intense rainfall events interspersed with long periods of elevated temperatures.

These selected zones are characterized by a rich archaeological heritage of significant historical and cultural interest, each telling different stories. In some areas, the terraces are now unused, while in others they continue to be actively used, representing a continuation of traditional agricultural practices and cultivation techniques (Fig. 17.10). These regions also showcase a variety of terracing types, as evidenced by the available historical cartography, which documents the evolution of the agricultural landscape over the centuries.

#### ***17.4.5 Some Preliminary Results of the Participatory Investigations***

The bottom-up approach of the research, as we have seen, places the citizen at the centre of the process of data collection and interpretation, collectively represented by the local community and individually involved in the scientific dialogue of the ongoing research, even as a direct contributor of informational content. An online survey is being conducted via Google Forms to assess the social perception of anthropogenic environmental risk in the Monti Lucretili.

The survey, conducted through the administration of questionnaires, targets local residents and potential stakeholders. The questions focus on residents' awareness of the vulnerability of the landscape in their area, the impact of climate change on

tangible and intangible cultural heritage, and their willingness to adopt direct measures to improve resilience.

The initial results of the ongoing survey reveal a significant natural degradation, exacerbated by the increasing depopulation that has led to the abandonment of lands and the loss of knowledge and skills related to traditional rural and agro-pastoral activities. This phenomenon is reflected in the instability of dry-stone walls, with widespread collapses, and could soon cause damage related to hydrogeological instability, triggering erosive processes and landslide phenomena that affect not only the mountain slopes but also the valley floor, already compromised by the climate crisis (ISPRA, 2021).

The main causes of environmental risk identified by the local population include both natural causes (fires, landslides, floods, and invasive vegetation) and anthropogenic origins (negligent management, abandonment, lack of maintenance, demographic decline and aging, loss of traditional knowledge, reforestation, and loss of agricultural land). In addition, there are the evident effects of climate change.

This investigation reveals clear evidence of an enhanced perception of risk among the populations of the Monti Lucretili. The majority of respondents express concern, accompanied by a sense of helplessness, along with a desire to deepen their understanding and feel more involved in efforts to address these risks. The collected responses also highlight significant awareness of the environmental and anthropogenic risks affecting the territory and the recognition of a strong link between exposure to risks and climate change. Furthermore, it is noteworthy that the vast majority of questionnaire participants report that they have been living a sustainable lifestyle for some time.

Understanding and knowledge of the population's perception of risk are of significant importance for effective management of dangerous situations and environmental threats. While quantitative analyses provide objective and measurable data, the social perception of risk reflects the emotions, fears, and concerns of the community. This perception can vary greatly among different social groups and influence their interaction with the territory and their reactions to risk events, both before and after such events (Wickes et al., 2015). A positive perception of the territory can motivate people to actively engage in its protection and enhancement, promoting sustainable behaviours and responsible management practices. Conversely, a negative or distorted perception of the territory can lead to choices that are harmful to the environment and the community (Geipel & Cesa Bianchi, 1980).

#### **17.4.6 Best Practices**

Thus, the ongoing investigation in the territory of the Monti Lucretili has revealed needs expressed by the local inhabitants themselves. Among the actions considered most urgent are the necessity to oversee and safeguard the rural territory, maintain riparian areas, and protect cultural heritage, ancient crafts, and local knowledge (of which, it should be noted, the dry-stone structures are an expression). The majority

of participants in the meetings and interviews believe that it is essential to involve citizens in formulating strategies for the mitigation and prevention of environmental risks, while also expressing confidence in the work of experts in the field.

Regarding the monitoring of environmental and cultural heritage, many participants in the questionnaire and the participatory labs emphasize the lack of controls and sanctions as a critical point. Proposals include initiatives such as raising awareness starting from preschool, organizing conferences and events with industry experts, and paying particular attention to maintenance. The working group has initiated several initiatives in this direction. Among these, the involvement of schools in creating mental maps and community maps aimed at promoting territorial awareness and participatory inventorying of historical and cultural heritage. A documentary is also planned that will narrate the terraced landscape of the Monti Lucretili and its evolution over time, highlighting the connection between the environment, history, and local communities. The documentary will also showcase academic activities and field research conducted by the working group as part of the CHANGES project. Additionally, the 16th Seminar on Historical and Cartographic Studies “From the Map to GIS,” which will take place in November 2024. Focused on “Settlement Systems, Spatial Analysis, and Local Knowledge: Interdisciplinary Pathways and Perspectives in Participatory Research”, the seminar will provide an important opportunity for debate and reflection on best practices in participatory action research and citizen science.

Lastly, a workshop dedicated to the construction of dry-stone walls is scheduled for 2025, which will involve students, local skilled workers, qualified artisans, institutions, and local communities, thus promoting an intergenerational exchange of skills and knowledge.

### ***17.4.7 Conclusions***

The relationship between humans and the environment, as well as that between human communities and cultural heritage, can become sustainable and long-lasting if it is based on the values and identity memory of the community. When communities are aware of their heritage, they become capable of recognizing and enhancing their resources, better defining their needs and appreciating the value of the landscape. This approach generates responsible actions and greater care for the territory, along with openness and a high level of hospitality. Visitors or “temporary citizens,” such as hikers, are also encouraged to actively participate and care for the place, enhancing commitment and sensitivity towards the preservation of heritage. In this context, rural dry-stone structures, such as the “macère”, become tangible symbols of a cultural heritage to be preserved, not only for their historical value but also for their role in protecting the territory from environmental and anthropic threats.

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