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GIS-based detection of terraced landscape heritage: comparative tests using regional DEMs and UAV data

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Abstract

The analysis of terraced heritage has implications in many different fields of study, as it is shaped itself by natural, socioeconomic, and cultural dynamics. Given that their abandonment impoverishes territories and communities and raises natural, especially hydrogeological hazards, and that their deactivation leads to a loss of cultural identity, this paper aims to study rapid mapping systems for their detection. Since a deep relation between high land division and the use of terraces for the exploitation of territories has been recognized, a first detection method is based on cadastral maps. The joint use of regional-scale digital elevation models (DEMs) and cadastral dataset polygons, based on a model that typically uses GIS analyses, identifies areas with a high probability of terracing. A second method is based on the use of new technologies for very high-scale data collection. The DEM models derived from UAV (unmanned aerial vehicle) photogrammetry, given their ability to determine the micro-topographical characterization of the terrain as well as the most expensive on-site techniques, can be considered an excellent low-cost means by which to locate terraced heritage. The proposed work includes comparative testing between methods implying GIS-based analysis of slope models. It aims to highlight the effectiveness of using both methods: regional-scale DEMs and cadastral maps to detect a high probability of terrace localization, and DEMs derived from the use of low-altitude aerial data and structure from motion (SfM) algorithms, which have greatly and effectively increased the use of aerial drone photogrammetry.

Keywords DEM analyses · GIS-based analyses · High-scale mapping · UAV photogrammetry · Terraced landscape

Introduction

The harmonious development of a country, and the exploitation of natural, environmental, and landscaping resources in addition to the entire intangible cultural complex associated with local resources, can become a modern engine of

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environmentally sustainable development. Considering this, landscaped terraces, forming a dotted line in a much wider virtuous design, may well be subject to reflections and tests that support their promotion and reactivation.

The 2000s have been a period of extensive studies on the terraced territories of the Mediterranean and Alps (e.g., Brancucci et al. 2000; Briffaud and Brochot 2010; Fontanari and Patassini 2008), and many interregional and European-community-financed projects have aimed at providing methods of knowledge conservation and protection. The PATTER project (Heritage of terraces in the Western Mediterranean), concluded in 2001, identified methodologies for cataloging and classifying the terraces of some Mediterranean basin regions. REPS (Réseau Européen de la Pierre Sèche), of the Interreg IIIC program, and TERRICS (Récupération de Paysages en Terrasses et Prevention de Risques Naturels) focused on the evaluation of the hydrogeological risk of terracing loss, especially in the Franco-Hispanic area (France, Spain, and Portugal) (Sangiorgi et al. 2006).

The recent vast ALPTER (Landscape of Alpine Arch Terraces) project of 2004–2007 (Scaramellini 2008) was aimed

Fig. 1 The Honghe Hani Rice Terraces in Southern Yunnan, China, that covers an immense area of 16,603 ha (Sources: UNESCO, China Daily, Travel China Guide)

at mapping existing terraced landscapes and identifying problems and solutions for the recovery and enhancement of terraces in the Alpine area. The ALPTER project identifies the most popular method commonly used to conduct a mapped census of terraced landscapes (Varotto and Ferrarese 2008). It can be summarized as follows: (a) identification of terraced sites based on regional topographic maps, (b) analysis of aerial photos and orthophotos of the study area (scale 1:5000–1:10,000), and (c) field surveys for the purpose of verifying and integrating. This requires the use of regional-scale maps, in conjunction with a checking system using photo-interpretation and a site survey, to examine statistically representative sample basins.

There are proposals for the integration of the study of the evolution in land use over time using GIS tools that support terrace mapping (Ažman Momirski 2008). There are also considerations of the problems of consolidated techniques: "In practice, the information obtained underestimates the actual amount of terracing due to the fact that it is impossible to recognize the terracing covered by vegetation, whether by woods or brambles" (Brancucci and Paliaga 2008).

The studies on terracing have led to a recognition that this particular transformation of the terrain morphology converts it into heritage landscape.

The terraced landscapes, which are spread across many areas of the world, are characterized by high levels of acclivity and are evidence of significant human work done to enable the supply of resources necessary to sustain life even when the natural conditions of the territory would not seem appropriate for this endeavor. Some of these terraced landscapes, such as those of the Ifugao Islands in the Philippines; the Yuanyang terraces in Yunnan, China; the island of Bali in Indonesia; and the Cinque Terre and Amalfi Coast in Italy; have received international awards

Fig. 2 Terraced slope in Cinque Terre area, Liguria region, Italy. (Brancucci and Paliaga 2008)

Fig. 3 Types of terraces. **a** Dry-stone wall construction: 1. construction of the downstream dry-stone wall; 2, displacement of soil volumes; 3, construction of the upstream dry-stone wall, and tillage of the flatten terrain. **b** Terracing accomplished by dry walls. **c** Short scarps terracing system (a"ciglioni")
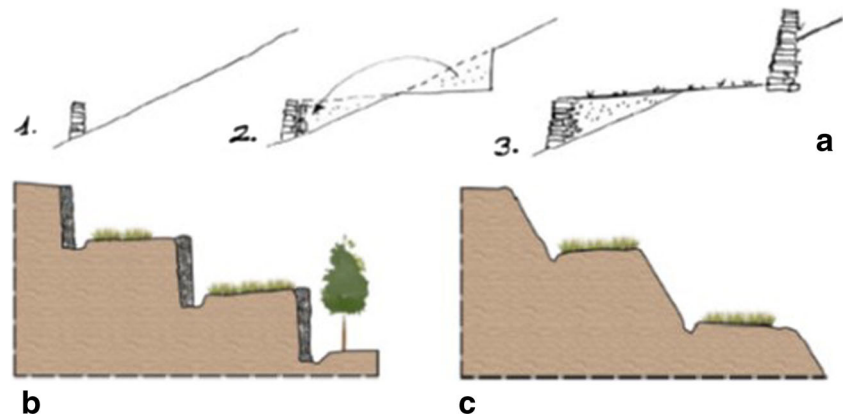
and are included in the UNESCO World Heritage List (Figs. 1 and 2) (http://www.terracedlandscapes2016.it/en/).

Beyond recognition as a world heritage, there is a growing scientific interest in analyzing different aspects: the historical anthropological and archeological roots has been recognized (Ferro-Vázquez et al. 2017); their intrinsic nature in environmental transformation and its implications on land use and soil properties has been investigated (Jiang et al. 2017), and interest is growing in the microclimate and geomorphology of the areas affected by the phenomenon. Consequently, the risks deriving from their abandonment are hydrogeological (Sammartano and Spanò 2014) and in weighing the agronomic and ecological balance of the territories with the necessarily social and economic consequences (Londoño et al. 2017). Some studies aim to highlight how their current use, enclosing tradition and innovation, could contribute to providing food solutions for the presently growing pressure in terms of food production (Balbo and Puy 2017).

Starting from this framework, and considering the great enhancement in techniques used for surveying, processing, and representation of spatial data that have been realized in recent years and led to achieving and providing application benefits for a wide variety of different application sectors, this paper will propose methods to improve terracing detection.

The opportunity to know and, thus, enhance the chance to protect a cultural landscape of outstanding importance, such as terraced heritage, is reached using both regional data and maps and UAV (unmanned aerial vehicle) photogrammetry.

Brief outline of data/DEM usage from UAV platforms

Over the last few years, there has been a sudden and growing development of the use of UAV platforms for detection purpose in many different application areas. Synthesis contributions are available, which report different platform solutions (fixed wing and multirotor) and data from the various sensors with which the vectors are equipped, highlighting the opportunities in mapping, monitoring, and realization of 3D models. (e.g., Nex and Remondino 2014).

The possibilities offered by digital photogrammetry and the continuous development of digital compact cameras, coupled with an ever-increasing miniaturization and sustainability in terms of the cost of the sensors, have allowed a substantial increase in diffusion of the UAV systems used for the achievement of photogrammetric surveys in urban areas,

Fig. 4 Example of dry walls in the first test area (Possi photo)

Fig. 5 Terracing performed by short scarps in Ferriere (Calcagno Tunin, Cerise photo)

environmental fields, and cultural heritage documentation. As known, the essential part of this success is certainly due to the ability to capture images with a high overlap, from an aerial point of view, and to process and access photogrammetry

products using algorithms that have automated the entire workflow. These algorithms are *Structure from Motion* (SfM) and *image matching*, both of which are now well known in the literature. (Lowe 2004; Förstner and Wrobel 2016).

In the environmental sciences, the literature that proposes the adoption of UAV systems is complex and rich. Proposals have been made in, for example, agriculture and forestry (Aicardi et al. 2016), geomorphology (Hackney and Clayton 2015), and vegetation monitoring using multisensory approach (Sankey et al. 2017).
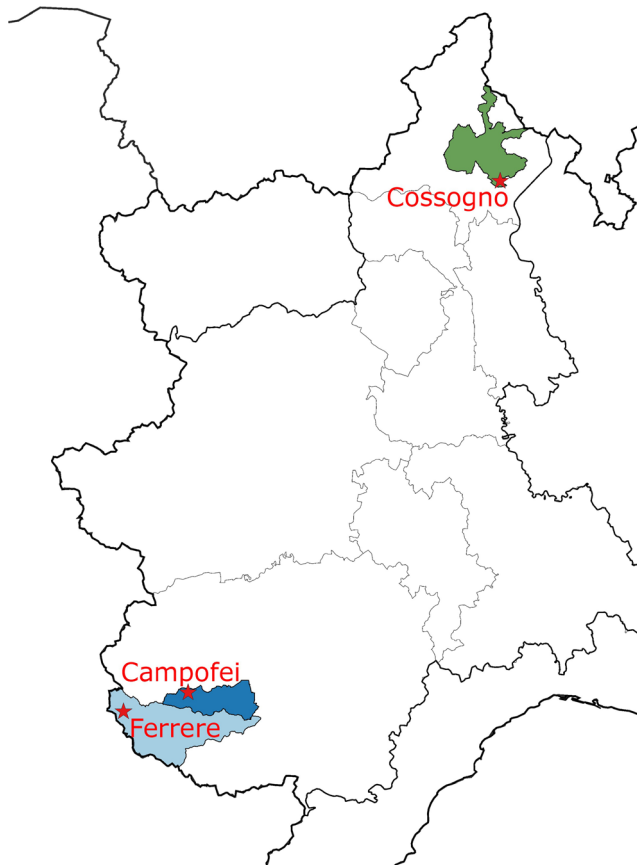

Fig. 6 Localization of three test sites in northern and western Italy (Piedmont): Cossogno in Valle Grande Park; Campofei in Grana Valley, Ferriere in Stura Valley
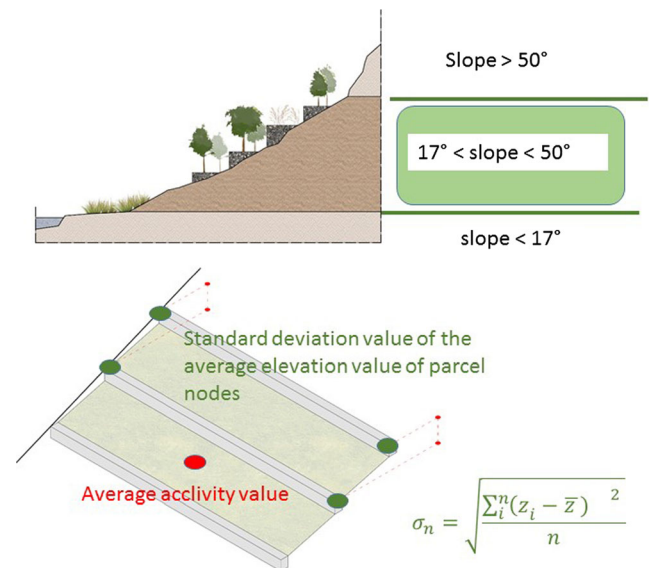

Fig. 7 Detection parameters for terraced cadastral parcels mining: average acclivity value in the range greater than 17° and less than 50°; standard deviation value of the average elevation value of parcels nodes less than 4 ÷ 5 m, depending on areas
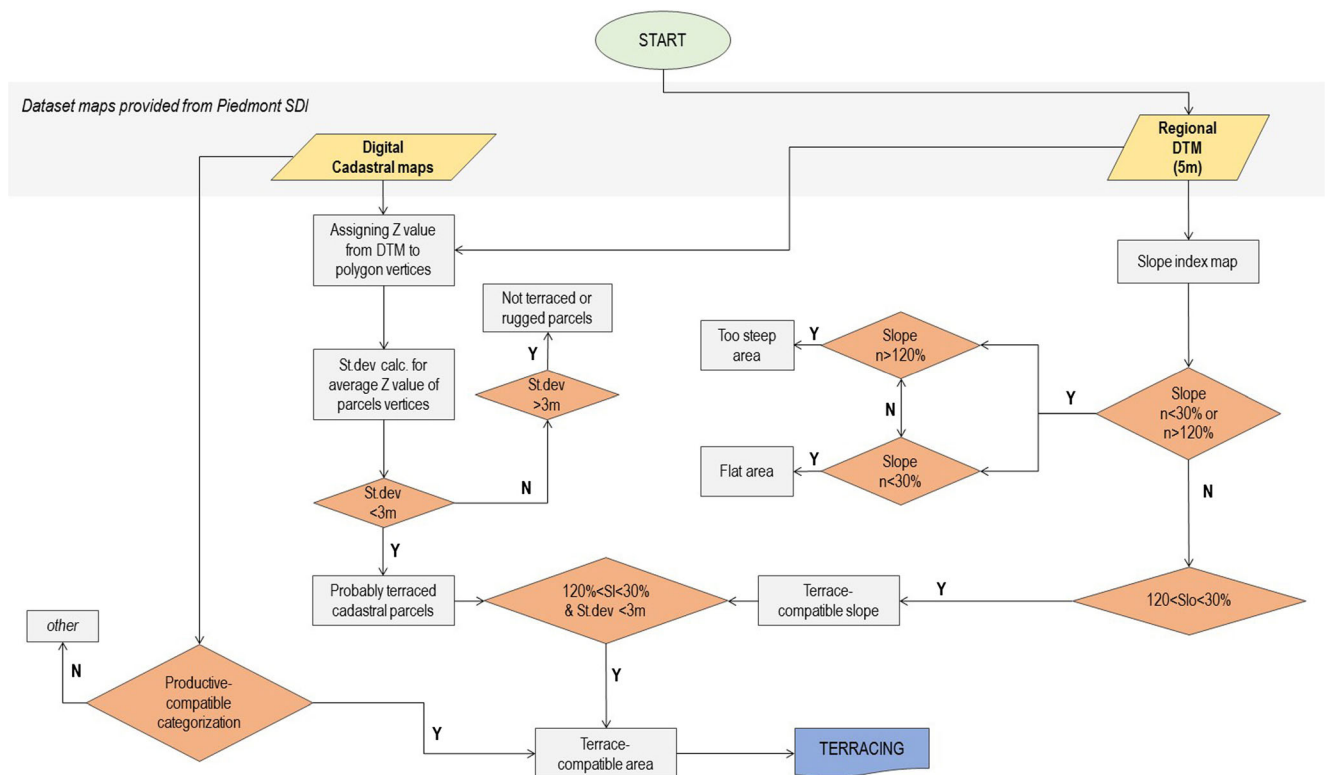
START

Dataset maps provided from Piedmont SDI

Digital Cadastral maps

Regional DTM (5m)

Assigning Z value from DTM to polygon vertices

Slope index map

Not terraced or rugged parcels

St.dev calc. for average Z value of parcels vertices

St.dev >3m

Too steep area — Y — Slope n>120%

Slope n<30% or n>120% — Y

N

St.dev <3m — N

Flat area — Y — Slope n<30%

Y

Probably terraced cadastral parcels

120%<Sl<30% & St.dev <3m — Y — Terrace-compatible slope — Y — 120<Slo<30%

N

other

N

Productive-compatible categorization

Terrace-compatible area — TERRACING

Y

Fig. 8 Entire workflow of method (A) for terrace detection

The experiments aiming at determinations with high detail, large scale, and high accuracy in the domain of the micro-topographical characterization of sites are particularly similar to the purposes of this contribution, such as those in wetland vegetation classification studies (Marcaccio et al. 2015), peatland micro-topography detection (Lucieer et al. 2014), or, moreover, in archeological studies (Roosevelt 2014).

Studies that, to some extent, are related to this research by the need for very detailed DEMs are those that use multi-temporal analyses to estimate phenomena in time-shifting, such as studies of landslides and glacial movements (Niethammer et al. 2012; Lindner et al. 2016) or multi-sensor tests in hazard contexts (Aicardi et al. 2017). A common trait of all the examples cited is taking advantage of UAV photogrammetry in order to bridge the scale gap between site surveys and conventional aerial photogrammetry products or airborne LiDAR collections. In the literature much research operates in terms of deriving DEM from DSM (Digital Surface Model), exploiting the processing of point clouds generated from aerial photogrammetry or airborne laser scanner with several approaches (Pfeifer et al. 2008; Masaharu and Ohtsubo 2002; Sithole 2001) using automatic or semiautomatic algorithms of classification, segmentation, and points filtering (along density, direction, slope).

The investigations based on high-scale UAV data on mountain landscapes, to which the present paper is dedicated, bring with them a series of difficulties related to both the high detail requested on the micro-topographical characterization of the terrain and the ground slope. The algorithms that recognize

objects according to their variation in height and density from ground must take into consideration: first, the significant slope of the ground and, then, any local specific variations of slope and roughness due to the high scale of the model surface. Some procedures have been proposed and tested for slope land applications (Perko et al. 2015; Hosseini et al. 2014; Sithole 2001; Zhang et al. 2016) and high-scale UAV documentation in an alpine context (e.g., Spanò and Sammartano 2016).

Two types of terracing and three test areas

The choice of terracing an area is made when the terrain presents high or falling slopes that make cultivation operations difficult. In many areas, the terrain is accompanied by the construction of dry walls (Figs. 3b and 4), whose stones are derived from the tillage and displacement of soil volumes (Fig. 3a). In other areas, the terraces are made up of so-called "ciglioni," a type of terrace in which the dry walls are replaced by short scarps (Figs. 3c and 5).

The first test area is the territory of Valle Grande in northern Piedmont (Fig. 6); although a general census has been carried out using the proposed method in many municipalities of this area (approximately 31,000 h), in this paper, only the sample map of the municipality of Cossogno will be presented in detail (Possi 2017). The second test area is in Valle Grana, in the municipality of Castelmagno (Campofei Village—Fig. 6), on which a feasibility study was carried out to evaluate the chances of

Table 1 Comparison between different cameras and flight parameters in the Ferriere (A) and Campofei (B) test sites using the same Ebee system. Table (B) refers to the flight that was not used because the GSD was too high

(A)

	Ebee flights data
	(September 2016)
	Used
	Test site Ferriere (valle Stura)
Camera	Power shot Canon S110 RGB
	CCD size 7.44 × 5.58 mm, pixel pitch 1.86 μm, focal length 5.20 mm
Area covered	0.95 km²
Type of terrace	"ciglioni", with short scarps
Altitude flight	About 120 m
Acquired images	426
GSD	0.057 m
Medium GCP error (RMS)	0.027 m

(B)

	Ebee flights data
	(September 2015)
	Not used
	Test site Campofei (valle Grama)
Camera	Canon PowerShot ELPH 110 HS
	CCD size 6.16 × 4.62 mm, pixel pitch 1.33 μm, focal length 4.3 mm
Area covered	Mixed (with dry wall and short scarps)
Altitude flight	370 m (from the minimum elevation) 120 m in the upper area
Acquired flight	544
GSD	0.11 m
Medium GCP error (RMS)	0.275 m

revitalization of the semi-abandoned area (Regis et al. 2017). The third case study is located in the Upper Stura Valley, in the hamlet

Table 2 Parameters of the camera and flight in Campofei using a multirotor platform; the GSD is now comparable with the Ferriere GSD

	Exacopter (microcopter) flight data
	(September)
	Used
	Test site Campofei (valle Grama)
Camera	Sony Nex5
	CMOS size 23.5 × 15.6 mm, pixel pitch 5 μm, focal length 16 mm
Area covered	0.18 km²
Type of terrace	Mixed (with dry wall and short scarps)
Altitude flight	About 70 m
Acquired images	626
GSD	0.022 m
Medium GCP error (RMS)	0.041 m

of Ferriere (Figs. 5 and 6), where studies concerning the recovery of built and landscape heritage using local resources are in progress (Calcagno Tunin and Cerise 2017). The three areas are united by the phenomenon of progressive abandonment, especially since World War II, and the terraces are often in a state of advanced decay. While impressive terracing works by dry walls are of interest in the Valle Grande, in the valleys of the Southern Piedmont, there is widespread short scarps terracing, and, in some cases, such as the second test area (Campofei), a mixed technique was used.

The two methods developed to detect terraces at different scales

This paper deals with terraced landscape detection, and it is focused on the validation and comparison of two possible strategies for different scale applications and, if possible, using the results cooperatively.

GIS-based tools perform the entire workflow of each method while managing different scale and source data. In particular, the open-source software Quantum GIS (Open Source Software QGIS) and some tools from GRASS and SAGA GIS have been used.

The next two paragraphs describe, in detail, the two methodologies developed, and the experimental section will present the applications of the two methods in three study areas. Since not all of the source data for each test area was available, the first method has been tested in just the first two areas, and the second method using UAV data has been applied only in the two areas of the Southern Piedmont. Validation of the results was done using traditional, ground-based approaches (GNSS/RTK techniques).

Method (A): regional-scale approach. Detection based on regional-scale DEMs and cadastral maps

The first method was conducted in collaboration with the Valle Grande National Park Authority and with the Gister Geomatica company of Verbania,[1] with the aim of carrying out a mapping of the terracing, realized through a probabilistic approach identifying the possible terraced areas (Possi 2017). It uses the experimental observation that the terracing can be found in lands with very varied slopes, between 17° and 50° (Fig. 7).

The first method uses regional-scale DEMs (grid resolution 5 m, height accuracy ±0.30 m),[2] from which the land's

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[1] http://www.amossola.it/musei_ossola/sites/default/files/iniziative_documenti/Renato%20Locarni.pdf

[2] Piedmont Spatial Data Infrastructure (SDI) provides the needed dataset: RIPRESA AEREA ICE 2009–2011—DTM. Uniform methodology (LIDAR) in level 4 standard. The grid resolution (pitch) is 5 m with a height accuracy of ± 0.30 m (± 0.60 m in areas corresponding to the wooded and densely urbanized areas).

Fig. 9 The UAV ortophoto (**a**) and RGB DSM (**b**) of Ferriere valley
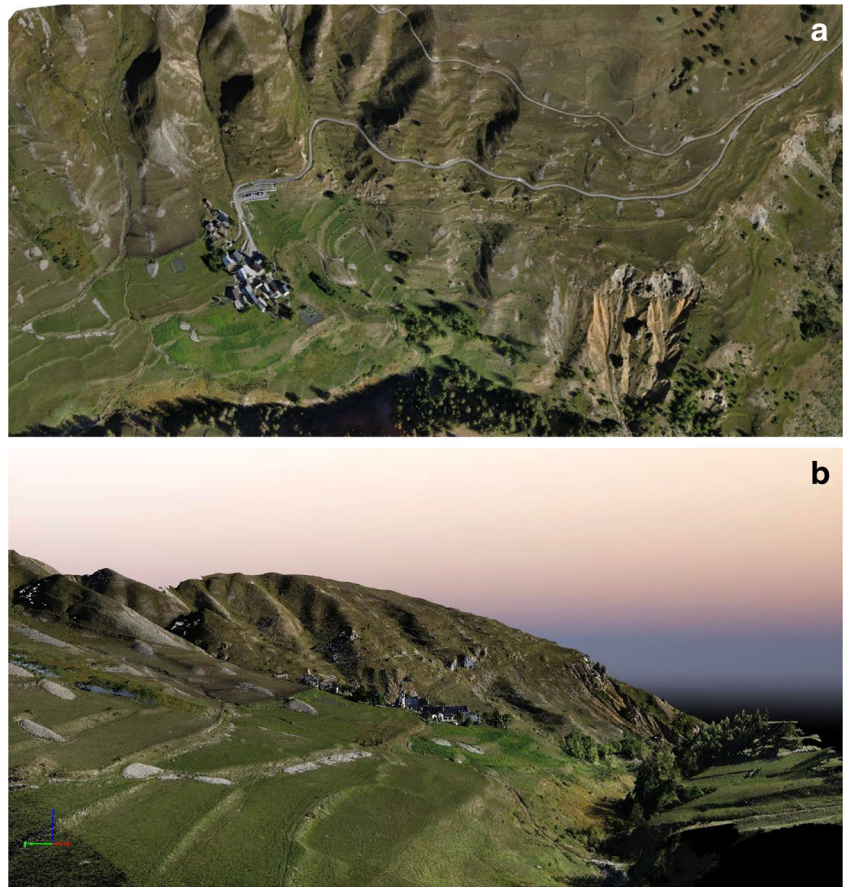
acclivity can be derived; further, the typical geometry of the cadastral parcels that have terraces is narrow and elongated, arranged according to the slope (i.e., parallel to the contours and perpendicular to the maximum slope

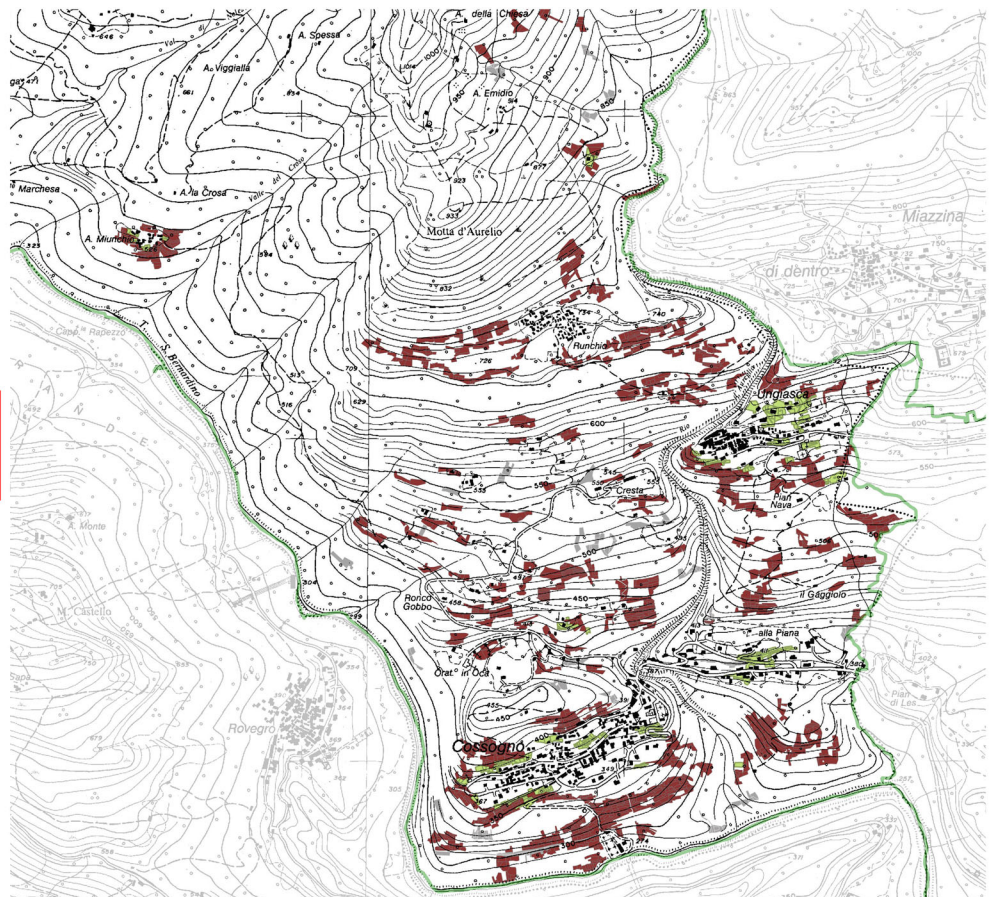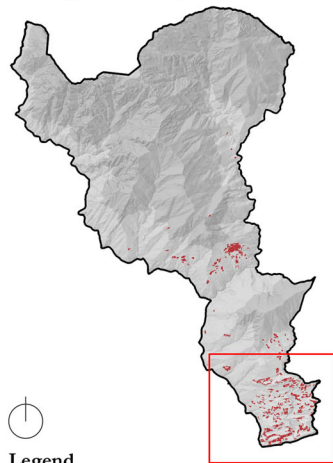Fig. 10 3D view using RGB DSM of the Campofei area

Fig. 11 Results of terracing detection responding to method (A) parameters in Cicogna village (Cossogno municipality)
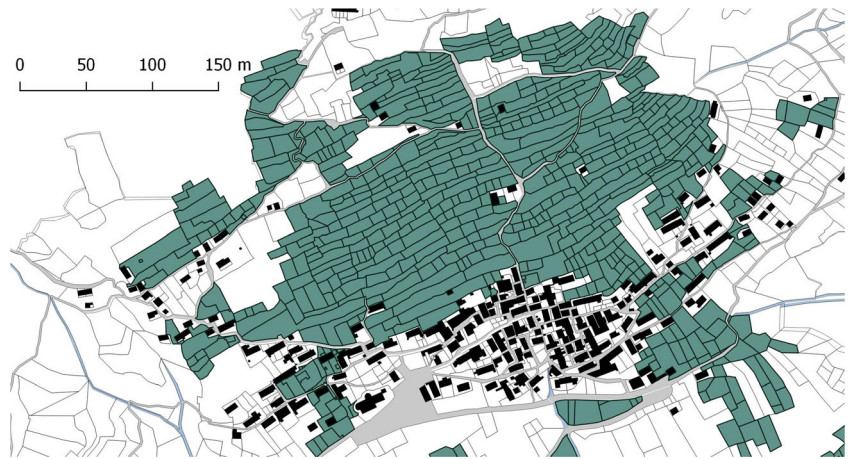
direction). Albeit, new-generation DEMs are used, derived from the LiDAR method (one point in 5 m), which do not allow the micro-topography of the territories to be read.

Next, the terrain acclivity is compared using statistical criteria introduced through the contents of cadastral maps (in particular, the cadastral parcels' boundary geometries) with the aim of identifying areas with a high probability of

Cossogno municipality

Legend

☐ Municipalities boundaries
☐ Used cadastral parcels
■ Abandoned cadastral parcels
☐ Not terraced cadastral parcels
☒ Not verified cadastral parcels

0   200   400   600   800 m

Cartografia elaborata con il software Quantum Gis 2.14.

Per la rappresentazione del costruito, della morfologia e della viabilità è stata utilizzata la CTR in scala 1:10.000

S.r: EPGS: 32632, WGS 84 / UTM zone 32

Fig. 12 Method (A) results for the entire Cossogno municipality (and a post classification concerning whether they are currently in use or not). Concentration of terraces detection near the villages
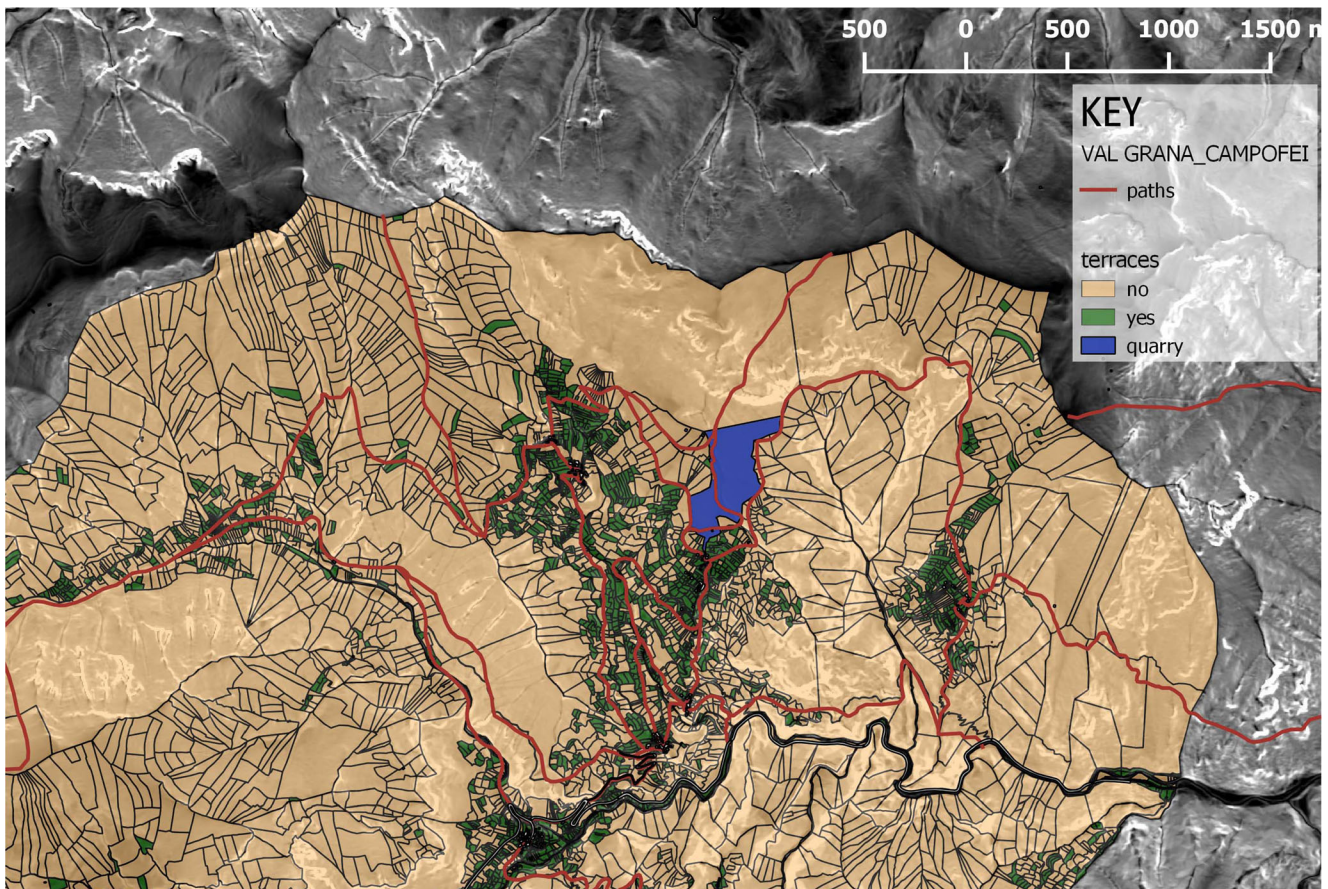
Fig. 13 Method (A) in Grana Valley. Detection of terraced parcels

terracing. Since a cadastral map is typically a planimetric map, one main principle of the operation of the method aims at determining the elevations of the vertices of the cadastral polygons and filtering them, assigning a high chance of terracing or not, on the basis of the difference in heights downstream and upstream. Such characteristics, together with other qualities of parcels connected to the land use, complete the statistic inference.

A schematic workflow of this method is as follows:

– Calculation of slope index map (from DEM)
– Identification of the average slope value for each cadastral parcel (computed by the *zonal statistics tool*).
– Calculation of the level value of the cadastral polygons vertices, interpolating them from DEM in order to assign a *z* value at each vertex.
– Calculation of the standard deviation of the average z values of vertexes of parcels: this statistical dispersion index, estimating the variability in heights of parcel boundary nodes, is able to identify whether the parcels polygon is near to horizontal flat or not.

Depending on the general average slope of the area, and considering that terraces are generally narrow strips of semi-flat ground, the standard deviation threshold to be used in the tests was a few meters (depending on the studied area and heights of dry walls, for example, 4 m).

The combinations of cadastral parcels that have been simultaneously attributed an average slope value compatible with the presence of a terrace and a standard deviation value of the difference in levels below the established threshold are selected as highly probable terraced parcels.

Further, the topographic database of the New Italian Land Register, dated back at 1952, reports coding regarding the type of agricultural macro-culture: the cadastral parcels already classified as probably terraced have been further winnowed on the basis on this coding (excluding, for example, encoding as quarry, graveyard, road wreck, and all types of buildings).

Figure 7 illustrates the method's detection parameters, while Fig. 8 illustrates, through a flowchart, the entire workflow, which also includes the final selection of the particles based on their land use coding.
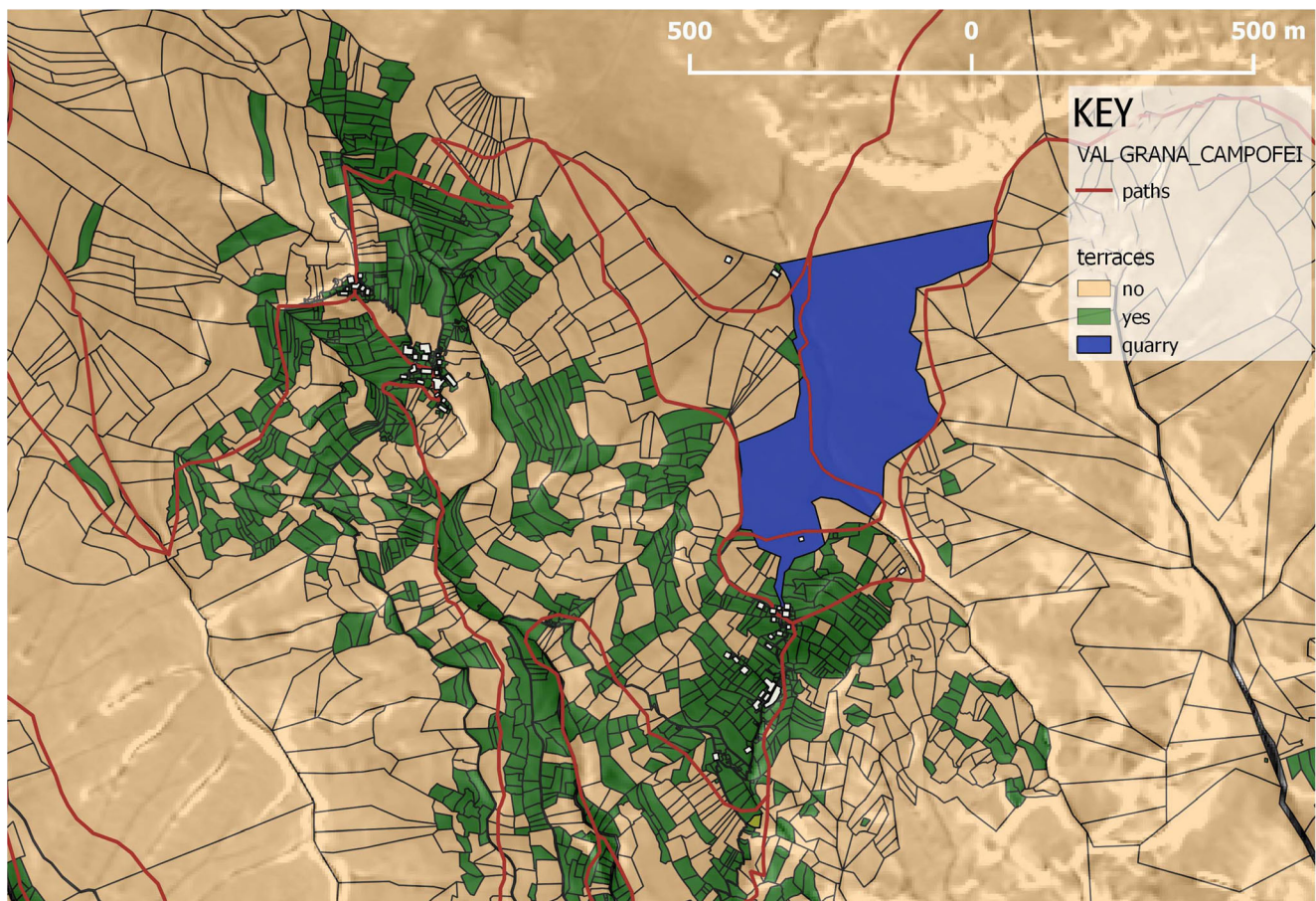
Fig. 14 Method (A) in Grana Valley. Concentration of terraces near the villages; quarry parcel not detected

Method (B): high-scale approach. Detection based on UAV data

The second method, used in two areas of the Southern Piedmont, was triggered downstream by some photogrammetric UAV data collection projects.

The availability of a much higher scale and resolution database (UAV digital surface model—DSM) has made it possible to detect terraces and relatively short scarps using only the elevation model and analyzing areas characterized by the appropriate range slope, compatible with the productive use of the soil.

The experiment provided an automatic detection phase, which led to isolating a set of areas with high probability of terracing, followed by a verification carried out with two different approaches.

UAV data collection and DSM/DEM generation

We present briefly the UAV data collection and extraction of the digital model since, while being applied in two rather different test areas, they are based on quite similar principles, already used experimentally (Chiabrando et al. 2016).

In particular, we used the fixed-wing drone Ebee (by the SenseFly company, https://www.sensefly.com/ drones/eBee. html, and distributed in Italy by MENCI, http://www.menci. com), as this system is one of the most recently updated and cost-effective platforms for autonomous flights. It is connected to a GCS (ground control station), which is able to define all of the characteristics of the flight and supervise, in real time, the platform during the flight.

The two test areas differ by the morphology of their terrains. The secondary valley where Ferriere stands (the Stura Valley) is quite open and wide, and the slope is rather steep, but not extreme. In the Grana Valley, contrariwise, the secondary valley in which the abandoned village of Campofei lies, is particularly precipitous and impervious. This latter feature required a high-altitude flight due to the danger of crashing the drone on the slope, so the ground sampling distance (GSD), equal to 11 cm on the Campofei images (Table 1(B)), was not comparable to the GSD of 5 cm for the Ferriere experiment (Table 1(A)), so it was not used.

Fig. 15 First locating of terraced areas (in red) using only the slope index raster map classification in different gradient ranges

Raster classification by Slope index map and tarracing location
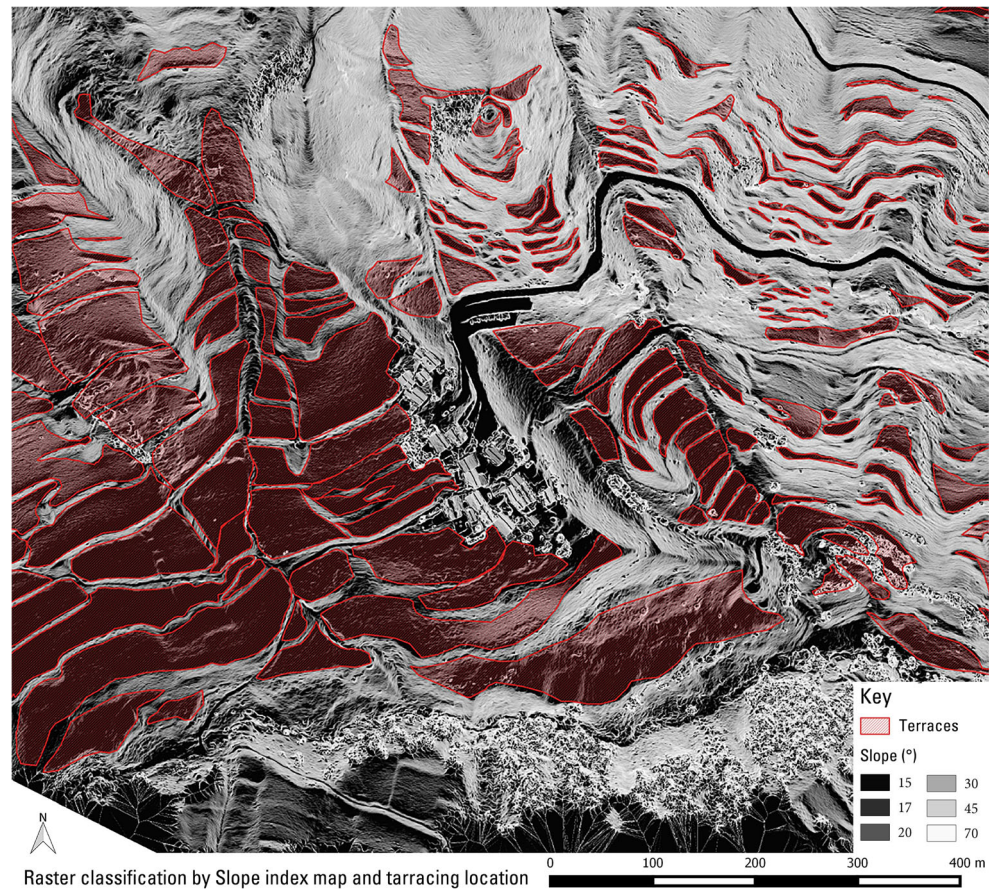
For the Campofei test area, it was then decided to use a more appropriate flight, comparable to Ferriere's GSD, using a multirotor drone (flight altitude 70 m) (Table 2).

In both test cases, the flights were preceded by the fulfillment of a topographic network measured by standard techniques such as GPS\GNSS. The usual measure of several Ground Control Points (GCPs) on the ground was aimed to optimize the orientation of the photogrammetric block (using the bundle adjustment method) and gain quality control for the final results (DSMs and orthophotos—Figs. 9 and 10) by the use of checkpoints (CPs) and their accuracy. Obviously, the use of GCPs is also useful in obtaining geo-referencing. Further, a vertex of the micro-geodetic networks was employed as a reference since the GSM connection did not work in alpine areas.

The next two tables compare the flight and camera parameters and the relative results provided by the two different platforms.

Regarding the transformation from DSM to DEM, at the Ferriere test site, this was not essential because, with the village at 1900 m in altitude above sea level, the valley has no

trees, while at Campofei (1500 m a.s.l.), a previous project transformed DSM into DEM (Spanò and Sammartano 2016).

Experimental phase

Method (A): quick detection of terraces types in the Cossogno and Campofei test areas

The method (A) was tested for detecting different terraces types in the Cossogno test area, where dry wall terracing is distributed, and in the Campofei area, where a mixed terracing solution was employed. The exact procedure set out in "Method (A): regional-scale approach. Detection based on regional-scale DEMs and cadastral maps" Section was used while employing, as a space base to be analyzed, the DTM derived from the regional Lidar flight (1 point for 5 m) together with the numerical cadastral map.

First of all, numerous municipalities of Valle Grande were assigned to the experiment; among them, the results obtained

Fig. 16 Studying the section profiles in relation to the trend of the contour (yellow lines) and in relation to the steepest slope lines of the terrain (red lines)
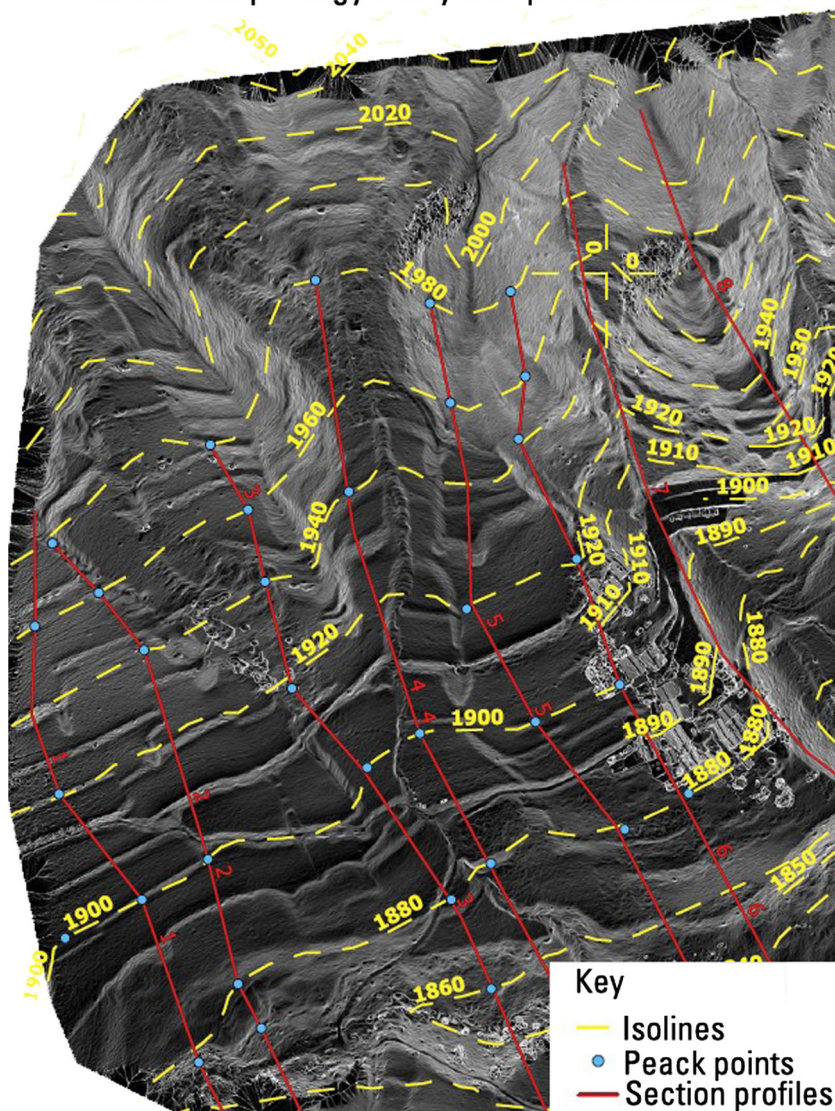
from the application of method (A) to the municipality of Cossogno (in Cicogna hamlet) are reported in Figs. 11 and 12.

Since, in Valle Grande, there was an intensive use of dry walls, this has led to the impression that, although they are abandoned and in a state of degradation, they are still easily identifiable, both when they are concentrated (Fig. 11), and when they are more scattered (Fig. 12).

It was therefore decided to test the same method (A) in Valle Grana, where the use of mixed terraces in Campofei (short scarps and dry wall) perhaps makes the method less effective. An adjustment of the parameters for cadastral parcel detection was required so that the method would be better adapted to the greater acclivity of the Grana Valley. In fact, the average parcels slope of terrain has been set between 20°

and 50°, and the mean deviation of the parcels polygons nodes average elevation was elevated to 10 m (from the 4 to 5 m used at the Val Grande test site).

$$20^\circ < slope < 50^\circ \cup st.dev. = 10m$$

It is interesting to note that method (A) correctly identifies possible terraces near the inhabited hamlets (Fig. 13), while ignoring the cadastral parcels located in the pasture areas, despite the fact that the land parceling is high and similar to the areas of land for agricultural use. It is also interesting to note that the stone quarry upstream of the village of Campofei was not detected (Fig. 14).

Fig. 17 Three sample graphs and corresponding section profiles on DEM and on the slopes index raster map, with the detection of the edges of "ciglioni"
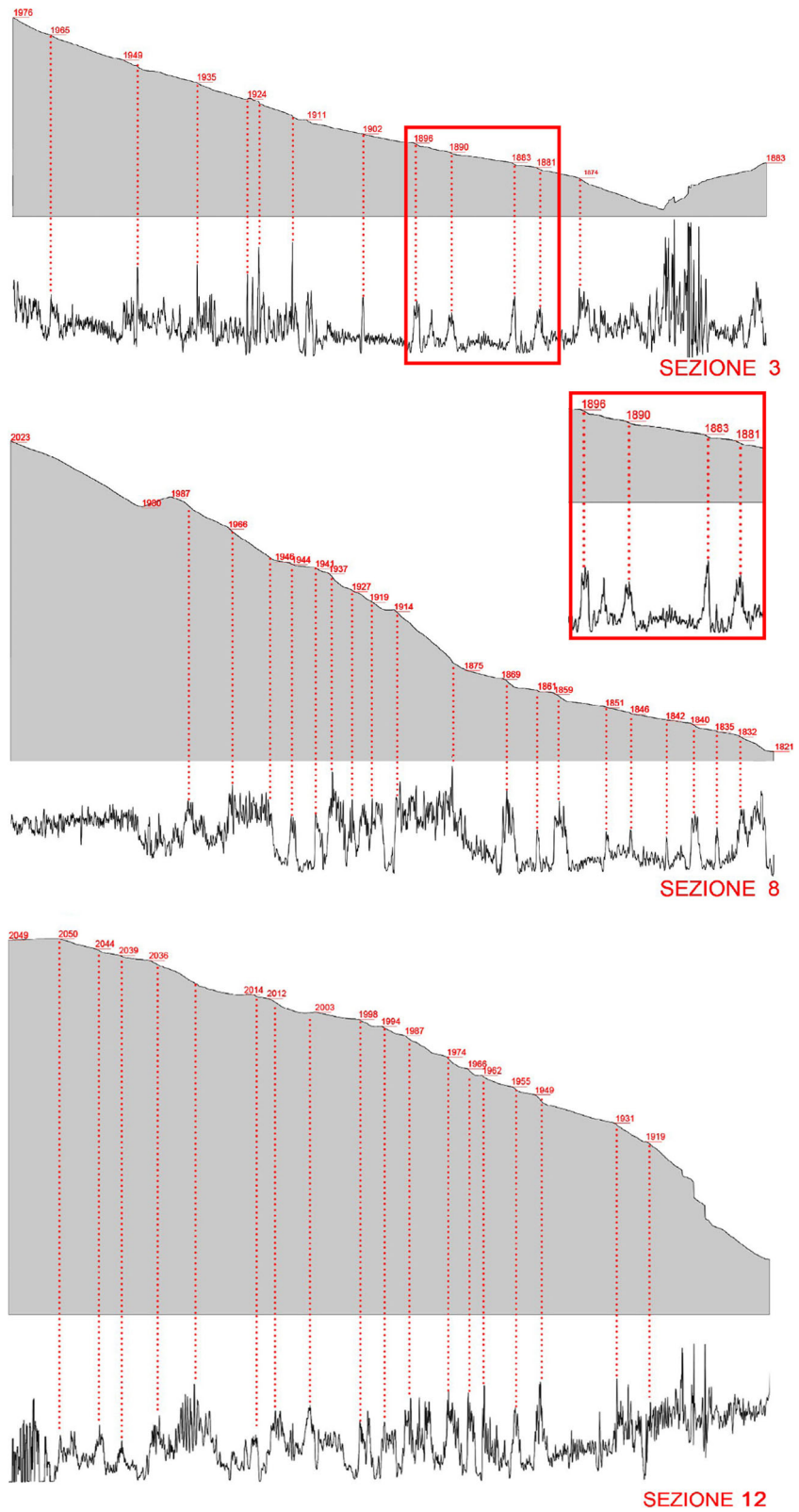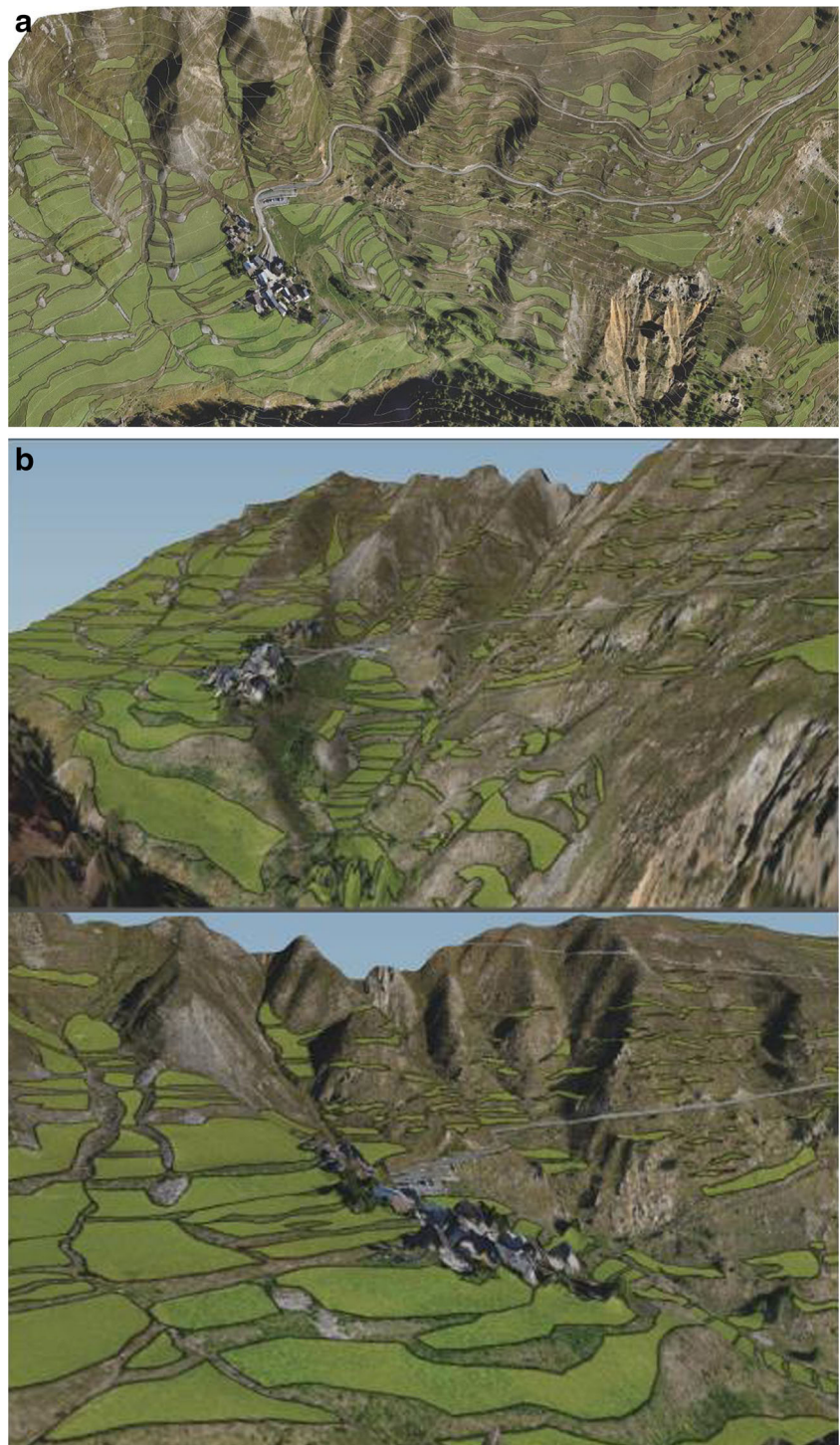
Fig. 18 **a** The final dataset of terrace polygons overlapping the orthophoto. **b** Two bird's-eye views of detected and mapped terrace areas

Method (B): semiautomatic approach for terrace mapping from UAV data in Ferriere test area

Method B is based on the exclusive use of UAV DEMs in order to evaluate their suitability in cases where good cadastral databases are not available. (This is not infrequent at high altitudes). The availability of a high-resolution and accurate

DSM has made it easy to locate the terraces, even if they have been abandoned. As mentioned above, the high altitude of the third test area in the Stura Valley and the consequent absence of trees as allowed deriving a DEM from a DSM to be avoided.

The latter has been reclassified to 1 point /5 cm to make calculations easier. Given that the method does not intend to
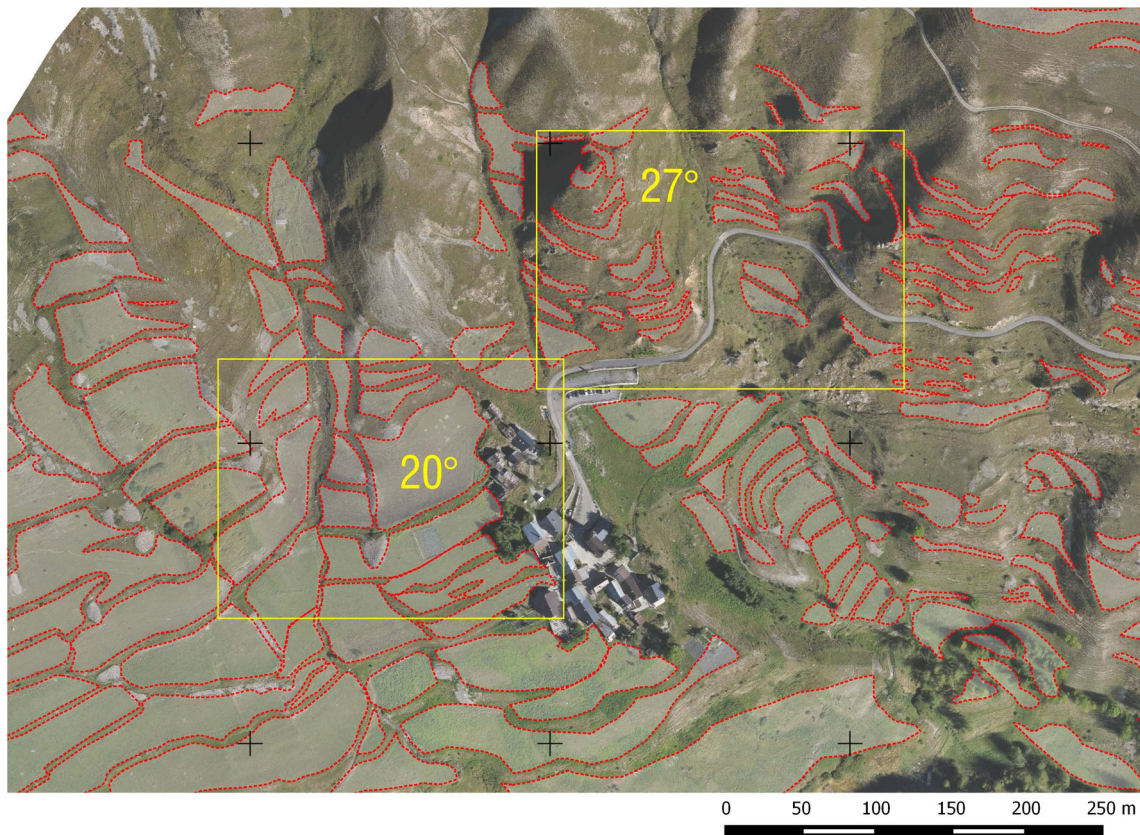
Fig. 19 Terraced mapped by method (B), detected by different values of the average slope index in two different areas of analysis

use the land registry map, the main difficulty was to study the classification of the *slope index raster map* and to clarify in which slope ranges terraces were implemented (Fig. 15).

This study was supported by a comparative photo-interpretation and analysis of the orthophoto, and further analyses were carried out using the generation of section profiles along contours and the steepest slope of the terrain. Both the altimetry profiles and profiles made on the slope raster map have been particularly helpful in identifying the abrupt slope change due to the presence of "*ciglioni*" (Figs. 16 and 17). Basically, the study led to the identification of terracing areas within the range of the slope included, i.e., between 20° and 45°. Figure 18 shows the results overlapping the orthophoto, and in 3D view.

Method (B): extension by automatic vectorization of detected terraces

An extension of method (B) is thus proposed and tested in two test areas surveyed by UAV flights in order to facilitate the automatic vectorialization of the terraced areas to be surveyed and measured. As this is a further implementation, the first phase of the workflow is identical to the previous and based on a GIS platform using OSS QGIS, but now some processing tools with SAGA GIS and GRASS GIS algorithms for the raster map editing and management are requested. After defining the selection of the best range value for the slope index raster map,

suitable for outlining the terraced areas, the raster has been managed to convert raster areas related to selected slopes ranges in polygons to be exported in a vector format representing the terraces. The goal is to automatize the workflow during the post-classification phase of the *Slope index map*. This is possible, thanks to the slope raster processing operations by:

- raster reclassifying in binary values with the establishment of cutoff value,
- resampling filters applied to raster reclassification to simplify edges between value changes, and
- converting a raster map in vector shapes (areas) and extracting boundaries (lines)

Applying an extended method (B) in different average slope areas

Since it was an aim to use mostly automatic methods, the lesson learned is that the application of this method showed that, even within a single area, it is necessary to differentiate the threshold values for reclassifying the slope index raster map. For example, only in the surroundings of Ferriere, in some cases, the threshold value of the slope below which the detection of the terraces was effective, was 20°, in other cases it was 27° (Fig. 19).
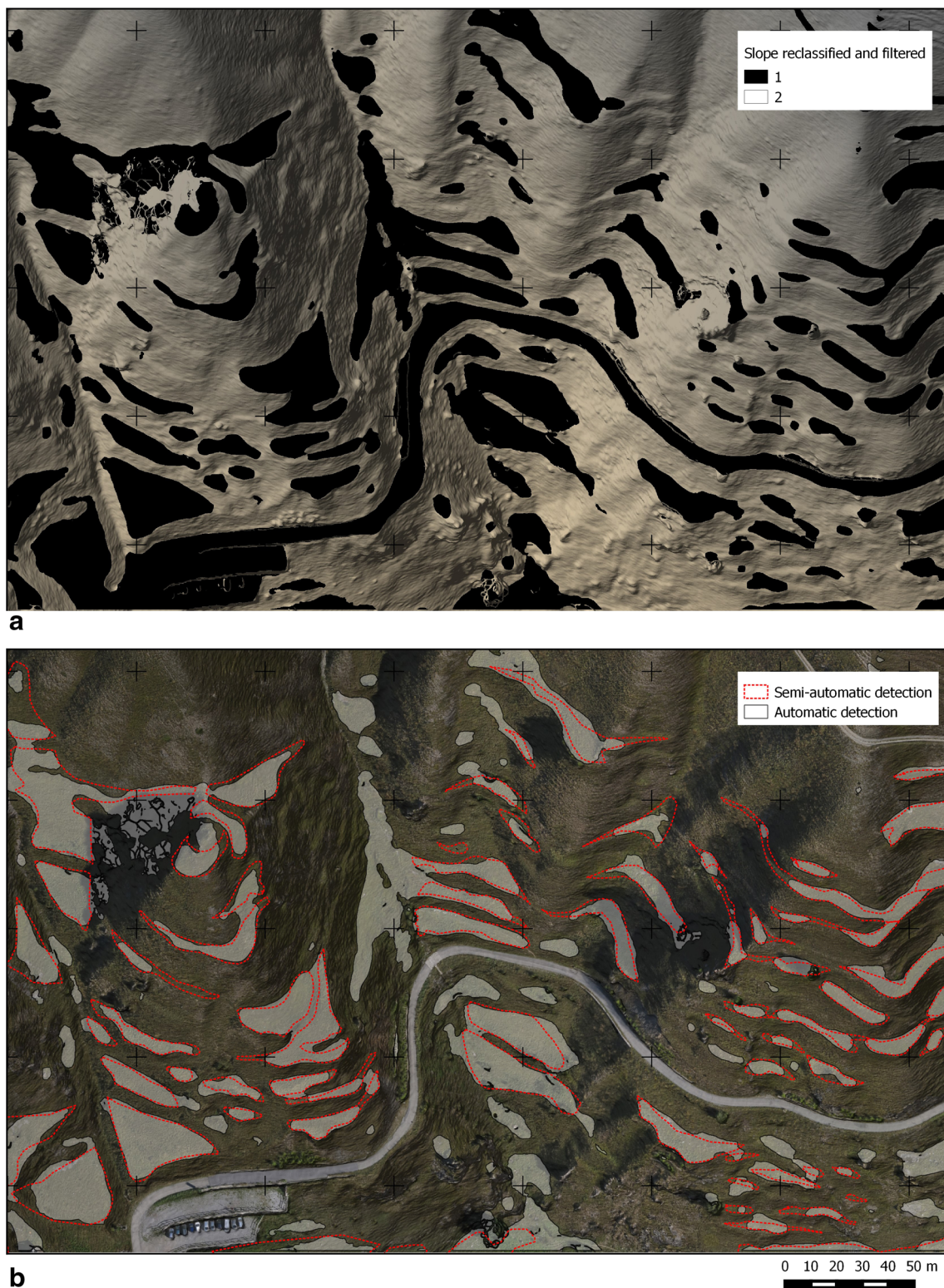
Fig. 20 **a** Raster processing for resampling [SAGA GIS-grid filter tools: majority filter]. **b** Terrace boundaries extracted from the filtered grid and converted into polygons

This is not surprising since it is within that interval of 17° to 50° set out at the beginning of the paper and derived from studies carried out in different areas of the world.

The next figures represent the operations carried out downstream of the reclassification into binary values [GRASS GIS-raster tools: R.reclass]. The terrace boundaries are extracted
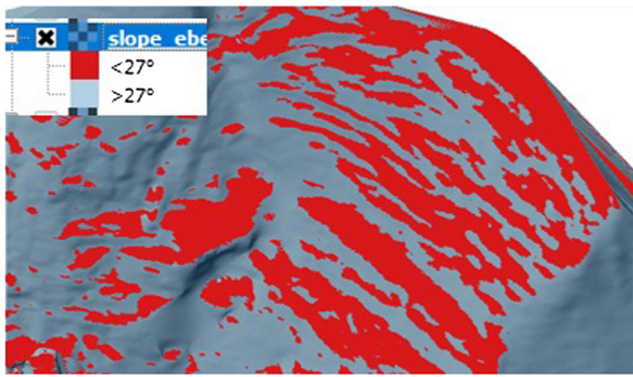
Fig. 21 Classification of the slope index map, with threshold value for detection = 27°

from the filtered grid [QGIS—raster tools: extraction-contour lines] and converted into polygons [QGIS—vector tools: conversion lines-polygons] (Fig. 20a, b).

The automatic method is at the end tested in the Campofei area, where the use of mixed terraces (short scarps and dry wall) makes the morphological structure of the slopes a little different from that in the previous test area and more difficult to recognize.

The average slope value useful as threshold detection has been 27° (Fig. 21), but the areal distribution along the slope side is fragmented and not well identifiable because of the abandonment and lack of maintenance of the terraces.

In both cases, the *SAGA Majority Filter* performance, which replaces cells in a raster based on the majority of their contiguous neighboring cells, has proved to be very effective for terraced polygons refinement in areas of varying slope.

Evaluation of method results through on-site measurements

Method (A): validation using location-based services in Valle Grande

The evaluation of the census obtained through method (A) was fulfilled in the field using a location-based service (LBS) accessible by a mobile device.

The LBS was an open-source software (Oruxmap), which utilizes satellite positioning technology via a smart localization device and offer the use of a webGIS that allows maps to be viewed (in online or offline mode) in order to track paths and record alphanumeric data concerning the on-site survey.

Essentially, the areas detected as featured by a high probability of terracing using method A, have been visited in the field and after the actual existence of the terracing was verified or not, other data has been recorded, such as the abandonment of terracing, the state of conservation of dry walls, and, if in use, the current culture.

This has allowed the creation of extremely interesting maps showing the terracing heritage actually in current use in comparison with the abandoned terracing.

However, extensive inspections in many municipalities allowed the statistical data to be further evaluated, which means that, in the 12 municipalities investigated (approximately 368 ha were checked), the success rate of method (A) in identifying terraces was approximately 70%.

Figure 22 shows the map of the village of Cicogna, previously used as sample case and here overlapping the regional map and showing the high percentage of abandoned terraces. The next map in Fig. 23 (Caprezzo
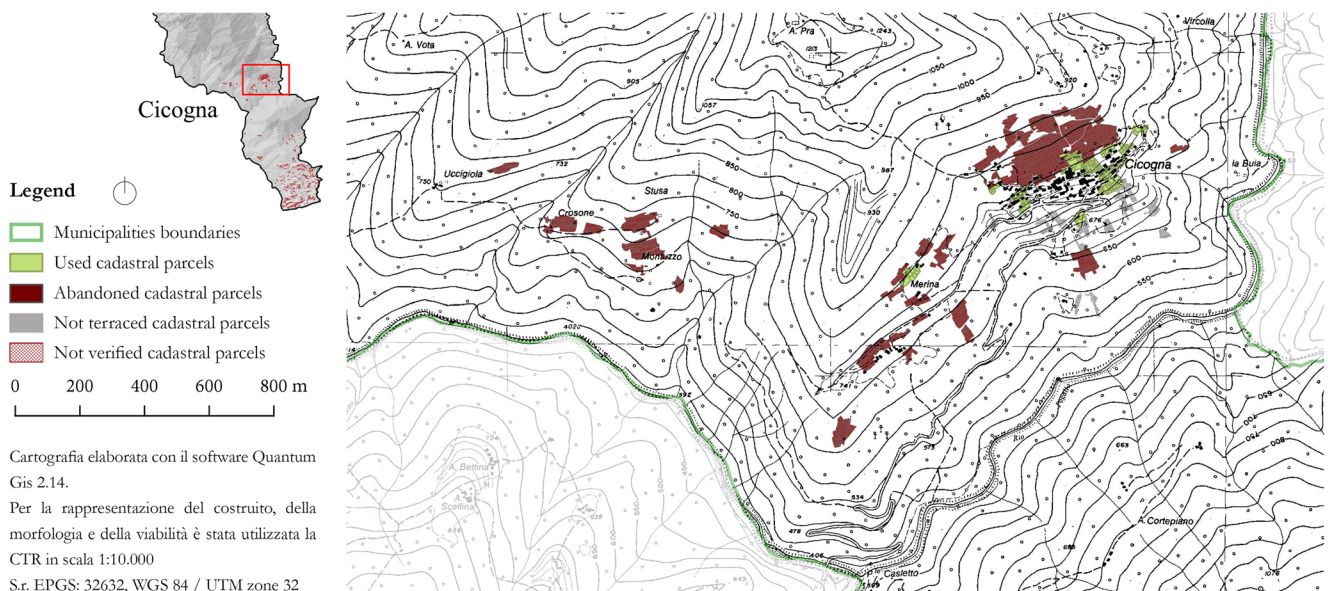

Fig. 22 The terrace map of Cicogna hamlet after the onsite survey detecting abandoned/used terraces
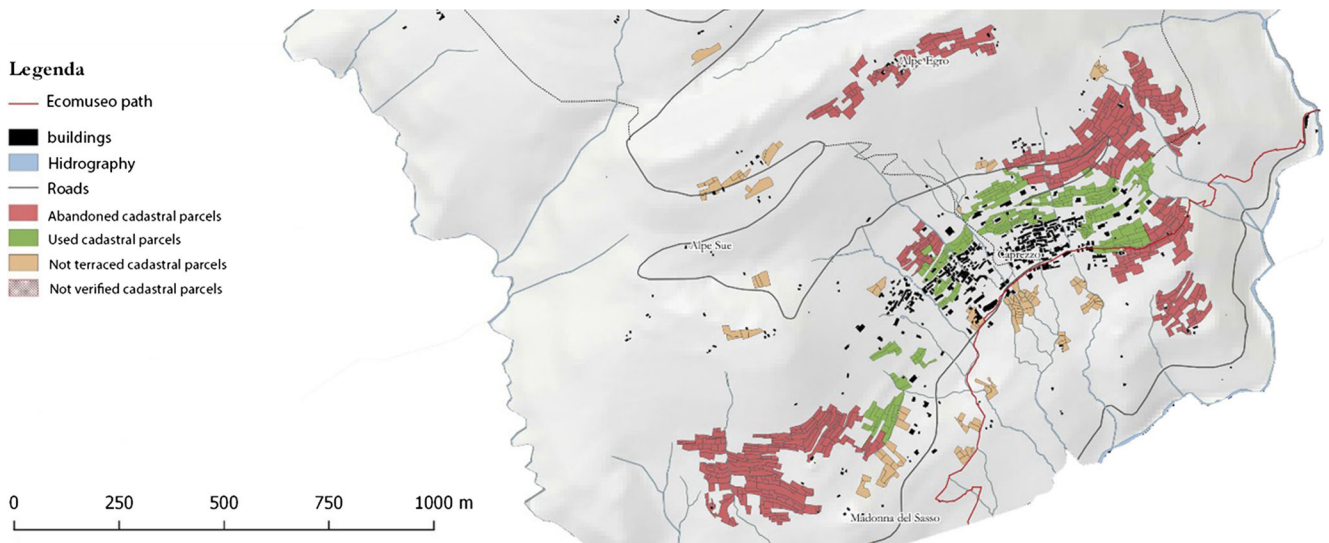
Fig. 23 Another example of a terrace map (Caprezzo Village) realized after the large validation survey based on LBS tools

municipalities) confirms that abandoned terraces are the furthest away from villages and that method (A) has identified terraces incorrectly in a few dispersed cases in the territory, demonstrating that terracing is a phenomenon compact in space and, consequently, a collaborative human behavior.

Method (B): validation using GPS/RTK measurements

Since method (B) has been configured from the outset as a method for locating terraces using a larger scale, a more accurate verification method was consistently used, namely, the topographic satellite survey RTK that provides centimeter precision.

Fig. 24 Four sample terraces chosen for methods comparison: blue, semiautomatic vectorizing; yellow, automatic vectorizing; red, GNSS/RTK measured on-site

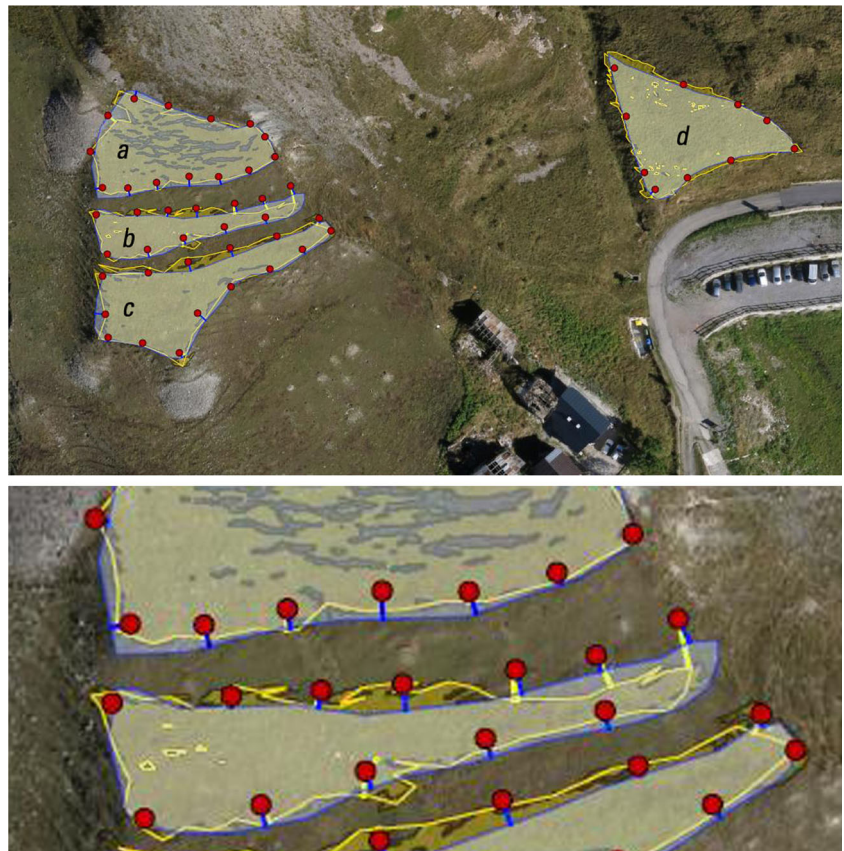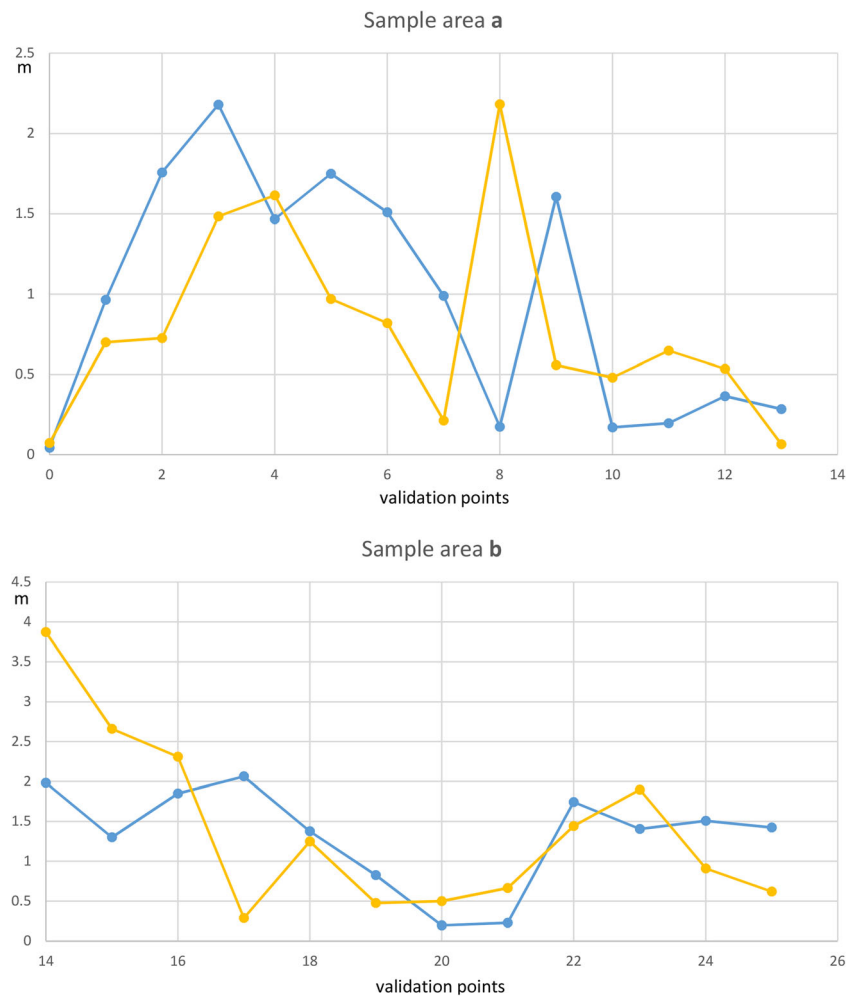**Fig. 25** Charts showing, for two sample areas (**a**, **b**), the deviation of the two detection methods from reference measures. On the graph points, the distances are between measured validation points and their respective points on boundaries identified by method (B) (blue) and the extended automatic method (B) (yellow)

Considering that the presence of operators on the site does not always guarantee the visual capability to discern where a "ciglione" begins or ends, the assessments carried out on four terraced sample areas provided a very good confirmation of the detection ability of method (B).

Figure 24 shows the four sample areas for which the boundaries were detected by using method (B) (using the first application, method (B), and using the extended automatic method (B)) are compared with RTK measured points.

The charts in Fig. 25 show the distances between on-site measured points and their respective points on boundaries identified by method (B) and the extended automatic method (B) in two sample areas; in some cases, they reach and exceed a meter, with the average being near a meter.

A similar comparison between the boundaries, area, and perimeter is shown in Fig. 26, where histograms show how casual it is and that it probably depends on the area type if method (B) or the extended automatic method (B) is approaching the boundary measured on the ground. The errors are similar, and perhaps the type of area is important in saying which method has approached more.

In essence, regardless, we can say that method (B) has achieved a 90–92% success rate (considering that the average value of areas detected by method B and the areas measured on sites differ of about 8–10%).

Conclusions and future perspectives

Concerning method (A), adding to the assessment applied to 368 ha of land in the Northern Piedmont, the good results observed in a completely different area, the Southern Piedmont, featuring different types of terraces, allows us to evaluate the validity of this first expeditious method.

This means that, at the scale of Land Registry maps, it has been shown that method (A) can yield significant results, achieving new knowledge on terraced landscapes without the acquisition of new data.

For a more detailed survey, however, the low-cost UAV photogrammetry that is rapidly being used in so many sectors has shown the perfect ability to detect terraces.

Fig. 26 The histograms show, for areas and perimeters of sample areas **a**, **b**, **c**, and **d** from Fig. 24, the variability of comparison between the two different approaches (blue and yellow) and the GPS/RTK verification on site (red)
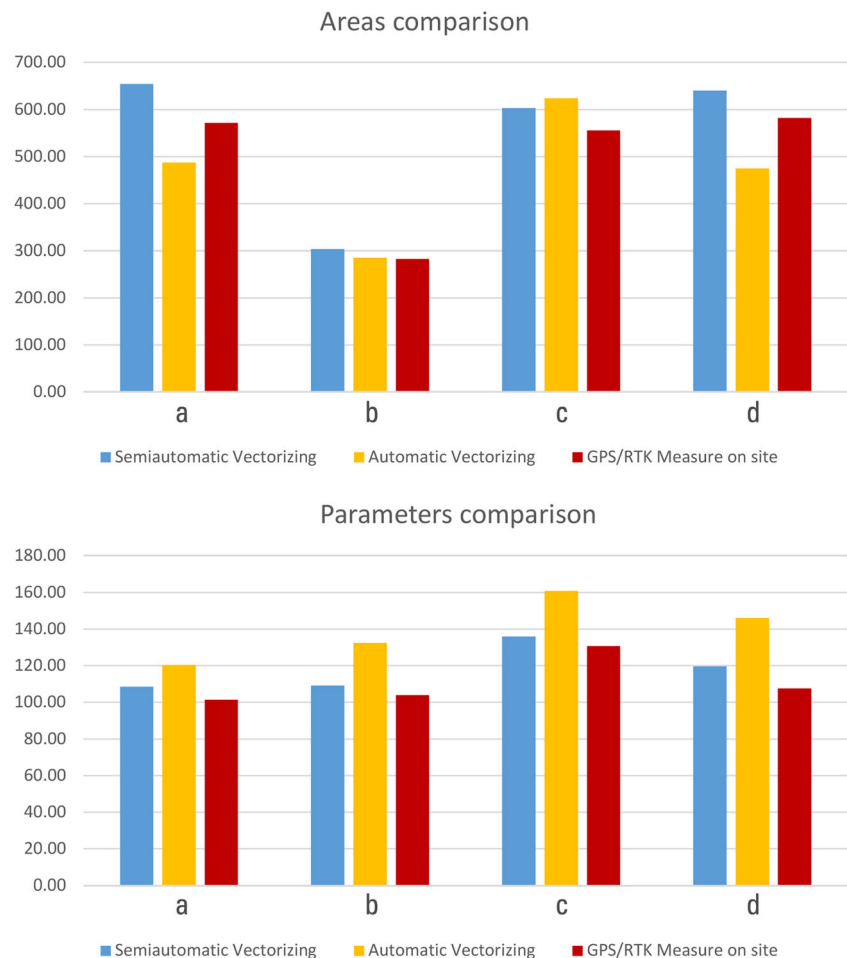
Nevertheless, we can summarize the critical features of the UAV method in alpine areas:

– a good DTM to plan flights is needed
– it is necessary to ensure good control of the radio remote control for drone-station communications
– sometimes the Geoid accuracy in elevated altitudes is not high
– the use of drones in alpine areas creates disturbances for predatory birds.

As a final consideration, both methods (A) and (B) have a degree of automation and could be serially used as a good tool for local authorities to quantify their heritage.

In perspective, the interest of this work is to have demonstrated the ability to employ survey methods available today for mapping and quantifying a phenomenon of interest for large-scale redevelopment projects in areas of disused territory, whose exploitation can only be triggered by a process of knowledge.

References

Aicardi I, Dabove P, Lingua A, Piras M (2016) Integration between TLS and UAV photogrammetry techniques for forestry applications. In: IFOREST. - ISSN 1971–7458

Aicardi I, Chiabrando F, Lingua A, Noardo F, Piras M, Vigna B (2017) A methodology for acquisition and processing of thermal data acquired by UAVs: a test about subfluvial springs' investigations.

Geomat Nat Haz Risk 8(1):5–17. https://doi.org/10.1080/19475705.2016.1225229

Ažman Momirski L (2008) Goriška Brda. The terraced vineyards of Goriška Brda. In: Scaramellini GE, Varotto M (eds) Terraced landscapes of the Alps. Atlas. ALPTER project, Venezia, Marsilio Editori

Balbo AL, Puy A (2017) Terrace landscapes. Editorial to the special issue. J Environ Manage 202(3):495–499 ISSN 0301-4797

Brancucci G, Paliaga G (2008) The problems with mapping: the case of Liguria. In: Scaramellini GE, Varotto M (eds), Terraced landscapes of the Alps. Atlas. ALPTER Project, Venezia, Marsilio Editori, p 39

Brancucci G, Ghersi A, Ruggiero ME (2000) Paesaggi liguri a terrazze. Riflessioni per una metodologia di studio. Alinea, Firenze

Briffaud S, Brochot A (2010) Paysages d'exception, paysages au quotidien. Une analyse comparative de sites viticoles européens du Patrimoine mondial, Rapport final de recherche pour la Direction des Etudes Economiques et de l'Evaluation Environnementale Ministère de l'Ecologie, de l'Energie, du Développement durable et de la Mer Programme «Paysage et Développement durable » Appel à propositions de recherche 2005 (Convention CV05000127)

Calcagno Tunin F, Cerise S (2017) Il recupero della borgata alpina di Ferriere in Valle Stura: sperimentazione tra metodi innovativi di rilievo da drone e GIS, tecniche costruttive tradizionali e progetto sostenibile, Msc thesis, Politecnico di Torino, tutors Regis D., Spanò A

Chiabrando F, Di Pietra V, Lingua A, Maschio P, Noardo F, Sammartano G, Spanò A (2016) TLS models generation assisted by UAV survey. Int Arch Photogramm Remote Sens Spat Inf Sci XLI-B5:413–420. https://doi.org/10.5194/isprs-archives-XLI-B5-413-2016

Ferro-Vázquez C, Lang C, Kaal J, Stump D (2017) When is a terrace not a terrace? The importance of understanding landscape evolution in studies of terraced agriculture. J Environ Manag 202(3):500–513 ISSN 0301-4797

Fontanari E, Patassini D (2008) Paesaggi terrazzati dell'arco alpino. Marsilio Editori, Venezia

Förstner W, Wrobel BP (2016) Photogrammetric computer vision—statistics, geometry, orientation and reconstruction. Springer

Hackney C, Clayton A (2015) Unmanned aerial vehicles (UAVs) and their application in geomorphic mapping, British Society for Geomorphology, Geomorphological Techniques, Chap. 2, Sec. 1.7, ISSN 2047-0371

Hosseini SA, Arefi H, Gharib Z (2014) Filtering of LiDAR point cloud using a strip-based algorithm in residential mountainous areas, ISPRS archives, volume XL-2/W3

Jiang Y, Li S, Chen W, Cai D, Liu Y (2017) The evolution of crop cultivation and paleoenvironment in the Longji Terraces, southern China: organic geochemical evidence from paleosols. J Environ Manag 202(3):524–531 ISSN 0301-4797

Lindner G, Schraml K, Mansberger RHJ (2016) UAV monitoring and documentation of a large landslide. Appl Geomat 8(1):1–11. https://doi.org/10.1007/s12518-015-0165-0

Londoño AC, Williams PR, Hart ML (2017) A change in landscape: lessons learned from abandonment of ancient Wari agricultural terraces in Southern Peru. J Environ Manag 202(3):532–542 ISSN 0301-4797

Lowe DG (2004) Distinctive image features from scale-invariant keypoints. Int J Comput Vis 2004(60):91–110

Lucieer A, Turner D, King DH, Robinson SA (2014) Using an unmanned aerial vehicle (UAV) to capture micro-topography of Antarctic moss beds. Int J Appl Earth Obs Geoinf 27:53–62

Marcaccio JV, Markle CE, Chow-Fraser P (2015) Unmanned aerial vehicles produce high-resolution, seasonally-relevant imagery for classifying wetland vegetation, the ISPRS archives, volume XL-1/W4

Masaharu H, Ohtsubo K (2002) A filtering method of airborne Laser scanner data for complex terrain, ISPRS archives, Commission III, 34 (3B):165–169

Nex F, Remondino F (2014) UAV for 3D mapping applications: a review. Appl Geomat 6:1–15

Niethammer U, Jamesb MR, Rothmunda S, Travellettic J, Joswiga M (2012) UAV-based remote sensing of the super-sauze landslide: evaluation and results. Eng Geol 128:2–11

Perko R, Raggam H, Gutjahr KH, Schardt M (2015) Advanced DTM generation from very high resolution satellite stereo images. ISPRS Ann Photogramm Remote Sens Spatial Inf Sci II-3/W4:165–172. https://doi.org/10.5194/isprsannals-II-3-W4-165-2015

Pfeifer N et al (2008) DSM/DTM Filtering, International School on Lidar Technology 2008 IIT Kanpur, India (from: http://www.iitk.ac.in/)

Possi G (2017) I terrazzamenti della val grande censimento e valorizzazione del patrimonio rurale tradizionale, Msc thesis, Politecnico di Torino, tutors Regis D., Spanò A

Regis D, Spanò A, Coscia C (2017) Alpine Complex Landscape Environment, In: DISLIVELLI Dislivelli.eu, pp 1–22, ISSN: 2039-5442

Roosevelt C (2014) Mapping site-level micro-topography with real-time kinematic global navigation satellite systems (RTK GNSS) and unmanned aerial vehicle photogrammetry (UAVP). Open Archaeol 2014:29–53

Sangiorgi F, Branduini P, Calvi G (2006) Muri a secco e terrazzamenti nel Parco dell'Adamello; linee guida per il recupero, University of Milano

Sankey T, McVay J, Swetnam TL, McClaran MP, Heilman P, Nichols M (2017) UAV hyperspectral and lidar data and their fusion for arid and semi-arid land vegetation monitoring. Remote Sens Ecol Conserv. https://doi.org/10.1002/rse2.44

Scaramellini G (2008) Terraced landscapes in the Alpine area: geohistorical observations and analitycal perspectives, in Scaramellini G. e Varotto M. (a cura), Terraced landscapes of the Alps. Atlas. ALPTER Project, Venezia, Marsilio Editori, 2008 (www.alpter.net)

Sithole G (2001) Filtering of laser altimetry data using a slope adaptive filter, ISPRS Archives, Volume XXXIV-3/W4

Sammartano G, Spanò A (2014) Quick mapping by mobile sensors for landscape values monitoring and conservation. In: Territorio Italia, vol 2. pp 35-55

Spanò A, Sammartano G (2016) DEM Generation based on UAV Photogrammetry Data in Critical Areas. In: Proceedings of the 2nd International Conference on Geographical Information Systems Theory, Applications and Management 2nd International Conference on Geographical Information Systems Theory, Applications and Management, Rome, pp. 92–98, ISBN: 978-989-758-188-5

Varotto M, Ferrarese F (2008) Mapping and geographical classification of terraced landscapes: problems and proposals. In: Scaramellini GE, Varotto M (a cura), Terraced landscapes of the Alps. Atlas. ALPTER project, Venezia, Marsilio Editori

Zhang W, Qi J, Wan P, Wang H, Xie D, Wang X, Yan G (2016) An easy-to-use airborne LiDAR data filtering method based on cloth simulation. Remote Sens 8(12):501