TERRACED LANDSCAPES LOCATED IN AREAS OF GREAT VALUE FOR TOURISTIC PURPOSES AS AN IRREVERSIBLE PRACTICE

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Abstract

Since Neolithic, terraced landscapes have been an essential element for moulding mountain or steep slope into habitable arable areas. Over the last decades, they have been subjected to a quick abandonment because of their inadequate economic competitiveness causing a gap in their maintenance and, consequently, incrementing the hydrogeological instability of those areas. Minori is a small municipality (256 ha), protected by UNESCO, located in Amalfi Coast. That area is well known not only for the beauty of its territory but also for some catastrophic raining events, like in 1954 when a rain shower of 500 mm topped up to 24 hours. The current research work intends to analyse the landscape changes in Minori over sixty year period (1956 - 2017) for assessing the new values taken on the land use and the agricultural sites. A detailed orthophoto and a high resolution Digital Elevation Model (DEM) of the study area have been reconstructed using the historical photogrammetric photos of 1954, acquired by the Italian Military Geographic Institute (IGM), and the aerial photogrammetric pictures of 2017, obtained by an own flight. DEM and orthophoto have been reconstructed applying Agisoft Photoscan Professional. The resolution of the generated DEM is equal to 0.48 and 0.1 m for 1956 and 2017, respectively. The orthophoto resolution is of 0.24 and 0.07 for 1956 and 2017, respectively. Comparing the generated products of the two periods, it is pointed out that terraces extension has not been amended, while the amount of human constructions have increased of about 800%. To give a first idea of the most vulnerable areas to be investigated more in depth through simulation procedures, a first proposal of an expeditious index of vulnerability (EVI) has been introduced and tested. It is based on the ratio between the amount of surface occupied by buildings and the amount of areas subjected to a debris flow event. The increase of the vulnerability, exposure values and probability of accident occurring involve a risk rise.

Keywords: Agricultural terraces, Risk assessment, Aerial photogrammetry, Historical series

Terraced landscapes are largely widespread in all Mediterranean area since Neolithic time. They have been built to exploit the great fertility of the slope of the mountain, making them arable and habitable. Indeed, that geomorphological element is recognized as the most significant human activity that affected and transformed the Earth Surface. Unfortunately, over the last few years, they have been quickly abandoned because of their scarce competitiveness in term of agriculture production [Tarolli et al., 2014]. This caused a lack of maintenance of their retaining walls and, consequently, the boost of hydrological instability, soil erosion, loss of agricultural lands and debris flow. Therefore, editing a proper management plan to preserve the terraced landscapes looks essential and priority in all the world, according also to the European Common Agricultural Policy (CAP). The situation becomes more complex when the considered area is included in the UNESCO World Heritage List, like Amalfi

Coast (year 1997 n. 830). Since 1972, UNESCO have pushed their members to preserve and conserve all the sites, involved in the World Heritage List, for present and future generation [“World Natural and Cultural Heritage”, Paris, 16 November 1972]. Nevertheless, UNESCO does not provide any models or indications regarding the management plans to be developed [Gullino et al., 2015]. Consequently, the necessity to define and implement a proper risk management program is still alive. It should be edited considering the natural hazard to be opposed. As underlined by Fuchs et al., (2007), natural hazard is a physical event which cause a catastrophic event in a defined time and space, damaging the human being and their environment. More in general, the natural hazard has been defined by United Nations (2004) as the “probability of the occurrence of a potential damaging phenomenon”. The debris flow, triggered by rainfall, is recognized as the most common hazard for terraced landscapes and, therefore, it needs a particular attention.

The vulnerability concept is directly connected to the natural hazard. It is defined as the probability to be damaged following the occurrence of a determined event [Birkmann, 2006]. Nevertheless, [Wilson et al., 2005] extended that definition, involving the three dimensions of vulnerability: exposure, intensity and impact. It is expressed by an index which varies between 0 and 1, where 1 is associated to a complete destruction while 0 is related to ability of the people, buildings and infrastructures to not be damaged. Even if several indices have been developed and tested for investigating the vulnerability of buildings and infrastructures, just few indicators have been introduced to assess the vulnerability of the landscape. Nevertheless, each of them requires a laborious and expensive procedure to evaluate the vulnerability in particular at detailed scale. Hence the need to develop an expeditious indicator for assessing the vulnerability of the areas subjected to a debris flow at detailed scale on terraces.

To fill that gap of knowledge, the information related to terraces position and status at detailed scale are necessary. Capolupo et al., (in review) developed a novel approach for detecting terraced landscapes at detailed scale, going beyond the limits of the traditional approaches. It was based on the combination of photogrammetry and object-oriented analysis (OBIA) technique. The former is an essential tool for generating high resolution Digital Elevation Models (DEMs) and orthophotos able to describe the morphological surface of the Earth [Capolupo et al., 2015a; Capolupo et al., 2015b; Capolupo et al., 2018a]. The latter, was preferred to the pixel oriented classification procedure because it is able to take advantages of both spectral signature and morphological contribution.

The new abilities of territorial analysis and terraced landscapes detection constitute the presuppositions to estimate the vulnerability at detailed scale. Indeed, the current research activity aimed to introduce a first proposal of a morphological Expeditious Indicator of Vulnerability (EVI) able to identify the most vulnerable areas, which need an analysis more in depth through simulation procedures.

2. MATERIAL AND METHOD

2.1 Study area

The research activity was conducted in Minori (40° 39’ 00” N, 14° 37’ 35” E), the most ancient municipality of Amalfi Coast, in Salerno province (Southern Italy). Its territory extends over 2.56 km^2 and, as underlined by Caneva and Cancellieri, (2007), it is well-known overall the world for several aspects: the uniqueness of its landscape, modelled by human activities since 950 – 1025 AC, the great variety of vegetation, the cultural heritage of great value, dating from Roman period, the high quality farming products, such as chestnuts, lemons and grapes. Although the first two points are getting prevalent in the last few years attracting more and more tourists, the agricultural was and is the main source of income [Caneva and Cancellieri, 2007; Pindozzi et al., 2016]. Indeed, the terraced landscapes construction started during the Middles Ages to increase the soil permeability and reduce the slope gradients of mountains in order to make that area arable and habitable [Tarolli et al., 2014]. Unfortunately, just traditional agricultural techniques can be adopted on terraced landscapes because of their structures and locations. This involves that agriculture sector of that area is not competitive anymore and, consequently, their abandonment has been getting more frequent, focusing the local economy on the tourism branch. The climate is mainly Mediterranean in the lower part of the municipality, while in the upper part, it is essentially temperate [Caneva and Cancellieri, 2007]. Usually, the annual rainfall average is higher than 1000 mm, even if the area has been subjected to some catastrophic events, like the showers of more than 500 mm fallen in about four hours on the 25th of October 1954. Those events cannot be described using the Gumbel distribution, the most widely applied for describing the meteorological problems, but by the Two Component Extreme Value (TCEV) [Rossi and Villani, 1994].

2.2 Field data and photogrammetric aerial photos collection

The data sources of the current research activity involves:

- the panchromatic historical series of the 13th of April 1956;
- the RGB photogrammetric aerial photos of the 13th of March 2017;
- the multispectral photogrammetric aerial photos of the 13th of March 2017;
- 162 Ground Control Points (GCPs).

The panchromatic historical series is composed by the three different frames (197-V-1811; 197-V-1812; 197-V-1813) acquired at the quotas of 3900 m. They have been scanned using a photogrammetric scanner by the Italian Military Geographical Institute (IGM). Their format is equal to 230 x 230 mm.

The RGB and the multispectral photogrammetric aerial photos were instead acquired by an own flight campaign, conducted under clear sky conditions at the altitude of 1000 m, using a Piper PA 18 Super CUB-I-CGAO & I-NIKI (VFR). That airplane was chosen because of the presence of a trapdoor located at the bottom of the chassis, where the cameras were placed. A Reflex Nikon D800e, characterized by 36.3 Mp and a pixel size of 0.00487 mm, was used to acquire the RGB images. A lens of 50 mm was mounted on it in order to adapt the final resolution to the size of the object under investigation. Also an external Global Position System (GPS) was employed on the camera in order to georeference the acquired pictures and to optimize the following metric reconstruction. A specific external circuit, composed by Arduino components, was designed and built by the Landscape and Rural Planning research unit (LARP) of the University of Naples Federico II to remotely control the shutter camera. The Tetracam ADC Snap, characterized by 1.3 Mp and a pixel size of 0.005 mm, was instead chosen to capture the multispectral photos. Its range of acquisition is comprised between 520 and 920 nm, corresponding to Red, Green and Near Infrared bands. Its internal timer was adequately set to control the camera shutter and to acquire the image at a specific instant.

As suggested by Nex and Remondino, (2014), the GCPs were acquired to improve the accuracy of the final metric reconstruction. Therefore, three field data campaigns were performed the 25th, 27th of January 2016 and the 27th of April 2017 and 162 GCPs were acquired using a Differential Global Position System (DGPS) Sokkia GRX1 in ETRF2000 Epoch 2008. Two different sub-datasets were randomly generated extracting the GCPs from the original data source, as suggested by Höhle and Höhle, (2009): the former was employed for the metric reconstruction; the latter for the accuracy assessment.

2.3 Scene metric reconstruction and terraces classification

Each block of images has been separately processed in order to obtain the photogrammetric outcomes from each of them. Before starting the metric reconstruction, two preliminary steps (quality check of the photogrammetric pictures and the image orientation) were performed on the historical and on the recent datasets in order to improve the final outcomes. In addition, also the laboratory camera calibration was carried out for the RGB contemporaneous dataset using Agisoft Photoscan Lens software (Agisoft LLC, St. Petersburg, Russia). That phase could not be applied on the historical series and on the multispectral images since, in the first case, the interior parameters of the camera were unknown while, in the second case, the dataset would be subjected to a specific procedure applying PixelWrench2 software (Tetracam, inc, Chatsworth, Cal.).

The quality check was performed selecting the photos to be utilized during the reconstruction stage through their visual inspection. The results of that phase were essentially different for the three data sources: no defects were detected on the historical series; on the other hand, the 3% of RGB and multispectral pictures were blurry, and, consequently, they were removed and not took into account during the following procedures. That step has not affected the final results of the reconstruction procedure because these frames had been acquired during the phase to achieve the flight quotas and the first waypoints. Thus, the image orientation phase, consisting in the extraction of tie points and pictures alignment, started in Agisoft Photoscan Professional environment (Agisoft LLC, St. Petersburg, Russia). The deformation of the images blocks was minimized importing the subdataset of GCPs suitable for the metric reconstruction in that environment. Two Digital Elevation Models (DEMs) were extracted from the historical series and from the contemporaneous RGB dataset; on the contrary, three orthophotos were generated from each data sources. All the details regarding the photogrammetric process have been reported in Capolupo et al., (2014, 2015a, 2017).

Before starting the classification phase to identify and classify the terraces, the small discontinuities in the two DEMs were removed applying ArcGis Hydrological tool of ESRI ArcGis Software, version 10.1 (Redlands, CA., USA) as reported in Infascelli et al., (2013). Moreover, all the obtained photogrammetric rasters were purified from the sea and the border areas, since they were characterized by a high error in terms of elevation caused by the lack of GCPs in that zones.

The photogrammetric results were subsequently processed in eCognition Developer 9 software (TRIMBLE Germany Gmbh) in order to generate a binary map, in which the terraced and not terraced landscapes were distinguished. An OBIA approach was preferred to the common pixel oriented classification technique in order to exploit the advantages of multispectral images and DEM. That procedure involved two different stages: the former, related to the segmentation phase, while, the latter, regarding the construction of a proper classification model. Two different segmentation algorithms, the “multiresolution segmentation” and the “spectral difference segmentation” were performed to fit the size of the generated objects to the real - world elements under investigations [Benz et al., 2004]. The second algorithm was applied only on the blocks of contemporaneous images since the spectral signature was not available for the historical series. The parameters of the two algorithms were set iteratively adapting them to the complexity and the heterogeneity of the study area, as described in Capolupo et al., (in review). A specific tree-level hierarchical structure, based on a proper rule – set, was built enhancing the contribution of each layer suitable for the terraces detection. The weighs attributed to each layer and the indices chosen for optimizing the classification have been reported and described in Capolupo et al., (in review). All the objects included in the terraces class were, subsequently, merged and exported as a single layer.

The accuracy assessment phase was composed by two different aspects: the error analysis of the photogrammetric products and of the detected terraced landscapes. The former was obtained developing a specific code in R environment, which was based on the statistical approach reported by Höhle and Höhle (2009). It considers the calculation of residuals between the estimated and measured points. Therefore, the coefficient of determination (R^2) and the Mean Error was examined to analyse their spatial trend. On the contrary, the accuracy of the generated binary map was expressed in terms of the percentage of terraced landscape correctly classified. It was assessed by comparing the final outcome with thirty validation data, manually selected during an interpretation phase of the generated orthophotos.

2.4 Landslide event and vulnerability indicator

The terraced landscapes largely widespread in the area under investigation have been subjected to a quick abandonment because of their scarce competitiveness (Tarolli et al., 2014). This caused a lack of maintenance of their retaining walls, which, consequently, are exposed to a high hazard for slope failures, easily triggered by the particular climate conditions of Minori, prone to heavy showers, like the event of the 25th of October 1954. The effects on the cultivations, buildings and safety of people depends on the intensity and prevalence of the phenomenon. Catastrophic rainfall entail the landslides of all the mountain slope, damaging the floodplain and destroying all the buildings. No actions could be taken to prevent that situation. On the contrary, the landslide of a small piece of terrace damages a defined area. That kind of incidents are more common, as shown by the bibliography [Crosta et al., 2003; Del Ventisette et al., 2012], and, consequently, they are more interesting to investigate.

In particular, the morphological characteristics of Giampilieri area in Messina Province are similar to that ones of Minori. Therefore, the seven debris flows occurred in Giampilieri on 1th of October 2009, described by Del Ventisette et al., (2012), could be similar to the landslides could verify in the area under investigation. In that case, they observed that the landslides volume of the seven debris flows was comprised between 817 and 13507 m^3.

In the current study, an hypothetical debris flow, which characteristics are similar to that ones of the incident occurred in Giampilieri, was supposed and its effects were investigated. Its volume was assumed equal to 1000 m^3, corresponding to an area of 20 x 30 m^2 with a depth of 1.5 m.

The pre-processed photogrammetric DEMs were separately processed in order to detect the slope direction for each cell using the Surface Tool of ArcGis software. Therefore, for each direction a travel distance (L) of the debris flow was computed using the Equation 1, introduced by Rickenmann (1999):

$$L = 1.9 \times V^{0.16} \times H^{0.83} \tag{1}$$

where V is the volume and H is the total fall height. Crosta et al., (2003) showed the efficiency of the Equation 1 for describing the debris flow on terraced slopes.

The comparison between the travel distance and the length of the mountain slope gives an idea of the debris flow hazard potential. Indeed, if L is smaller than the length of the mountain slope, the underlying area will not be not reached by any debris and, consequently, it is not damaged. On the contrary, if L is bigger than the other parameter, the underlying zones will be reached by the landslides and the damages will be proportional to the travel distance and the speed of the flow. The bigger the travel distance (L), the more vulnerable the underlying zone is. Therefore, on one hand the travel distance is an empirical indicator of the debris flow hazard potential, as underlined by Rickenmann (1999), on the other hand it allows to detect the vulnerable areas to be analyse more in depth. Examining the bibliography [Crosta et al., 2003; Del Ventisette et al., 2012] and the geometry of terraced landscapes, the overall conclusion is that the surface mainly interested by the debris flow on the flat at the basis of the terraced landscapes is of the order of 25 m. Each identified zone is characterize by a vulnerability value depending on the amount of buildings, historical ruins and the quantity of people which live in that area. To be able to define an univocal vulnerability value adapted to each area requires a laborious work based on the knowledge of each territorial element and the exact trend of the debris flow through an expensive simulation process.

The assessment of the house volume (m^3) in the detected vulnerable areas could be a first expeditious indicator of the vulnerability value for each identified areas. Such justification shall demonstrate the acronym Expeditious Vulnerability Index (EVI) (Equation 2). That index allows to minimize the simulations by limiting them just to the areas managed by a high value of EVI.

$$EVI = \Sigma V_{bi} / A_V \tag{2}$$

where V_{bi} is the volume of each building included in that area and A_v is the area of the vulnerable zone in question. EVI is expressed in term of percentage. Each building was detected by manually interpreting the obtained orthophoto. The volume of each of them was calculated by multiplying the surface occupied and its height.

3. RESULTS

3.1 Scene metric reconstruction and terraces classification

Each block of images were separately processed to generate the photogrammetric outcomes. A high resolution orthophoto was generated from the three data sources: block of 1956, RGB pictures of 2017 and multispectral photos of 2017. Their resolution (GSD) was equal to 240 mm, 7 mm and 15 mm, respectively. Instead, the DEMs were obtained only from the dataset of 1956 and the RGB pictures of 2017. Their resolution was equal to 480 mm and 10 mm, respectively. Comparing the two orthophotos show that the buildings have boosted of 800% in the last 60 years. The consecutive procedure has led to generate a binary map, where the non terraced landscapes were distinguished from the terraced landscapes, shown in Figure 1. The accuracy assessment of the two final binary maps (Figure 1) was equal to 93% and 98% for the historical and the contemporaneous series, since three points have not been recognized in the first one and just one in the second one. The not recognized terraces have been marked with the yellow dots in Figure 1.

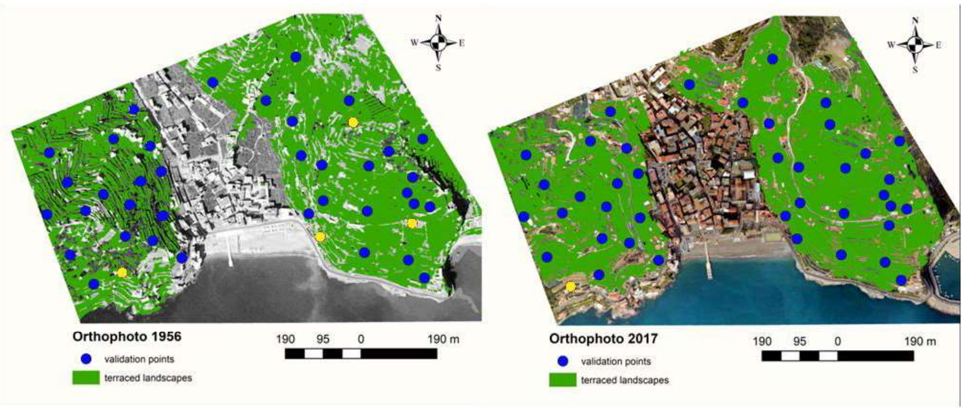

Figure 1: Validation of terraced landscapes for the dataset of 1956 and 2017, respectively. The blue points are correctly recognized; while, the yellow points are not recognized

3.2 Vulnerability indicator

Nine slopes, corresponding to nine directions of flow have been identified on the two sides of the mountains which go downs towards the municipality of Minori (Figure 2). For each of them the travel distance have been computed and compared with the length of the considered slope in order to identify the vulnerable areas. The results are reported in Table 1.

Table 4: Travel distance for each slope and the length of each of them

Slopes ID	*Colour corresponding to the slopes in Figure 2*	*Length of each slope (m)*	*Travel Distance (L)(m)*	*Difference between the length of the slope and L (m)*
1	Red	222	1425	1203
2	Yellow	361	941	579
3	Green	288	751	463
4	Blue	310	933	623
5	Black	205	2768	2563
6	White	329	1305	977
7	Orange	118	4102	3984
8	Purple	269	74	-195
9	Pink	303	861	557

The travel distance (L) (Equation 1) of the slope number 8 (the purple area in Figure 2) is smaller than the length of the slopes, as shown in Table 1. Indeed, the difference between the length and the travel distance is -195 m. Therefore, a landslide generated at the top of that slope is not dangerous because the debris will not reach the underlying portion of municipality. Consequently, there is no reason to investigate the vulnerability of that area more in depth. On the contrary, the highest debris flow hazard potential is traced in the numbers 1, 5, 7 with a value of 1203 m, 2563 m and 3984 m, respectively. The values identified was the same for both data sources.

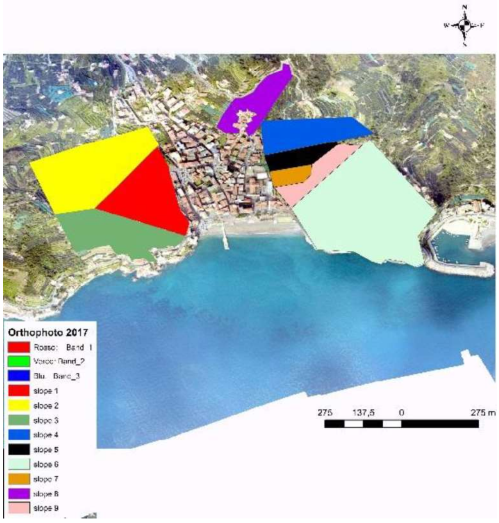

Figure 2: Slope direction

Eight vulnerable areas with a thickness of 25 m have been inspected in correspondence of slopes 1, 2, 3, 4, 5, 6, 7, 9. In each of them, EVI have been computed and shown in Figure 3, where the colour at each areas was assigned according to the vulnerability significance: green to the lowest value, orange to the medium rate and red to the highest one. The higher the EVI, the more vulnerable the area is. For the contemporaneous dataset, the highest value was detected for the slope number 5 with the value of 75%, followed by the number 1 and 7 with the value of 45% and 44%, respectively. The highest value of the dataset of 1956 (45%) has been identified in slope number 1. That slope shows the same value for both periods since the area has not been subjected to any changes. On the contrary, the remaining areas show a substantially lower value: the zones number 5 and 7 equal to 0%, the number 6 equal to 1%, the number 4 equal to 5%, the numbers 9, 3 and 2 equal to 15%, 18% and 22% respectively.

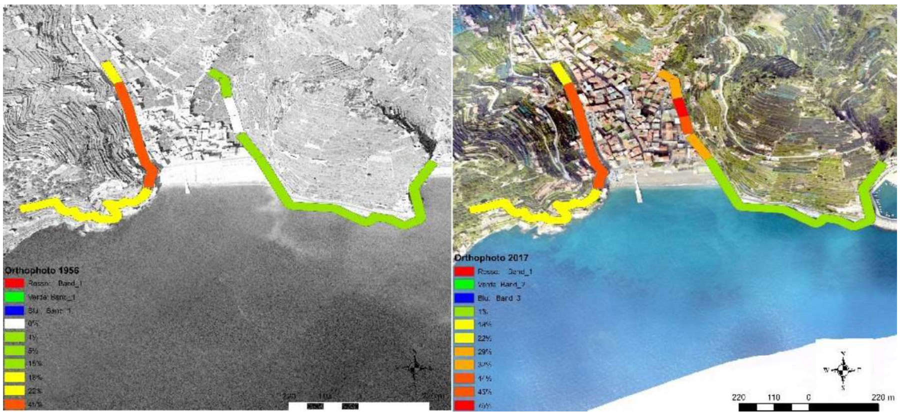

Figure 3: Expeditious Index of Vulnerability for dataset of 1956 and 2017, respectively

4. DISCUSSION AND CONCLUSIONS

The current paper was intended to develop an easy and quick methodology to detect and investigate the vulnerable areas subjected to a debris flow caused on terraced landscapes slope. Indeed, in the last few years, the abandonment of terraces is becoming a problem more and more evident due to their scarce competitiveness. This phenomenon, in conjunction with the lack of knowledge related to their position and conservation status (Capolupo et al., in review), caused a lack of maintenance of those areas. Consequently, the possibility of occurrence of debris flows, triggered by rainfall, is more and more frequent, damaging the underlying areas [Crosta et al., 2003; Del Ventisette et al., 2012]. In addition, those events are more recurring in Amalfi Coast because of difficult meteorological situation, characterized by the occurrence of catastrophic event, like that one of the 25th of October 1954, when more than 500 mm fell in about four hours. That situation cannot be described using Gumbel distribution [Rossi and Villani, 1994]. Analysing the status of Amalfi Coast terraces is even more interesting since they have been included in the UNESCO World Heritage List (year 1997 n. 830). Preserving them is perfectly in line with UNESCO policy, expressed in the "World Cultural and Natural Heritage" convention of 1972, in which is underlined that all the historical sites to be protected and brought to the future generations. Therefore, Minori, the most ancient municipality of Amalfi Coast, has been chosen as the study area of the current research activity.

The experiment was mainly composed by two steps. First of all, the position of terraced landscapes in the area under investigation have been detected using the combination of aerial photogrammetry and OBIA approach, as suggested in Capolupo et al., (in review). The generated binary maps show a high accuracy equal to 93% and 98% for the historical and contemporaneous datasets (Figure 1). The different result related to the accuracy assessment depends on the different resolution and the lack of multispectral information for the data of 1956. Both results are satisfying since they are suitable for describing complexity of territory at detailed scale. Moreover, the approach is really innovative and it allows to go beyond the limits of the traditional methods. Moreover, that technique can be applied at detailed scale. Moreover, it is based on an objectively classification approach and not an image interpretation. Comparing both orthophotos (Figure 1), it is also possible to point out that Minori has been subjected to an anthropization process: the amount of buildings have increased of about 800% [Capolupo et al., 2018b; Capolupo et al., 20148c], while the extension of terraces has not changed. That observation has been also confirmed by the results reported in Figure 2 and Table 1, related to the length of the slopes and the travel distance of an hypothetical debris flow caused by a small portion of terraces with a volume of 1000 m^3. Those components have the same values both for the historical and the contemporaneous series. Nevertheless, the EVI, an expeditious indicator of the vulnerability, shows different values for the two investigated periods because of the anthropization process of the municipality of Minori (Figure 3). Figure 3 underlines that the vulnerability of each area has been subjected to an enormous rise.

The methodology introduced in the present paper looks promising because it allows to quickly identify the priority areas to be investigated more in depth through the simulations of debris flow. Indeed, the amount of buildings underlying the terraces is just one of the indicator to be considered to define the most vulnerable areas, since, first of all, the travel distance of debris flow and the length of the slopes of the mountains have to be investigated. Therefore, the EVI indicator looks an important tool for the landscape planners.

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