Hillslope degradation in representative Italian areas: just soil erosion risk or opportunity of development?

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TITLE PAGE

Title:

HILLSLOPE DEGRADATION IN REPRESENTATIVE ITALIAN AREAS: JUST SOIL EROSION RISK OR OPPORTUNITY OF DEVELOPMENT?

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ABSTRACT

In the recent years, many researches dealt with the impact of human and climate change on the morpho-evolution of Mediterranean catchments characterized by high ecological and cultural value. In this paper, we speculated how humans can influence hillslope degradation by reviewing the relationships between denudation processes and land use changes in some representative areas located in different Italian regions (i.e., Liguria, Tuscany, Basilicata and Sicily). The selected study cases are characterized by different climatic and geological features, land use and land management and can be considered indicative of the hillslope degradation issues that affected the Apennines during the last century. We compared and discussed the main outcomes from previous studies, with the aim of identifying the main drivers leading to hillslope degradation and to shed light on the role of human action. We revealed that hillslope degradation can be mainly related to deforestation for land reclamation, cropland abandonment and the increase of hazardous rainfall. Moreover, we focused on how human impact can have both positive and negative feedbacks. In some cases (e.g., badlands), the land levelling has produced an initial inhibition of land degradation, while after intensive agricultural practices accelerated soil depletion has occurred, favouring erosion processes. Analogously, terracing contrasted erosion until the entire terrace system was maintained but abandoned terraced slopes can increase the magnitude of geo-hydrological phenomena in response to high-intensity rainfall. On the other hand, both rural landscape and related erosional landforms can be appreciated as elements of landscape diversity and contribute to tourism development.

KEYWORDS: badlands; hillslope degradation; human impact; geomorphological risk; terraced landscape.

1 INTRODUCTION

In the recent decades, there has been an increasing global perception of the environmental issues deriving from slope degradation and of their impacts on natural landscape, biodiversity, ecosystems and society (Müller & Weigelt, 2013; Blaikie & Brookfield, 2015; Keesstra *et al*., 2016). Over the centuries humans have modified large areas of Mediterranean natural landscape to develop agricultural and livestock activities (Grove & Rackham, 2003; Butzer, 2005; Blondel, 2006; Lasanta *et al*., 2017). Large areas on natural slopes were shaped because of deforestation, reworking of soil covers and farming practices. Generally, gently slopes were cultivated as sloping fields whereas steep ones were terraced (Grove & Rackham, 2003; Sluiter & de Jong, 2007). Agricultural terraces are traditional farming systems and represent one of the most evident human signatures on hilly and mountainous landscapes (Tarolli *et al*., 2014; Arnáez *et al*., 2015). Traditional agro-silvo-pastoral systems are of considerable importance since they contribute to the meticulous management of land, preserving both the natural environments and the ecosystems (Morgan, 1995; Lasanta *et al*., 2005). Numerous studies testified that, if properly practiced and maintained, traditional farming systems are essential for soil conservation and play a crucial role in reducing the effects of hydrological and geomorphological processes (Wakindiki & Ben-Hur, 2002; Louwagie *et al*., 2011).

Starting from the mid-20th century, many hilly and mountainous landscapes of Europe faced significant demographic, social and economic changes (McDonald *et al*., 2000; Mottet *et al*., 2006). One of the major consequences of this trend was the abandonment of farming areas (García-Ruiz & Lana-Renault, 2011). Agricultural landscapes have been gradually replaced by scrublands, natural woods and reforested areas, causing a homogenization of the landscape (McDonald *et al*., 2000; Poyatos *et al*., 2003; Vicente-Serrano *et al*., 2005; Lasanta *et al*., 2015). On the contrary, many hilly territories passed from traditional to intensive agriculture in response to the growing market demand and to the increase in population density (García-Ruiz & Lasanta, 1990; Antrop, 2004; Lasanta *et al*., 2017). The need for new cultivable and well-exposed areas led to extensive deforestation practices and remodelling of badlands areas (Piccarreta *et al*., 2006a). Due to land abandonment and land reclamation, hilly and mountainous landscapes have been subject to widespread degradation (García-Ruiz & Lana-Renault, 2011). Slope degradation, together with new scenarios of climate change, has an essential role in increasing erosion and landslide susceptibility (Glade, 2003; Piccarreta *et al*., 2006a; Capolongo *et al*., 2008; Lesschen *et al*., 2008; Vergari *et al*., 2011; Cevasco *et al*., 2015; Galve *et al*., 2015; Brunetti *et al*., 2018). Where peculiar geologic (e.g., environments characterized by erodible terrains) and climatic settings exist, slope degradation can favour the development of badlands (Capelli *et al*., 1997; Phillips, 1998; Clarke & Rendell, 2000; Faulkner *et al*., 2003; Farifteh & Soeters, 2006; Nadal-Romero *et al*., 2008; Vergari *et al*., 2013a; Vergari, 2015). In these landscapes, the intense effect of surface runoff is accompanied by the increase of connectivity between hillslopes and channels that can favour the occurrence of flooding phenomena at the valley floors (Poesen & Hooke, 1997; Faulkner, 2008; García-Ruiz *et al*., 2008). Hillslope degradation in response to land abandonment, management changes and climatic factors has been also documented in many areas of the Mediterranean Basin (Ispikoudis *et al*., 1993; Cerdà 1997;

Lasanta *et al*., 2001; Grove & Rackham, 2003; van Eetvelde & Antrop, 2003; Lasanta *et al*., 2005; Giupponi *et al*., 2006; Sluiter & de Jong, 2007; Agnoletti, 2007; Koulouri & Giourga, 2007; García-Ruiz, 2010; García-Ruiz & Lana-Renault, 2011; Arnáez *et al*., 2011; Stringer & Harris, 2014; Lasanta *et al*., 2015). Moreover, in recent years many researches dealt with the impact of human and climate changes within Mediterranean catchments characterized by high ecological and cultural values and revealed that these basins can be considered as representative of the land degradation issues occurring at wider scales (García-Ruiz *et al*., 2008; Cevasco *et al*., 2014; Brandolini *et al*., 2018).

In the last two decades, the availability of powerful remote sensing techniques has greatly improved the assessment of the hydro-geomorphic effects connected to hillslope degradation (Roering *et al*., 2013; Tarolli, 2014; Passalacqua *et al*., 2015 and references therein). High-resolution topographic data from airborne and terrestrial LiDAR (Light Detection and Ranging), for example, offered great opportunities of measuring and monitoring soil erosion and mass movements in hilly environments (Ardizzone *et al*., 2007; Jaboyedoff *et al*., 2012; Pirotti *et al*., 2012; Trevisani *et al*., 2012; Cavalli *et al*., 2013). Moreover, Structure from Motion (SfM) techniques are recently increasingly being used in detecting topographic changes, also through Unmanned Aerial Vehicles (UAVs) (Passalacqua *et al*., 2014; Smith & Vericat, 2015). In Italy, different methods were applied for the quantification of the morpho-evolution rates in highly erodible areas under different spatial scales, covering different time intervals and with different resolutions (Del Monte *et al*., 2015): monitoring with erosion pins (Della Seta *et al*., 2009), repeated topographic surveys with differential GPS (Vergari *et al*., 2013b) and LiDAR or UAV derived high-resolution DEMs comparison (Cavalli *et al*., 2017; Neugirg *et al*., 2016; Brandolini *et al*., 2018). Moreover, the obtained results contributed to produce geomorphological susceptibility and hazard estimation by means of statistical methods (Vergari *et al*., 2011; Conoscenti *et al*., 2014; Galve *et al*., 2015).

This paper aims to shed light on how humans can influence hillslope degradation and provide some insights useful to define virtuous management strategies that are able to conciliate the land reclamation with the soil conservation. We review and discuss the geomorphological and hydrological aspects concerning the morpho-evolution and the degradation processes of some representative hilly and mountainous Mediterranean areas based on previous studies conducted in the recent years. The key outcomes of hillslope degradation were analyzed in four representative catchments selected in different Italian regions: Liguria (Cinque Terre), Tuscany (Val d'Orcia), Basilicata (Fossa Bradanica) and Sicily (Scillato). In detail, we gathered from literature some relevant findings on the quantification of the relationships between denudation processes and land use changes in the selected study areas. We examined the effects of erosion processes acting both over small (e.g., slopes) and large (e.g., catchment) scales and referred to short (i.e., single extreme rainfall events) or long (i.e., some decades) time spans. We compared and discussed these outcomes to identify the main driving factors leading to hillslope degradation issues. Degradation processes are widespread in the selected areas causing loss and depletion of soil, economic damage, risk conditions and environmental changes. Considering also the increasingly growing tourist activities in the selected areas, the results of this study are expected to contribute in defining a proper land management and support the decision-making in planning and scheduling effective strategies for landscape conservation and enhancement.

2 STUDY AREAS

The study areas are located along the Apennine chain (Figure 1) and are representative of hilly and mountainous Mediterranean landscapes particularly sensitive to climatic and anthropic changes. The selected study cases can be considered indicative of the land degradation issues that overall affected wide portions of the Italian territory during the last century. Information on the main climatic, morphological and lithological conditions in the areas studied, together with the dominant denudation processes, were collected from previous studies and summarized in Table 1. Additional data were gathered on land use changes, erosion rates, land management and main land degradation factors. The considered basins show wide ranges of climatic, geological and geomorphological settings, different land use evolutions and land management practices.

Although the climatic features are typical of the mild Mediterranean climate, among the study areas there are some differences in terms of rainfall regimes. On average, rainfall amounts decrease moving from the northern (i.e., Cinque Terre and Val d'Orcia) to the southern (i.e., Fossa Bradanica and Scillato) sectors of the Apennines. As can be noted by Table 1, all the considered areas underwent very severe landscape changes because of both unsustainable anthropogenic actions and management policies that concur to increase proneness to hydrological and geomorphological phenomena. Different erosion processes occurred, and with different magnitude, depending on both the lithological and the morphological features. In case of steep slopes (i.e., Cinque Terre) shallow landslides prevail while in presence of more gently slopes gully and rill erosions are more frequent. However, it is interesting to note that in spite of the land degradation issues and hazard implications, attracting tourist activities were developed.

2.1 Cinque Terre - Vernazza catchment

Cinque Terre area is located in the eastern Tyrrhenian side of Liguria (north-western Italy) and represents a unique and dramatic example of terraced coastal landscape within the Mediterranean region (Brandolini, 2017). In this sector of northern Apennines, ophiolite (serpentinites and gabbros) and sedimentary (limestones, sandstones and clay–shales) rocks mainly outcrop. From a geomorphological point of view, this part of Liguria is characterized by a sequence of small coastal basins with the main water divide located very close to the coastline that mainly consists of rocky cliffs. The inner territory shows very steep slopes covered by thin eluvial-colluvial deposits and carved by short linear streams often controlled by tectonics (Brandolini, 2017). The geographical and morphological features of the region determine a mild Mediterranean climate. The southerly aspect together with the presence of a chain effect, due to the ridge of mountains very close to the sea, produce mild mean annual temperature (14.5-15.5 °C). Generally, winter is mild (lowest mean temperatures of 7-8 °C) while summer is hot and dry (mean peaks of 22.0-24.5 °C). On average, because of the combined effect of the humidifying action of the sea and the chain effect, the coastal sectors receive somewhat abundant rainfall annually (mean annual value of about 1040 mm referred to the Levanto rain gauge station and considering a period of 62 years between 1954 and 2016), mainly concentrated in autumn and winter (Figure 2A) (Cevasco *et al.*, 2015). It is worth to note that heavy and very concentrated rainfall can affect this area during the autumn season, as dramatically evidenced by the October 25th, 2011 rainstorm event (Cevasco *et al*., 2015; Galanti *et al*., 2017; Brunetti *et al*., 2018).

In the Cinque Terre area, since the 12th century natural slopes were deeply modified by human intervention. Through deforestation practices and reworking of soil covers, natural slopes were shaped by terraces retained by thousands of kilometres of dry stone walls, mainly for vineyards and olive groves. In the 19th century terraces reached the maximum extension occupying up to 60% of the entire territory of Cinque Terre (33 km^2) (Terranova *et al*., 2002; Terranova *et al.*, 2006). Due to the severe morphological features of the area, characterized by very steep slopes, agricultural terraces emphasize harmony among human and natural landscape. In 1997 UNESCO classified the Cinque Terre area as a World Heritage Site because of its scenic, environmental, historical and cultural values, while since 1999 the entire area was declared National Park. In this area, as for the entire Liguria region, agricultural terraces have played an important social and economic role, enabling the development of a thriving agriculture that provided a variety of resources that supported many inhabitants. Beginning in the 1950s, but following a trend started at the end of the 19th century, Ligurian hilly and mountainous areas experienced important management changes because of the progressive exodus of farmers towards cities of northern Italy, where dynamic economic activities were growing fast after the Second World War. These changes led to an extensive abandonment of farming activity and of a significant percentage of traditional agricultural terraced slopes. At the beginning of the 21st century, approximately 80% of terraces resulted abandoned in the Cinque Terre area (Terranova *et al*., 2002). The lack of maintenance of terraces due to farmer abandonment increased the effects of hydrological and geomorphological processes, leading to widespread slope degradation issues (Faccini *et al.*, 2005; Cevasco *et al*., 2013a; 2014; Brandolini *et al*., 2018). The instability of the dry-stone masonry and the poor functioning of runoff artificial water drainage systems represented mainly causes in increasing both the erosion and the landslide susceptibility. The effects of land degradation occur forcefully in concomitance of intense rainstorms that can affect the coastal sectors of the Liguria region (Cevasco *et al*., 2009; Cevasco *et al*., 2012). The case of the Vernazza small coastal catchment (5.8 km^2) was selected as the most representative example of links between land use, land management practices and single extreme rainfall event. This basin shows very steep slopes (more than 50% of the slope gradient varies between 30° and 40°) covered by thin soil layers (thickness from few centimetres to 2.5 m) overlying sandstone-claystone flysch and pelitic complex bedrocks (Cevasco *et al*., 2013b; Cevasco *et al*., 2014). Streams are short and present an ephemeral hydrological regime; moreover, due to their steep profiles are characterized by a high erosive and transport power. Land use mapping, performed through field surveys and aerial photographs interpretation (Cevasco *et al*., 2013a), revealed that agricultural terraces occupy approximately 49% of the entire basin extension whereas 51% is characterized by wood/scrub land, mainly concentrated in the upper portion (Figure 3). Terraced slopes were grouped into still cultivated (CT) and abandoned with poor (ATP) and dense (ATD) vegetation cover, respectively. ATP have been abandoned from less than 25–30 years and characterized by herbaceous cover or shrubs; ATD have been abandoned for more than 25–30 years and are mainly covered by forest tree species or scrub (Carl & Richter, 1989). ATD resulted the most widespread (67.9% of the total terraced slopes) followed by CT (16.1%) and ATP (16.0%). Many studies were focused on the relationships between land use and geo-hydrological phenomena caused by the 25th October 2011 extreme rainstorm within the Vernazza catchment. During the rainstorm, rain gauges located along the coast a few kilometers west of the Vernazza village registered hourly intensity rainfall peaks slightly higher than 110 mmh^{-1} (Figure 2B). Rainfall amounts were even more severe within the inland Vara/Magra valleys, where a cumulative daily rainfall value of 539 mm was recorded, with an hourly rainfall intensity up to 153 mmh^{-1} (Figure 2C) (Cevasco *et al*., 2015). The mobilized materials from the slopes were charged by streams giving rise to mud/debris floods that affected the Vernazza village, causing considerable damage and three casualties. Immediately after the event, coupling detailed analysis of high-resolution aerial photograph with field surveys, an inventory of the geo-hydrological processes was performed (Cevasco *et al*., 2013a). Within the Vernazza catchment, more than 500 rainfall induced shallow landslides were mapped along with many intense accelerated erosion processes, corresponding to about 1.50 and 1.65% of the entire basin area, respectively. The analyses of the landslide distribution in relation to land use revealed that landslides particularly affected agricultural terraced slopes pointing out their extreme vulnerability. In fact, approximately 88% of the landslides were triggered on terraced environment (Cevasco *et al*., 2014). In this regard, pre-event and post-event LiDAR DTMs comparison (Figure 2D) revealed that shallow landslide mobilized soil volumes were higher for abandoned terraced slopes than still cultivated ones (Brandolini *et al*., 2018). Furthermore, important findings came from the relationships between landslide magnitude and degree of abandonment. Brandolini *et al*. (2018) evaluated the mobilized debris volumes per unit area, by means of the definition of the Landslide Volumetric Index (LVI), revealing that ATP represented the most hazardous land use class since characterized by erosion rates resulting approximately 2 and 3 times higher than ATD and CT, respectively (Figure 2E, F). These results confirm that land abandonment and agricultural mismanagement can play a key role in intensifying the magnitude of shallow landslides in case of a single extreme rainfall. Because of the high environmental and cultural values of the area, the restoration of abandoned terraces along with the recovery and maintenance of drainage systems must have a primary role in the future scheduling of mitigation and prevention strategies of geomorphological risk (Brandolini & Cevasco, 2015).

2.2 Upper Orcia Valley – Tuscany

The Upper Orcia Valley is located in Southern Tuscany, within the Ombrone River Basin. The geology of the area mainly consists of Plio-Pleistocene highly erodible marine and continental successions (chiefly clays, silty clays and sandy clays) deposited within a NW–SE trending graben. The climate is temperate warm, presenting the typical Mediterranean variability. Data from the National Hydrological Year Books, related to certain local stations and referred to the time period comprises between 1951 and 1996, indicate that the average annual precipitation is about 700 mm, with peaks ranging from about 500 to 1100 mm during exceptional years, while the mean annual temperature is around 14°C (Aucelli *et al*., 2016).

During the Holocene, severe erosion processes occurred on Plio-Pleistocene marine deposits, mainly clayey, highly uplifted during the Quaternary. Here, fluvial incision and hillslope denudation entail high suspended sediment load and, in particular, water erosion is responsible for the development of the typical badlands with *calanchi* and *biancane* landforms (Del Monte, 2017).

"Biancane" are small clay domes up to approximately 15 m high that are mostly bare of vegetation on the typically steeper southern slopes, where rill erosion is particularly strong. *Biancane* landforms are frequent on the smooth hilly landscape, although they have been widely levelled due to local crop-growing activities during the last centuries. "Calanchi" mark the rougher landscape, where the steepest hillslopes prevent relevant human activities; *calanchi* show a resistant caprock, driving a parallel-retreating evolution of rugged steep slopes (Del Monte, 2017). Shallow mass movements are highly representative, contributing to slope denudation along with water erosion. The most frequent mass movement types are rotational slides and complex landslides. On gentler slopes, mudflows, soil creep and solifluction are greatly widespread.

Land reclamation has significantly affected the landscape of the study areas during the last decades: as a result, the vegetation cover is sparse because of the widespread deforestation of the hills reserved for crops and grazing. Moreover, Figure 4 shows the vast levelled badland zones of the Upper Orcia Valley, which reach almost the 70% of the original *calanchi* and *biancane* landforms (Guasparri, 1993). Many *calanchi* have been modified or deleted, but the very steep slopes of the most picturesque *calanchi* have deterred the anthropic remodelling (Figure 5A). Conversely, *biancane* areas, developed on low-dip slopes, have been almost completely deleted, and they survive today in a few areas protected by law (Figure 5B). Thus, nowadays, most of the area is characterized by sowable or uncultivated ground. Rills and gullies, ephemeral or permanent, often develop in croplands because of concentrated rainfall. In many sites, piping is also favored by land-use changes, such as cropland abandonment. The disappearance of the *biancana* landscape is also due to the encroaching vegetation, and the following loss of ground for pioneer vegetation, resulting in a global decrease in biodiversity, as the encroachment was widely attributable to ruderal species.

A long-lasting field monitoring program have contributed to quantify erosion rates at the catchment scale, thus assessing the on-site effects of water erosion. Data obtained showed that the mean annual values of ground level variations due to water erosion range between 1 and 2.5 cm a^{-1} on badlands (Figure 5C). Nonetheless, at the hillslope scale considerable space variability of ground level changes can be explained, for example, by temporary deposition landforms due to frequent landsliding. Comparison of pluviometric data and measured erosion rates attested that clay removal by water erosion is generally due to intense rainfall event preceded by quite long dry periods, while small landslides or gully banks collapses are favoured by intense rainfall falling on the already saturated terrain, condition that is frequent in spring (Vergari *et al*., 2013a). The strongest surface lowering rates were observed in *biancane* sites, in particular where they are in a more juvenile development phase. Here, results of parent material analyses (Vergari *et al*., 2013b) showed that clayey mineralogy appears quite uniform, while the more dispersive behavior of *biancane* bedrock indicates a stronger tendency of *biancane* clays to spontaneous colloidal dispersion. Multitemporal volumetric estimation performed for a small catchment of Upper Orcia Valley by means of the photogrammetric analysis showed for the 1976-2003 time span a mean erosion rate of 1.5 cm a^{-1}, with a maximum value of 6 cm a^{-1} in the badlands areas (Aucelli *et al*., 2016). Similar erosion rates resulted after monitoring with multitemporal high-resolution terrestrial LiDAR and UAV surveys (Neugirg *et al*., 2016).

Due to this rapid morphogenesis, this catchment is a key site for studying the denudation processes typically acting in Mediterranean badlands areas, thanks to the availability of long-lasting erosion monitoring datasets and the rapidity of erosion processes development (Del Monte, 2017). Since 1988, many attempts have been made to control erosion like building check-dams along the gullies draining *calanchi*, using mattresses or gabions and practicing reforestation since the 1960s to contain soil erosion. Most of these works appear to be severely damaged and reforestation failed to limit hillslope denudation, as often the re-planted trees caused an overload that favored deeper landslides (Vergari *et al*., 2011).

Today, a lot of protected areas have been established on *calanchi* and/or *biancane* badlands. In the Orcia Valley, the Lucciolabella Natural Reserve, part of the Natura 2000 network of special areas of conservation, was established in 1996 to protect the typical biancane landscape (and its priority habitats).

The badland areas, in fact, attract tourists for their spectacular scenery, especially where they are widespread and are connected with the history of the territory, art, culture, nature, and, last but not least, food and wine products (many top-quality gourmet products are available). Since 2004, Val d'Orcia was included in the UNESCO World Heritage List as "cultural landscape". Val d'Orcia hosts many historical towns. Castles, villages, towers and isolated monasteries complete the picture of a fascinating landscape; even the art is linked to geomorphology and agriculture. The valley is crossed by many natural paths used for trekking or riding; one of this is a very important "paths of faith" in Europe, the "via francigena" ("the road from France", that was covered by Pilgrims coming from the countries of north-west of Europe).

2.3 Fossa Bradanica – Basilicata

The study area is the central-southern part of Fossa Bradanica, a sedimentary basin of the Pliocene–Pleistocene with a NW-SE trend which is placed between the Apulian foreland and the southern Apennines (Pieri *et al*., 1996; Ciccacci *et al*., 1999). The successions that outcrop in this area are mainly characterized by shallow-marine silty clays of the Argille sub-Appennine Unit and by coarse-grained units that close the Fossa Bradanica sedimentary cycle (Ricchetti, 1981). In the Middle Pleistocene the rivers incised deep valleys that extend perpendicular to the coast due to the continuous regional uplift, while the lateral erosion acted on the hillslopes exposing the highly erodible clayey bedrock because of the increased dissection (Piccarreta *et al*., 2011). Gray-blue marly clay formation outcrops widespread in the study area where badlands formed, and the hillslopes are cut by deep gullies.

This region enjoys the Mediterranean weather, characterized by warm dry summers and temperate wet winters with a mean annual temperature of about 17°C. In detail, the mean maximum summer temperature is between 24°C and 25.5°C and the winter mean minimum ranges between 8°C and 9.5°C.

The annual rainfall is between 738 mm and 581 mm (considering the time interval between 1955 and 2000), with the heavy rain period from November to January (Piccarreta *et al*., 2006a). The last decades of previous century were witness of a reduction in the total annual precipitation against the growth of rainfall intensity. Piccarreta *et al*. (2013) show an increase of both the total precipitation and the daily rainfall amount since the begin of the millennium. Instead of an increase of single day's intense rain, these authors highlighted an increase of small periods of three to five consecutive days of moderate to heavy rainfall events. The rise in the intensity/frequency of multi-days extreme rainfall triggered a considerable number of flooding and landsliding events with consequent land degradation. In the same period, the maximum erosion value was about 10 cm recorded in the gullies in valley fill, while the mean value on the degradated hillslopes was about 3 cm. The vegetation cover consists of scrub oak and/or pine woodland with a mixed understory shrub modified by human intervention (Boenzi *et al*., 2008). Woodland areas increased after the 1950s due to reforestation policy to the detriment of both the Mediterranean "macchia" of the bushy grassland areas and of the *Pistacia lentiscus* and *Lygeum Spartum* steppe that are dominant on badlands. The gentle dip slopes, if not land-levelled, keep a fairly good vegetation cover and are used for agriculture (Piccarreta *et al*., 2006b). The cultivations of the olive groves are on hilly areas and thus act on rainfall interception and runoff reduction. The durum wheat is the prevalent cultivation of the arable land and it is mainly farmed in valley bottoms and terraced surfaces (Figure 6).

In this area, there are three types of land degraded zones especially in term of accelerated soil erosion: *Calanchi* areas, *Biancane* areas and gullies in valley fills. The *Calanchi* areas develop on high energy relief and large degraded landscapes (Alexander, 1982). These areas present parallel close-packed gullies with vertically elongated grooves, narrow and sharp ridges with steep, naked walls that are quickly incised and eroded headwards (Figure 7A, C). *Biancane* areas are low energy relief degraded land, generally shaped on slopes highly incised by rills, gullies and collapsed pipes. They are dome-shaped forms (Figure 7C) enclosed by a micropediment (Torri & Bryan, 1997) and they develop when the erosion of a network of slightly inclined pipes is achieved: many domes remain isolated from the slope as the pipe roof collapse (Piccarreta *et al*., 2006b). Gullies form in valley fills; they have vertical sidewalls and they are about 10–30 m deep and 25–450 m wide (Figure 7D), due to the heavy lateral erosion (Piccarreta *et al*., 2006b; Piccarreta *et al*., 2012b). The head-ward gully erosion starts often from the collapse of tunnels and pipes (Figure 7B).

Land degradation and soil erosion have been shown to be linked with specific land use changes, encouraged by agricultural policy, and with changes in precipitation. The clayey nature of the soils suffers from the erosion, especially if disrupted by the land remodeling process. The total annual precipitation and the daily rainfall drive the rainfall erosivity: the reducing in annual rainfall amount is somewhat compensated by the augment of single storm rainfall intensity to preserve the long-term values of annual rainfall erosivity in the region (Capolongo *et al*., 2008). Thus, long-lasting dry periods with low frequency heavy rains cause rill razing; this soil smoothing allows mass movements such as slope creep due to more homogeneous percolation. The lengthened drought periods before the extreme rainfall events increased the water flows erosivity and caused changes in gully sediment budget. The net erosion becomes really high since most of the deposit of the gully bottom was detached and transported downstream to and accumulated in the pediment channels (Piccarreta *et al*., 2012b).

In the last decades, a conspicuous reduction in degraded areas occurred mainly as a result of badlands (*calanchi* and *biancane*) use for the increase in sown areas promoted by the European Union's Common Agricultural Policy (CAP) practices. In fact, many badlands were leveled for cultivation of durum wheat mainly in valley bottoms and river terraces: therefore, the slopes are now characterized by fewer erosive features (Piccarreta *et al*., 2006a). On other hand, the cereal cultivation of remodeled areas supports the surface crusts formation since the soil aggregates became vulnerable to rainfall impact, reducing infiltration and increasing runoff. Moreover, cultivation does not stabilize hillslopes and due to a rainfall event can produce erosion leading back hills to their original non-productive badlands (Piccarreta *et al*., 2006a). In many cases the adjacent remodeled and vegetated areas behave differently on the same hillslope: in fact, the remodeled areas suffer intense erosion due to rills and gullies formation while the areas with vegetation (native or not) generally show less erosion (Figure 7E). The multi-temporal analysis also shows that razing of gully heads by earthworks machinery promotes the sediment production, triggering slope instability processes, muddy floods and infilling of valley floor.

This badland landscape has always fascinated tourists and travelers and, after many years of state of abandonment and/or mistreatment, the inhabitants understood the importance of its preservation. Then, both natural and literary parks were established to enhance this badlands geoheritage.

2.4 Scillato - Sicily

Scillato Basin is a N–S-oriented structural depression that appears deformed as an asymmetric synform. This area is located in the central-northern sector of the Sicilian Chain and may be considered representative of the general environmental conditions of this sector of Sicily. Rocks cropping out in the area show a great variability as they form part of a multi-cyclic sequence of alluvial clastic and marine sediments which consist of conglomerates, sandstones, silts and clays (Gugliotta *et al*., 2012). Due to the lithological and structural setting (characterized by the presence of a cuesta relief), the slopes show a high variability of landforms which are mainly related to water erosion processes. In the low-angle and north-facing slopes, dominant processes are creep, solifluction, gullying, landsliding and sheet wash. On the other hand, the steep south-facing scarp slopes are affected by different type of pipes, rills, gullies and mass movements (shallow slides/flows and falls); here the processes associated to these landforms contribute to defining a typical *calanchi* landscape characterized by a sub-parallel pattern (Pulice *et al*., 2012; Cappadonia *et al*., 2016). The area is characterized by a typical Mediterranean climate with hot and dry summers and mild and wet winters. Weather data recorded in the period 1970-2000 by the Regional Hydrographic Service at the stations of Caltavuturo (635 m a.s.l.), Scillato (376 m a.s.l.) and Cerda (274 m a.s.l.) indicate that average annual rainfall is 620 mm, with minimum and maximum average monthly rainfall occurring in July (5 mm) and January (90 mm), respectively. Temperature distribution, with summer and winter average values accounting for 24°C and 9°C, respectively, is very well-suited to intensive cultivation (mainly cereals crops) but at the same time affects some characteristics of the soil, such as fertility and erodibility (Figure 8).

In the last decade, a multidisciplinary study was carried out on the *calanchi* fronts in the Scillato Basin. A continuous monitoring of the *calanchi* surface performed in the period 2005–2009 allowed us to quantify relative height variations due to erosion (negative variations) and deposition (positive variations) processes (Figure 9 and Table 1). A rain gauge installed in the area was employed to record precipitation and thus to calculate the USLE Rainfall-Runoff Erosivity Factor (Cappadonia *et al*., 2011). The Scillato Basin has been used as a dynamic natural laboratory for our research scopes. In addition to the above-mentioned analyses, geomorphological, chemical, physical and mineralogical properties have been analyzed to assess their control in the evolution of the *calanchi* fronts (Pulice *et al*., 2012). Furthermore, field surveys were carried out to measure the density of pipes and their correlation with the drainage network, the presence of vegetation cover and the variation of lithological layers. Also, morphometric and statistical analyses were performed to identify and study the effects of the slope morphometry on the spatial distribution of morphogenetic processes and their associated landforms in a *calanchi* area (Buccolini *et al*., 2012; Cappadonia *et al*., 2016). The slopes affected by *calanchi* landforms are generally south facing and show average slope angle of around 32°–33° together with deep furrows separated by sharp ridges when the concentrated runoff prevails. Conversely, when mass movements and piping are predominant, the slopes are characterized by less sharp ridges and rounded channels filled by the removed material. The laboratory analysis showed that the involved terrains mainly consist on silty-clay deposits. From the chemical and mineralogical point of view, the collected data show that the clayey fractions are mainly inactive and composed by phyllosilicates. However, all samples are characterized by sodium adsorption ratio (SAR) values greater than 10, which are typical of the dispersive materials. The values of the plasticity and liquidity indices are coherent with the landslides spatial distribution. Finally, the high pH values indicate limited leached conditions during low precipitation periods (Pulice *et al*., 2012). During the monitoring period a general erosive re-treatment trend was recorded, even if different phases of both erosion and deposition have been identified (Cappadonia *et al*., 2011). The main controlling factors of the morphodynamic evolution of the Scillato area are the temporal distribution and intensity of the rainfall, the terrain properties and the topographic characteristics, as well as the concurrence of processes such as piping. Specifically, there is an important variability as regard to frequency, intensity and different types of pipes (Cappadonia *et al*., 2016) and also a strong correlation among pipes and drainage network, presence of vegetation cover and variation of different lithological layers.

These badlands areas have landforms with important scientific value, landscape aspect and educational interest, and are very close to the natural reserves, the archaeological areas and the touristic sites. Human impact is principally related to the various agricultural practices at the foot of the slopes while the badlands slopes are used only as agricultural areas like arable land or pastures; in the latter two cases, there seems to have been a tendency towards the *biancane* landforms development. If we look at the fronts in which the agricultural practice was most intense (either crops or grass, mainly) or where the activities to removal of material at the foot of the slopes were carried out, the variability of the distribution and intensity of the slope processes appears to increase; especially, in these areas the landslide phenomena that contribute to the evolution of the *calanchi* fronts (Cappadonia *et al*., 2011). The Scillato basin shows a low human pressure (predominantly agricultural areas and road infrastructures) and forms part of a cultural-naturalistic heritage itinerary if we look at both to the environmental characteristics of the area and its proximity to the archaeological ruins of Himera and the Madonie Unesco Global Geopark. Furthermore, in a few years numerous little agricultural enterprises engaged in agri-food activities are growing up. In addition, this area is only a few kilometers from Cefalù, one of the most important Sicilian seaside resort.

3 RESULTS AND DISCUSSIONS

The comprehensive examination of the case studies allowed to gather information on the main factors responsible for land degradation in representative Mediterranean areas located along the Apennine chain, under different morphoclimatic and land use contexts. Hillslope degradation issues have been addressed at different spatial and temporal scales and with various data sources. The review of the studies conducted in the selected areas allows to highlight the crucial role of both human actions and of climate conditions. Although the study areas are in different contexts, they show common features related to human intervention. The flow chart diagram in Figure 10, summarizes the key aspects of our analysis. The main drivers leading to hillslope degradation in the study areas can be summarized as: i) deforestation for land reclamation, ii) cropland abandonment, iii) increase of hazardous rainfall. The major indicators of land degradation for each study area are also included in Table 1, together with the main current local strategies for landscape management and conservation. It is interesting to note how the human practices can have both positive and negative consequences (Figure 10). As evidenced in the Cinque Terre area, on terraced slopes the combined effect of land use changes and of single extreme rainfall can accelerate considerably hillslope degradation. In this area, the strong abandonment of agricultural practices occurred since 1950s resulted in the most important predisposing factor for erosion and shallow landslide phenomena (Cevasco *et al*., 2014; Brandolini *et al*., 2018; Schilirò *et al*., 2018). This has been also recently confirmed by landslide susceptibility modelling (Bordoni *et al*., 2015; Galve *et al*., 2015; Persichillo *et al*., 2016; Persichillo *et al*., 2017). These simulations of different land use evolutions highlighted that the transition from still cultivated terraced areas to those abandoned lead to a remarkable increase of landslide susceptibility. On the contrary, slope stability greatly improves if an already abandoned terraced slope is turn into woodlands by gradually increasing the vegetation cover (Galve *et al*., 2015; Persichillo *et al*., 2016). Accordingly, multi-temporal analysis of both land use and high-resolution topographic data revealed that land degradation could be particularly severe during the first stages of abandonment (Brandolini *et al*., 2018). We emphasize two relevant aspects about terraced slopes degradation. Firstly, when no longer adequately maintained, terraced slopes can become very hazardous environments. In literature, this negative trend was extensively documented in various Mediterranean terraced areas, where many researchers observed that hydrological and geomorphic processes are favoured by land abandonment and that these phenomena contribute to soil depletion issues (Lasanta *et al*., 2001; Koulouri & Giourga, 2007; Freppaz *et al*., 2008; Lesschen *et al*., 2008; García-Ruiz & Lana

Ranault, 2011; Stanchi *et al*., 2012; Arnáez *et al*., 2015; Arnáez *et al*., 2017). On the other hand, as observed in other environments (Cammeraat *et al*., 2005; Latocha, 2014), increasing time since abandonment the beneficial effect of vegetation cover becomes increasingly effective in preventing erosion and landsliding. In this regard, according to detailed analysis of cost-effectiveness, reforestation practises would represent the most appropriate mitigation measure to stabilize abandoned terraces (Galve *et al*., 2016). However, this solution is not fully consistent with the cultural value of traditional agricultural systems, which is recognized worldwide by organizations like UNESCO and FAO. Moreover, terraced slopes and their resulting landscapes represent relevant tourism attractions. Therefore, major efforts need to be done to propose suitable preservation approaches. Considering the great economic resources needed to cope with degradation issues, the planning and political strategies of institutions should be raising awareness of local inhabitants and tourism operators. In this way, humans could have a primary role in enhancing terraced heritage. However, it is worth to note that the effect of the human actions did not have only negative implications (Figure 10). Indeed, this is also confirmed by the Val d'Orcia study case, where man has a dual role in land degradation: whilst human impact involves soil loss and degradation due to intense agriculture and land mismanagement, it is also true that it has significant importance in the genesis of spectacular erosion landforms and landscape diversity (Bollati *et al*., 2016; Del Monte, 2017). Those characteristics attract many tourists, being an important resource for the economic development of the area. Dealing with the first issue (human as factor of land degradation), the effects of land levelling for land reclamation have been investigated by different authors, especially for the Crete Senesi landscape of Southern Tuscany badlands sites (Amici *et al*., 2017), where this process is very widespread and it is also a consequence of the land reforms of the 1950s and, during the last decade, of the European Common Agricultural Policy (CAP). Deforestation, grazing and farming significantly affect the frequency and extension of denudational processes, being among the most important triggers for accelerated water erosion, tillage erosion and gravitational movements on slopes. The reworking of the clay material reduces the bedrock bulk density and changes its infiltration properties, causing an intensification of rill and gully erosion but also of piping (Marignani *et al*., 2008). In fact, despite the considerations made by Phillips (1998), who pointed out a reduction in clay dispersivity of the upper soil layers following reclamation as a critical factor in increasing soil stability, many studies on badlands dynamics in the Mediterranean area (e.g., Lopez-Bermudez & Romero-Diaz, 1989; Calvo-Cases & Harvey, 1996; Calzolari *et al*., 1997; Torri *et al*., 1999, 2002, 2006; Borselli *et al*., 2006; Desir & Marín, 2007; Faulkner *et al*., 2008; Nadal-Romero & Regüés, 2010; Cappadonia *et al*., 2011; Pulice *et al*., 2012; Vergari *et al*., 2013a; Vergari, 2015) confirmed that accelerated erosion in those areas is even enhanced by agricultural manipulation. Land abandonment without any land management strategy causes a further piping increase (Vergari *et al*., 2013a), due to increased erodibility of the soil, and the great loss of material from the surface might cause the collapse of tunnel roofs, giving rise to deeply incised gully networks, as observed in a cropland in central Italy. In fact, revegetation by indigenous species rarely occurs when cropland is abandoned. Considering the human history of the Upper Orcia Valley, Torri *et al*. (2013) state that badlands developed during periods of intense and prolonged mismanagement and they persist because vegetation encroaching is limited by continuous anthropic disturbance. These authors show that during the last centuries there have been many occasions for badlands initiation to be generated by human actions. This also support the thesis that *biancana* landforms are mainly an effect of human activity as well. This point of view emphasizes how human impact has a significant importance in the maintenance of a very particular landscape, in which badlands existence represents an opportunity of landscape geodiversity increase and of geoheritage enhancement for tourism development (Zgłobicki *et al*., 2017). Thus, the coexistence of a typical rural landscape and of a spectacular semi-natural badlands represents the key aspect of the area that makes it worthy of UNESCO recognition as cultural landscape.

As depicted in the flow chart of Figure 10, hillslope degradation also derives from the combined actions of human role and of climate change condition. As occurred in Basilicata, land degradation and soil erosion features have been shown to be linked with specific land use changes, encouraged by agricultural policy, and with changes in precipitation regime. In Basilicata, the risk of land degradation is due to several factors, such as the seasonality of rainfall events according to the different agricultural practice (e.g., planting) (Piccarreta *et al*., 2006a). The recent changes in rainfall regime, which shows an increase of the dry periods and a tendency of great magnitude rain to concentrate into macro-events of 3–4 consecutive wet days, seem to lead to an increase of the erosion processes (Capolongo *et al*., 2008; Piccarreta *et al*., 2013). The clayey nature of the soils promotes the erosion, particularly because of land remodeling processes. These degradation processes are also due to the wrong application of specific policies that allowed the cultivation of bushy lands and badlands with durum wheat. Nevertheless, most of this land is progressively abandoned and is subject to erosion processes (Bentivenga *et al*., 2015). However, studies on land use change data showed that the land degradation decreased since 1995. This trend is mainly due to the augment in sown areas, even if the reforestation policy, started after the 1950s, contributed to improve the quality of the land. This reduction is also due to the widespread badlands remodeling for the durum wheat cultivation mainly along valley bottoms and river terraces: the resulting landscape has fewer erosive forms (Piccarreta *et al*., 2012b). More recently, especially in badland dominated areas, large regional parks have been created. Those areas are exploited both from the environmental and cultural point of view where natural and historical initiative coexist (Ciaranfi *et al*., 2012). In fact, the Regional Park of Calanchi of Montalbano Jonico (set up with a Regional Law of 2011) and the Literary Park of Carlo Levi at Aliano (declared since 1998) were established to enhance the badlands landscape. This results in benefits to local communities in term of income and jobs in the tourism sector, thus expanding the local economic opportunities. Agricultural practices represented important influencing factors of land degradation also in the Scillato basin, the southernmost study area, which is representative of the Sicily island peculiarities from an environmental viewpoint but historical and economic too. During the last years the Scillato Basin showed a general erosive trend where the different processes (i.e., rill and gully erosion, mass movements and piping) are predominant. The landscape is deeply influenced by lithological characteristics and structural settings. However, some hydrographic units have been modified by the human practices, particularly pastures or arable lands; here, it is possible to observe the rise in intensity of the landslides but the *biancana* landforms increased as well, showing the trend observed by Torri *et al*. (2002, 2013) in other areas. In general, an overall trend towards high erosion rates was observed for the whole area (Cappadonia *et al*., 2011). Moreover, despite the relatively lower SAR values observed in the badlands crust (Pulice *et al*., 2012), the easier mobilization of the outer layer of the slopes could be related to other factors such as higher macroporosity. The representativeness of the study area could allow the comparison and the projection of the results to the other badlands areas with similar conditions in the Apennine chain. Considering the above-mentioned observations, the location of the study areas can be considered as a very good observatory to exploit the *calanchi* landscape. The fact that these landforms are close to important archeological, naturalistic and touristic places, has permitted the preservation over time of the spectacular landscape that could be appreciated into a tourist itinerary inclusive of the other peculiarities, especially if considering that in the tourist market the geotourism activities are constantly increasing. Particular attention needs to be paid also to the agri-food sector in this context because of its strong environmental and social component. The inclusion of these areas into tourist itineraries could really become a great opportunity for the farms and the local food producers.

The comparison of the four study cases has aided in delineating the main anthropic and climatic influences in land degradation dynamics (Figure 10). If land degradation in all the considered areas has been historically initiated and favoured by deforestation for land reclamation, the hillslope denudation trend of the last decades can be credited to both the land use changes and mismanagement and to the increase of intense rainfall. The latter has proved to be the main triggering driver causing increased soil erosion in the Basilicata badlands, while it can poorly explain the erosion trends highlighted for the Upper Orcia Valley, where the trend on the erosion rates of the last decades, deduced by volumetric estimation after photogrammetric analysis (Aucelli *et al*., 2016), cannot be easily correlated to the variations on rainfall regime (Giaccone *et al*., 2015). The increase in high-intensity rainfall events is also relevant in the Cinque Terre area, where the last extreme events have determined hillslope instability issues (Cevasco *et al*., 2015; Brunetti *et al*., 2018), concentrating landsliding where land mismanagement predominates (Cevasco *et al*., 2014; Brandolini *et al*., 2007; Cevasco *et al*., 2017; Brandolini *et al*., 2018). As well in Sicily, agricultural practices come up to be a contributing factor for enhanced soil erosion. Therefore, as a matter of fact, in all cases man-induced land degradation is pervasive. On the other hand, both the spectacular erosion landforms (e.g., *calanchi* and *biancane*) and the rural landscapes (e.g., terraced slopes and cultivated hilly territories) that characterize all these areas are undeniably sources of tourism attractiveness. In such a context, in order to protect both erosion landforms and the considered man-induced semi-natural landscapes, land management strategies should focus on adequate monitoring activities and on the adoption of effective geomorphological risk mitigation measures.

4 CONCLUSIONS

Several studies performed in some representative Italian areas show that human impact on land management has a double role that may induce positive or negative feedbacks. Land reclamation during the last decades has involved many land changes: the main by levelling and/or terracing, with different consequences. Concerning to badlands development, land levelling induces an initial inhibition of land degradation (soil loss decreasing); later, if agricultural exploitation of soils becomes intensive, the soil and fertility loss produce again acceleration of erosion processes. Conversely, slope terracing allows to contrast the soil loss, provided that the whole terrace system is well maintained, while it can be considered an important proneness cause of soil erosion when terrace system becomes abandoned. Considering the increasing of high-intensity rainfall events, these land use changes contribute to grow geo-hydrological hazard. Land reclamation is essential for agriculture development; moreover, as the study on typical rural areas of the Apennines demonstrates, land reclamation can also increase the landscape diversity and then the tourism attractions. Therefore, the performed review highlights that cropland abandonment after land reclamation is a serious mismanagement practice, causing hillslope degradation, sometimes more severe than in natural conditions, as soil reworking makes it very vulnerable to erosion. In this perspective, extreme rainfall events are nowadays more hazardous for arable or abandoned lands. Nevertheless, human-induced or natural fast erosion landforms can be appreciated by tourists: they are surely elements of landscape diversity, frequently spectacular, and they can contribute to geoheritage enhancement. In naturally evolving landscapes, the geo- and bio-diversity increasing represents, of course, an opportunity for the tourism and for the economic development of a territory.

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Table 1. Summary of the main hillslope degradation factors for each study case.

Study area	Cinque Terre	Val d'Orcia	Fossa Bradanica	Scillato
Mean annual rainfall (mm and reference period)	1040 (1954-2016)	700 (1951-1996)	660 (1955-2000)	620 (1970-2000)
Mean annual temperature (°C)	15.0	14.0	16.7	16.0
Main lithology	Sandstone and claystone	Clay and sandy clay	Clay and silty clay	Clay and silty clay
Dominant slope (°)	30-40	5-15	10-40	32-33
Main land degradation processes	Shallow landsliding	Rill and gully erosion, shallow landslides	Gully and rill erosion, landsliding	Rill and gully erosion, mass movements, piping
Maximum recorded erosion (cm)	3.3 (single event value)	6 (mean annual value)	3 (mean annual value)	3.7 (mean annual value)
% human impact	49	46	71	24
Main land degradation factors	Land abandonment	Deforestation for land reclamation	Land abandonment/Improper agricultural practices	Land abandonment
Existence of protected areas	Yes	Yes	Yes	Yes
Geo-hydrological risk mitigation measures	Yes/planned	Yes but not significant	Planned	Yes/planned
Strategy for geoheritage conservation and enhancement	Yes	Yes	Yes	Yes

Figure captions

Figure 1. Location of the study areas: 1 -Cinque Terre, Liguria; 2 - Val D'Orcia, Tuscany; 3 - Fossa Bradanica, Basilicata; 4 – Scillato, Sicily.

Figure 2. Main climatic features of the Cinque Terre area (Liguria): mean monthly precipitation (1954-2016 period) (A); representative hyetographs and cumulative rainfall plots (B, C) of the 25 October 2011 extreme rainfall event. Shallow landslide volumes evaluation: pre-event (D) and post-event (E) LiDAR-derived DSMs; DEM of differences (DoD) (F) (after Brandolini *et al*., 2018, modified). Shallow landslides volumes results: histograms reporting eroded volumes (G) and indices LVI_{er} and LIA (H) in relation to terraced slope conditions (CT - cultivated terraces; ATP abandoned terraces with poor cover, ATD – abandoned terraces with dense cover) (modified after Brandolini *et al*., 2018).

Figure 3. Land use map of the Vernazza catchment (Cinque Terre, Liguria) (modified after Cevasco *et al*., 2013a).

Figure 4. Land use map of the Upper Orcia Valley (Tuscany).

Figure 5. A) *Calanchi* badlands levelled for land reclamation. B) *Biancane* badlands (on the right) survive next to an area (on the left) remodeled to enlarge cropland surfaces. C) Summary of the mean erosion rates recorded at all *calanchi* and *biancane* sites during long-lasting geomorphological studies in Tyrrhenian side of central Italy (after Vergari, 2015); both vertical (Δy) and horizontal (Δx) variations of ground level were recorded at different sites and positions on slopes.

Figure 6. Land use in the Basilicata study area derived by the Corine Land Cover 2012.

Figure 7. Some features of the Basilicata land degradation areas: A) *calanchi* beneath the town of Pisticci; B) landsliding of the gully walls due to piping (see the big pipe in the middle of the wall); C) *biancane* landscape near the Aliano town, in foreground a remodeled area and new forming rills; D) deep gully in the Basento floodplain; E) remodeled slope where superimposed rills are highlighted by difference in humidity and vegetation.

Figure 8. Land use map of the Scillato area (Sicily).

Figure 9. An example of survey cell to measure the density of pipes; B) a small pipe; C) examples of relative height variations of erosion pins; D) erosion pins and drainage line on an old pipe after the fall of the top; E) Some geochemical and physical parameters: pH, sodium adsorption ratio (SAR), Plasticity index (IP) and liquidity index (WL); F) Sampling and arenitic level.

Figure 10. Flow chart diagram summarizing the key aspects of hillslope degradation in the study areas.

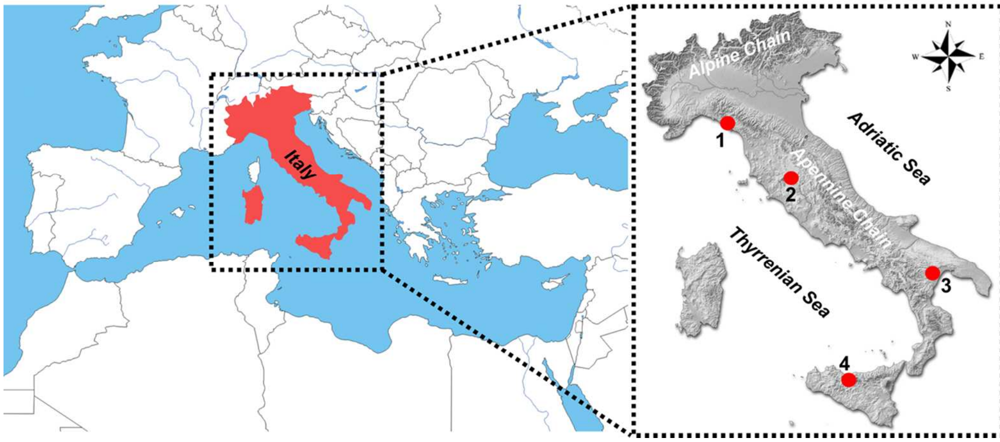

Figure 1. Location of the study areas: 1 -Cinque Terre, Liguria; 2 - Val D'Orcia, Tuscany; 3 - Fossa Bradanica, Basilicata; 4 – Scillato, Sicily.

149x65mm (250 x 250 DPI)

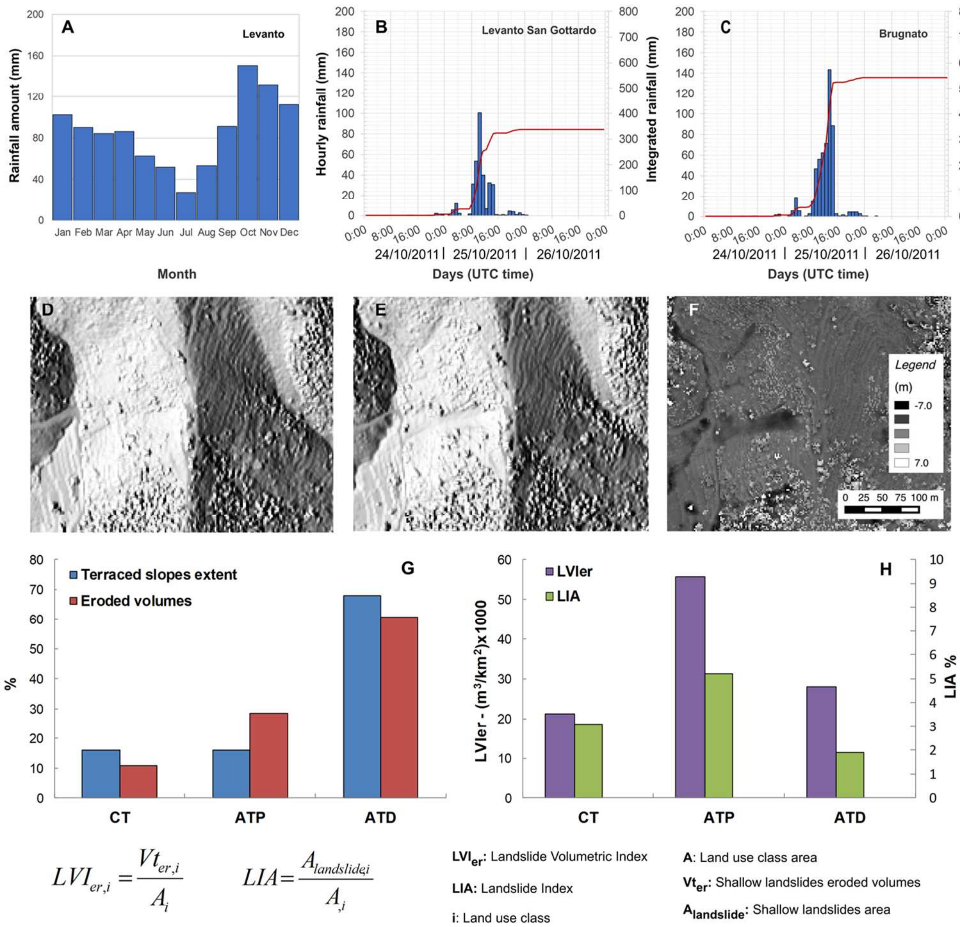

Figure 2. Main climatic features of the Cinque Terre area (Liguria): mean monthly precipitation (1954-2016 period) (A); representative hyetographs and cumulative rainfall plots (B, C) of the 25 October 2011 extreme rainfall event. Shallow landslide volumes evaluation: pre-event (D) and post-event (E) LiDAR-derived DSMs; DEM of differences (DoD) (F) (after Brandolini et al., 2017, modified). Shallow landslides volumes results: histograms reporting eroded volumes (G) and indices LVIer and LIA (H) in relation to terraced slope conditions (CT - cultivated terraces; ATP abandoned terraces with poor cover, ATD – abandoned terraces with dense cover) (modified after Brandolini et al., 2017).

161x152mm (250 x 250 DPI)

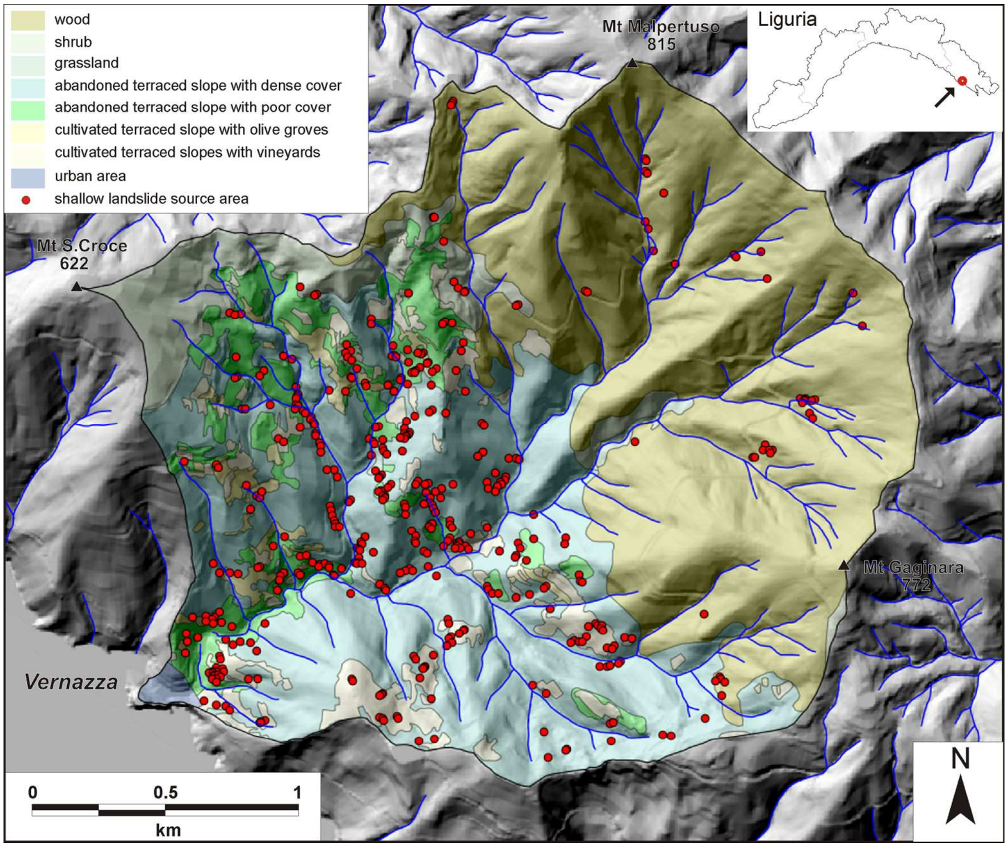

Figure 3. Land use map of the Vernazza catchment (Cinque Terre, Liguria) (modified after Cevasco et al., 2013a).

174x146mm (300 x 300 DPI)

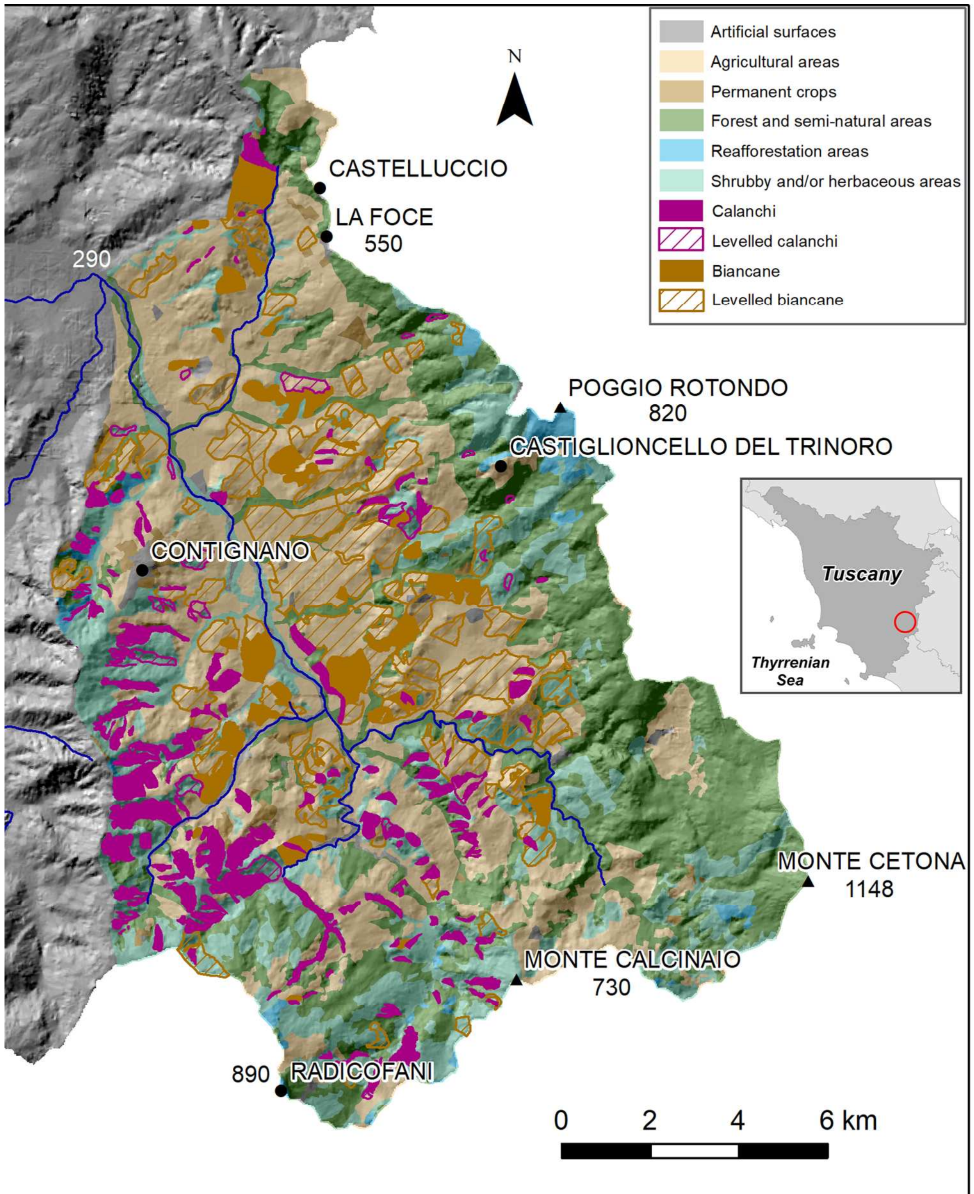

Figure 4. Land use map of the Upper Orcia Valley (Tuscany).

175x213mm (300 x 300 DPI)

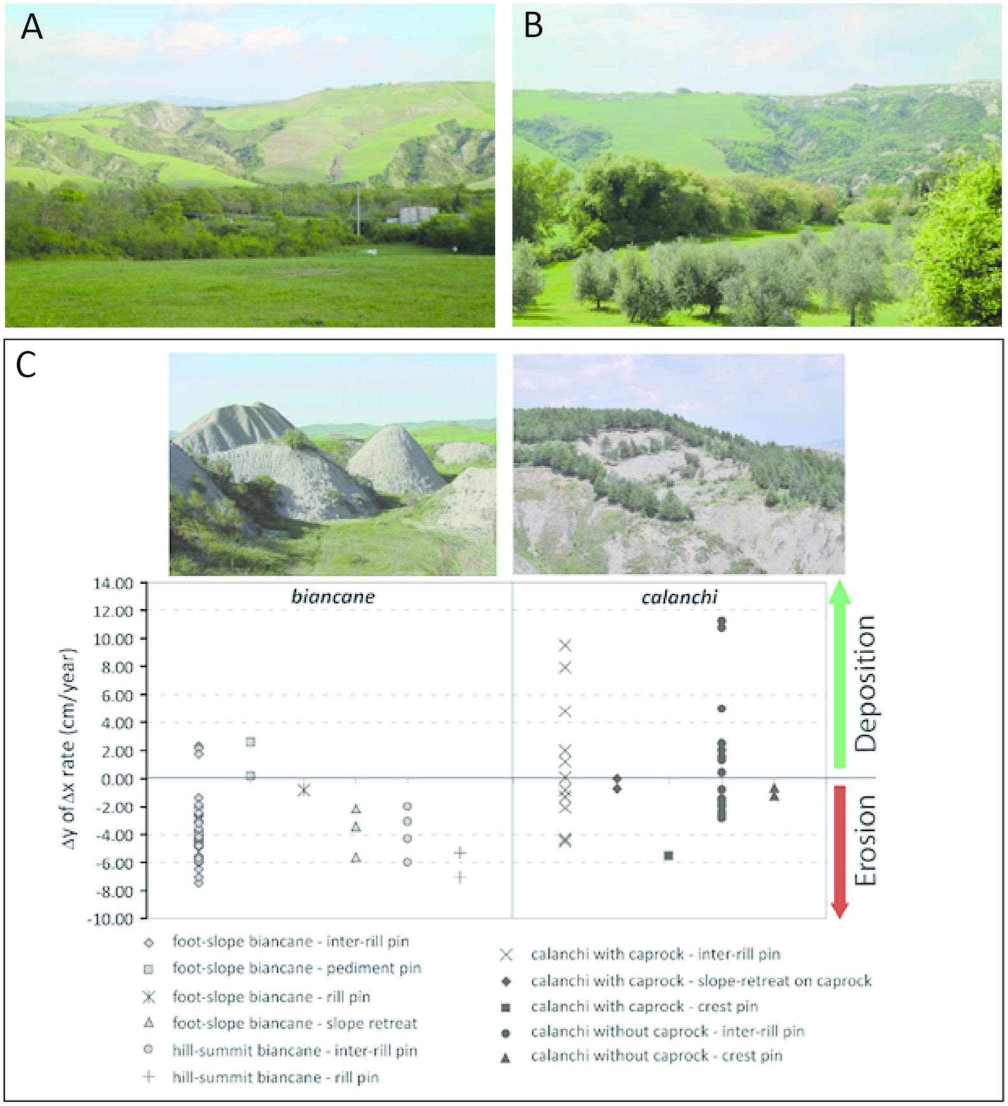

Figure 5. A) Calanchi badlands levelled for land reclamation. B) Biancane badlands (on the right) survive next to an area (on the left) remodeled to enlarge cropland surfaces. C) Summary of the mean erosion rates recorded at all calanchi and biancane sites during long-lasting geomorphological studies in Tyrrhenian side of central Italy (after Vergari, 2015); both vertical (Δy) and horizontal (Δx) variations of ground level were recorded at different sites and positions on slopes.

175x192mm (300 x 300 DPI)

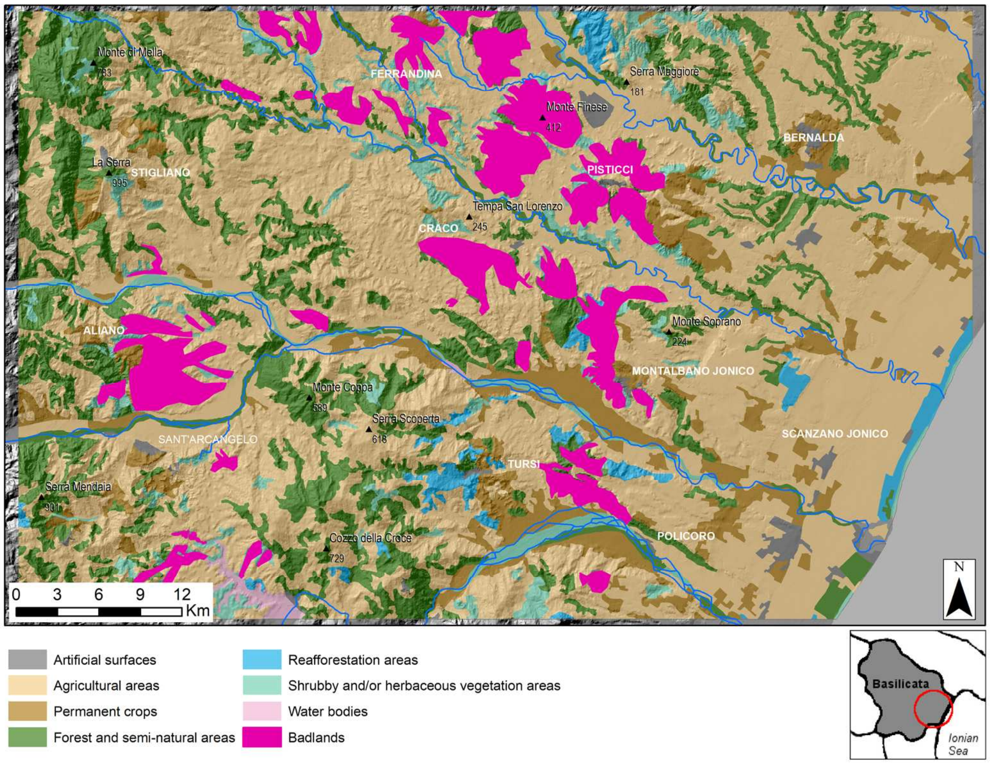

Figure 6. Land use in the Basilicata study area derived by the Corine Land Cover 2012.

175x135mm (300 x 300 DPI)

Figure 7. Some features of the Basilicata land degradation areas: A) calanchi beneath the town of Pisticci; B) landsliding of the gully walls due to piping (see the big pipe in the middle of the wall); C) biancane landscape near the Aliano town, in foreground a remodeled area and new forming rills; D) deep gully in the Basento floodplain; E) remodeled slope where superimposed rills are highlighted by difference in humidity and vegetation.

175x175mm (300 x 300 DPI)

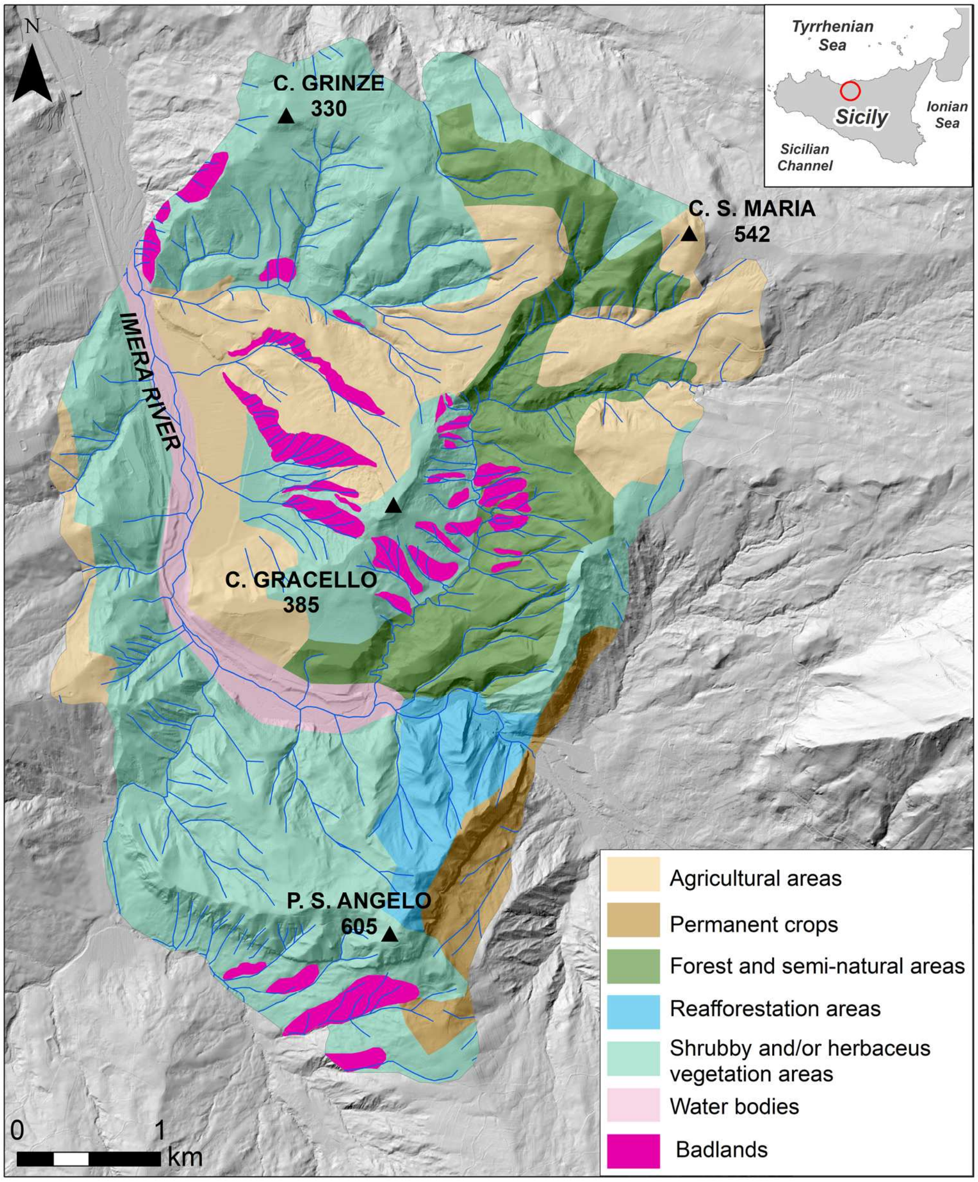

Figure 8. Land use map of the Scillato area (Sicily).

175x209mm (300 x 300 DPI)

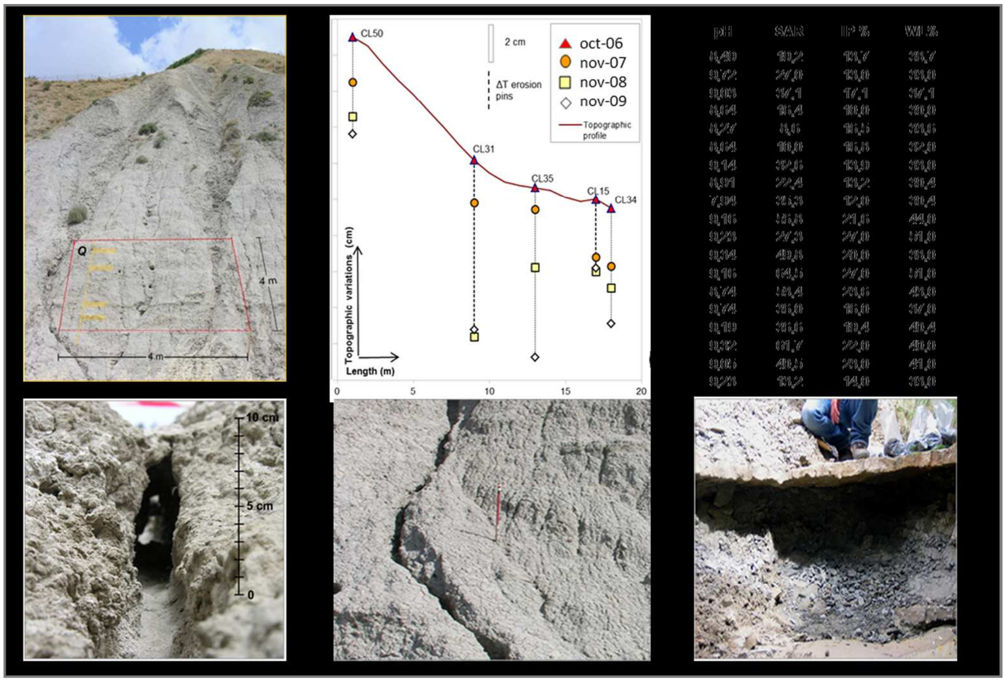

Figure 9. An example of survey cell to measure the density of pipes; B) a small pipe; C) examples of relative height variations of erosion pins; D) erosion pins and drainage line on an old pipe after the fall of the top; E) Some geochemical and physical parameters: pH, sodium adsorption ratio (SAR), Plasticity index (IP) and liquidity index (WL); F) Sampling and arenitic level.

175x118mm (300 x 300 DPI)

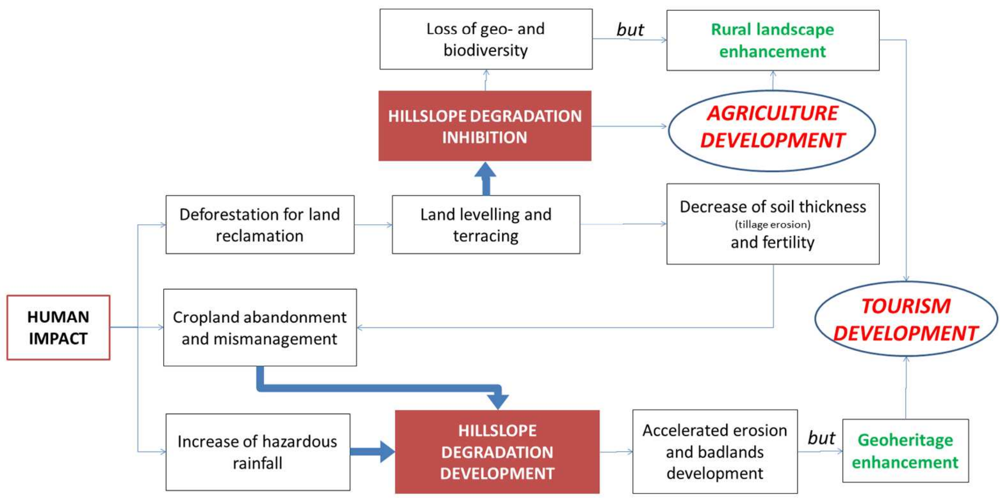

Figure 10. Flow chart diagram summarizing the key aspects of hillslope degradation in the study areas.

450x300mm (96 x 96 DPI)