Integrating temporal probability in landslide hazard evaluation towards the assessment of the economic risk at regional scale

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Integrating temporal probability in landslide hazard evaluation towards the assessment of the economic risk at regional scale

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EXTENDED ABSTRACT (ENG)

Among the others, the number of disasters caused by natural hazards and the consequent economic losses have continuously increased during last decades. The risk management posed by the occurrence of natural hazards is challenging. Nowadays, the consequences of natural hazards are expected to worsen. The effect of climate change, as well as the interaction between natural hazards, environmental and human drivers make the consequent risks more complex to manage.

The growing awareness of international community about disaster risk reduction is remarked by the ratification of international agreements, guidelines and global targets from local to global scales. However, hazardous phenomena, in particular recurring small-scale and slow-onset ones, have continued to significantly impact communities and their assets undermining the efforts to achieve a sustainable development.

The present research work deals with the landslide hazard, which is one of the most frequent natural phenomena and a major threat to human safety and the environment. In future, since most of landslides are rainfall-triggered, an increase of their recurrence is expected in some areas because of the variation in the hydrological cycles and the increased frequency of extreme weather events. Moreover, the urbanization of steep and unstable slopes exposes more people and more assets to the negative impacts of landslide events.

Landslide hazard and risk assessment, which are fundamental tools in the management of natural hazards, are a main subject of research since a long time. Several factors influence the choice of the methodological approach, such as: the purpose of the assessment, the landslide triggering factors, the types of elements at risk, the kind of involved mass movements, the available data and those to be collected, the scale of the study (i.e. individual, local, regional, national or global), and the available time. According to these factors, literature provides us many approaches to assess landslide hazard and risk. Whatever the method is, the key basis to start the analysis is a reliable landslide inventory, i.e. a detailed record of spatial and time characteristics of past landslides within a territory. Collecting data about past landslide occurrences may constitute a tedious procedure, inasmuch mass movements are generally isolated and

localised events, which need to be mapped and described individually because of their diverse attributes.

Most of the analyses aiming at assessing the landslide hazard and risk are limited to the spatial probability of occurrence. As the matter of fact, they do not include the assessment of the temporal probability of landsliding. The difficulty in determining the frequency of landslide events is mainly due to the lack of information about the date of occurrence within landslide databases. Thus, adding the temporal dimension to the hazard module results challenging.

In the light of the above, this work aims at improving the current procedures concerning hazard and risk analysis by dealing with the landslide risk assessment of a hazard-prone area located in southern Italy (Daunia area, Apulia region).

What clearly emerges from the overview about the current procedure to assess landslide hazard and risk within the study area is that there are many procedures for the assessment of landslide hazard and risk in many areas of the study area, inasmuch different Basin Authorities were competent. Nowadays, although they have been grouped from the administrative point of view in the District Basin Authority of the Southern Apennines, the landslide hazard and risk procedures have not been standardised yet. Therefore, an attempt has been made to develop a methodological approach to hazard and risk assessment, which was univocal for the same territory and took into account the spatial and temporal probability of landslide phenomena.

The spatial probability assessment derives from a susceptibility assessment. It consists in a procedure that involves predisposing and triggering factors, which cause landslides. Regarding the temporal aspect, after counting the number of landslide events occurred within slope units, it has been quantified by applying a Poisson probability model. Since the available databases have scarce information about the temporal occurrence of landslide events, a new multi-temporal landslide inventory was necessary. The new inventory has been obtained by the analysis of paper documents collected by the Apulian administrative *Difesa del Suolo* office (namely, Soil Defence), which is in charge of planning structural mitigation interventions in the field of soil protection. From the analysis of the paper documents associated to the study area (the southern part of

the Daunia area), 493 landslide events have been counted in the period 1998-2018. These events have complete information about spatial and temporal aspects, and thus they were useful to carry out the temporal probability assessment.

The following landslide risk analysis consists in the combination of the spatial and temporal probability of landsliding, the areal extent of the elements at risk and their economic values. The outputs of landslide risk analysis result in economic values associated to each municipality located in the study area. Moreover, the risk value in monetary terms has been assessed for each slope unit within the municipality in the study area. The comparison between the economic values permits to rank the areas most-at-risk from an economic point of view. Moreover, the estimated economic risk per each municipality has been normalised by the corresponding areal extent, in order to avoid its influence on the risk assessment.

After that, the results of risk assessment have been compared with the funds that concern mitigation measures. The results of such comparison could be used as a tool in the management of landslide risk at regional scale, guiding the choices of decision makers involved in the financing of mitigation measures.

KEY-WORDS: Natural hazard, Landslide, Risk analysis, Temporal probability, Daunia area

EXTENDED ABSTRACT (ITA)

Negli ultimi decenni, si è registrato un continuo aumento sia del numero di disastri causati da fenomeni naturali, sia delle conseguenti perdite economiche. La gestione del rischio dovuta all'occorrenza spazio-temporale di fenomeni naturali è alquanto impegnativa in quanto si prevede che le loro conseguenze si aggraveranno a causa dell'effetto del cambiamento climatico, così come a causa della complessa interazione tra fattori ambientali e fattori umani.

La crescente consapevolezza della comunità internazionale in merito al tema del *disaster risk reduction* è rimarcata dalla ratifica di accordi internazionali, linee guida e la definizione di obiettivi a diversa scala (locale, nazionale e globale). Nonostante ciò, i fenomeni naturali, in particolare quelli lenti e quelli caratterizzati da un'elevata frequenza e una bassa magnitudo, continuano ad avere un impatto significativo sulle comunità e sui beni, minando gli sforzi per raggiungere uno sviluppo sostenibile.

Questo lavoro di ricerca si focalizza sui fenomeni franosi, i quali sono tra i fenomeni calamitosi più frequenti e costituiscono una seria minaccia per l'uomo e l'ambiente. Poiché la maggior parte dei processi franosi è indotta da precipitazioni, in futuro si prevede un aumento della loro ricorrenza dovuta alla variazione dei cicli idrologici e dell'aumento della frequenza di eventi meteorologici estremi. Inoltre, l'urbanizzazione di pendii ripidi ed instabili espone sempre più persone ed i loro beni agli impatti negativi delle frane.

La valutazione della pericolosità e del rischio da frane, i quali rappresentano strumenti fondamentali nella gestione dei fenomeni naturali, sono da tempo oggetto di ricerca. Diversi fattori influenzano la scelta dell'approccio metodologico, tra cui l'obiettivo della valutazione, i fattori scatenanti, i tipi di elementi a rischio, i tipi di movimenti, i dati disponibili e quelli da raccogliere, la scala dello studio (individuale, locale, regionale, nazionale o globale) e il tempo disponibile. A seconda di quali fattori si considerano, in letteratura sono presenti molteplici approcci al fine di valutare il pericolo e il rischio dovuto all'occorrenza di fenomeni franosi. Indipendentemente dal metodo utilizzato, il dato fondamentale per approcciarsi all'analisi del rischio da frana è un inventario delle frane occorse affidabile, ovvero un registro dettagliato delle caratteristiche spaziali e

temporali delle frane avvenute all'interno del territorio investigato. La raccolta di dati sugli eventi franosi trascorsi può costituire una procedura tediosa, in quanto i movimenti di massa sono generalmente eventi isolati e localizzati, che necessitano di essere mappati e descritti individualmente.
La maggior parte delle analisi volte a valutare la pericolosità da frana, che costituisce una delle componenti del rischio, sono limitate alla sola probabilità spaziale di accadimento dei fenomeni franosi, escludendo dalla valutazione della pericolosità la probabilità temporale, ovvero la frequenza dei fenomeni franosi. Di fatto, la difficoltà nel determinare la frequenza di tali eventi è dovuta principalmente alla mancanza di informazioni all'interno delle banche dati di frane sulla data di accadimento dei singoli eventi. Pertanto, aggiungere la componente temporale al modulo di pericolosità risulta alquanto difficile.
Alla luce di quanto evidenziato, questo lavoro mira a migliorare le attuali procedure trattando la valutazione del rischio da frana di un'area prona a questo tipo di calamità, situata in Italia meridionale (area della Daunia, regione Puglia). Per diverse parti del territorio in esame, è stato possibile constatare che esistono molteplici procedure di valutazione della pericolosità e del rischio da frana, in quanto diverse erano le competenti Autorità di Bacino, ad oggi raggruppate nell'Autorità di Bacino Distrettuale dell'Appennino Meridionale. Di fatto, seppur ci sia stato un raggruppamento dal punto di vista amministrativo, ad oggi il calcolo della pericolosità e del rischio non risulta essere stato uniformato. Si è cercato, dunque, di sviluppare una metodologia del calcolo del rischio che fosse univoca per uno stesso territorio, e che tenesse in considerazione la probabilità spaziale e temporale di accadimento di fenomeni franosi.
Nell'ambito di questo lavoro di tesi, il calcolo della probabilità spaziale è stato effettuato attraverso la valutazione della suscettibilità del territorio al franamento. Al fine di procedere al succitato calcolo, si è attuata una procedura che considera molteplici fattori che predispongono e scatenano i meccanismi franosi. Per quanto riguarda il calcolo della probabilità temporale, esso è stato quantificato applicando un modello di probabilità di Poisson, che partisse dal conteggio degli eventi franosi verificatisi all'interno delle unità territoriali (versanti). Per il territorio in esame, poiché le banche dati a disposizione

presentavano scarse informazioni sull'occorrenza temporale degli eventi di frana, si è resa necessaria la costruzione di un nuovo inventario multi-temporale delle frane. Il nuovo inventario è stato ottenuto dall'analisi dei documenti cartacei raccolti dall'ufficio amministrativo pugliese "Difesa del Suolo", il quale è coinvolto nella pianificazione degli interventi strutturali di mitigazione del rischio nel campo della difesa del suolo. Dall'analisi dei documenti cartacei relativi all'area di studio (la parte meridionale della Daunia), sono stati censiti 493 eventi franosi occorsi nel periodo 1998-2018. Gli eventi registrati avevano informazioni adeguate dal punto di vista spaziale e temporale; dunque, essi sono risultati utili al fine di effettuare il calcolo della probabilità temporale.
Dopodiché, combinando il risultato del calcolo delle probabilità spaziale e temporale, dell'estensione areale degli elementi a rischio e dei rispettivi valori economici, è stato possibile ottenere un valore economico di rischio da frana associato a ciascun comune situato all'interno dell'area di studio. Inoltre, il valore di rischio è stato valutato in termini economici per ogni unità territoriale (versante) all'interno dei singoli comuni nell'area di studio. Confrontando i valori economici, è stato possibile classificare le aree più a rischio dal punto di vista economico. Infine, il rischio economico stimato per i singoli comuni è stato normalizzato rispetto alla corrispondente estensione areale, al fine di ridurre l'influenza dell'estensione spaziale dei comini nel calcolo del rischio.
Il risultato della valutazione economica del rischio sono stati confrontati con i fondi delle misure di mitigazione strutturali messi distribuiti nei comuni del territorio in esame. Tale confronto potrebbe essere uno strumento utile di gestione del rischio da frana su scala regionale, guidando le scelte dei decisori coinvolti nel finanziamento delle misure di mitigazione.

PAROLE CHIAVE: Fenomeni naturali, Frane, Analisi del rischio, Probabilità temporale, Daunia

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1. INTRODUCTION

During the last decades, both the number of disasters caused by natural hazards and the consequent economic losses continuously increased. This worrying trend highlights the need to deal with them, aiming at reducing their potential impacts.

Natural hazards can adversely affect the life of communities and their assets. Managing the risk posed by natural hazard in challenging. Nowadays, the consequences of natural hazards are expected to be worsen because of the effect of climate change, as well as the interaction between natural hazards and environmental and human drivers, which make risk more complex to manage.

The increased awareness of international community about disaster risk reduction is remarked by the ratification of international agreements, guidelines and global targets from local to global scales. However, despite this increased public and institutional awareness, natural hazards, in particular the recurring small-scale and slow-onset ones, have continued to significantly impact communities and their assets, undermining the efforts to achieve a sustainable development.

The present research work deals with the landslide hazard, which is one of the most frequent natural phenomena and a major threat to human safety and the environment. In future, since most of landslides are rainfall-triggered, an increase of their activity is expected in some areas because of variation in the hydrological cycles and increased frequency of extreme weather events. Moreover, the urbanization of steep and unstable slopes has increased worldwide the number of people exposed to landslides.

The assessment of landslide hazard and risk, which is a fundamental tool in the management of natural hazards, is from long time the subject of research. Several factors influence the choice of the methodological approach, such as the purpose of the assessment, the landslide triggering factors, the elements at risk, the types of involved mass movements, the available data and those to be collected, the scale of the study (such as individual, local, regional, national or global), and the available time.

Literature provides many approaches to assess landslide hazard and risk. Whatever the method is, the key basis to start the analysis is a reliable landslide inventory, i.e. a

detailed record of spatial and time characteristics of past landslides within a territory. Collecting data about past landslide occurrences may constitute a tedious procedure, inasmuch mass movements are generally isolated and localised events, which need to be mapped and described individually because of their diverse attributes.
The difficulties in collecting landslide data might affect the model approach and the assumptions to assess risk. It is often estimated by the product of two terms:

- spatial and temporal probability related to the occurrence of hazardous phenomena of a given magnitude;
- the consequences, which represent the sum of the product between physical vulnerability and the amount (or cost) of each element at risk.

Most of the analyses aiming at defining the landslide risk are limited to spatial probability of occurrence, not including temporal probability of landsliding. Adding the temporal dimension to the hazard module is however challenging because of the lack of temporal information in current databases.
In the light of the above limits about current inventories and methodological approaches, this work aims at improving the current procedures concerning hazard and risk analysis by dealing with the landslide risk assessment at regional scale of a hazard-prone area located in southern Italy (Daunia area, Apulia region). Thus, it attempts to develop a procedure that considers spatial and temporal aspects in the hazard assessment, as well as assesses the landslide risk of exposed assets in monetary terms. The outputs of landslide risk analysis result in economic values associated to each municipality located in the study area. After that, the results of risk assessment have been compared with the funds that concern mitigation measures. The results of such comparison could be used as tool in the management of landslide risk at regional scale, guiding the choices of decision makers involved in funding mitigation interventions.
After a general overview about natural hazards and risk fields, chapter 2 deals with an overall description of hazard management components and its cycling phases. Moreover, chapter 2 deals with a frame of the cost of natural hazards worldwide and the main International Frameworks, Targets and Guidelines in the field of Disaster Risk Reduction and Sustainable Development.

Chapter 3 is about basics on landslides descriptions of their causes and consequences and methods and data to assess landslide hazard and risk. In particular, the focus is on the harmfulness of landslides in Italy, that is the most impacted country among the European ones. Finally, an analysis of the Italian legislation concerning landslide hazard and risk assessment, as well as mitigation measures has been done. Chapter 4 frames the case study, located in the southern Italy (the Daunia area, Apulia region), that is one of the main Italian areas recurrently impacted by landslide phenomena. After describing the predisposing and triggering factors concerning mass movements, this section discusses the existing landslide inventories and related methodological approaches and their limitations.

Chapter 5 deals with the development of a new landslide inventory able to overcome current limits about input data. This allows implementing a procedure to assess temporal probability, as well as an analysis towards the evaluation of landslide risk at regional scale.

Chapter 6 is about the results of analysis. Finally, along with the future steps of the research, Chapter 7 deals with strengths and weaknesses of the new landslide inventory and the implemented method of risk analysis.

2. THE RISK POSED BY NATURAL HAZARDS ON SOCIETY

2.1 Main definitions and costs of natural hazards

Natural hazards can adversely affect the life of communities and their assets. According to the United Nation Office for Disaster Risk Reduction (UNISDR), natural hazards are defined as “natural processes or phenomena that have the potential to bring about loss of lives, injuries or other health impacts, property damages, livelihood and service losses, social and economic disruptions, or environmental damages” (UNISDR 2009, p. 20). According to their characteristics, several classifications of natural hazards are available. Table 1 shows the six families of natural hazards defined by the Centre for Research on the Epidemiology of Disasters (CRED), that are geophysical, hydrological, meteorological, climatological, biological and extraterrestrial.

Table 1 - Hazard-based classification of natural disasters according to the Centre for Research on the Epidemiology of Disasters.

NATURAL DISASTERS		
BIOLOGICAL	CLIMATOLOGICAL	EXTRATERRESTRIAL
• Animal incident • Disease • Insect infestation	• Drought • Glacial Lake Outburst • Wildfire	• Impact • Space weather
GEOPHYSICAL	HYDROLOGICAL	METEOROLOGICAL
• Earthquake • Mass Movement • Volcanic Activity	• Flood • Landslide • Wave Action	• Convective storm • Extratropical storm • Extreme temperature • Fog • Tropical Cyclone

Over the period 1900-2018, both number of disasters caused by natural hazards and consequent economic losses have been increasing. Approximately 30 million people have lost their lives as a result of disasters, which caused $3.43 trillion of economic losses (Fig. 1).

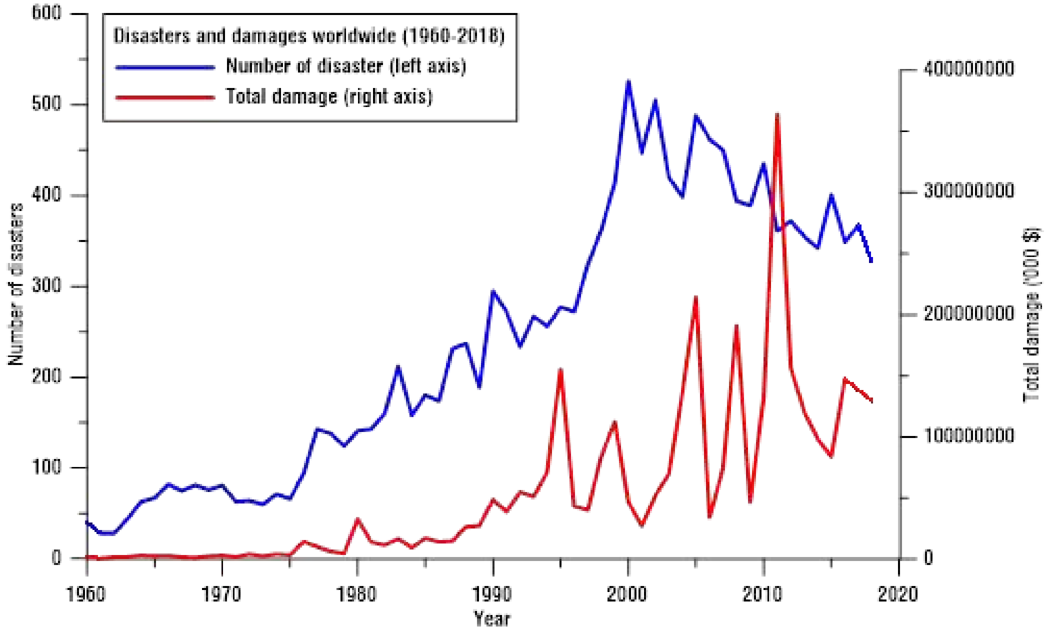


Fig. 1 - Number of natural disasters worldwide (1960-2016) and total economic damages ('000 $) (Source: EM-DAT of CRED - 2019).

Because of the uncertainty related to their potential occurrence, hazards are expressed as a probability of occurrence to something adverse with a given magnitude in a specified period of time (Crozier and Glade, 2012). Therefore, "hazard" has two acceptations: it represents the physical processes that is potentially damaging, and the threatening state indicated by the likelihood of occurrence.

If a natural hazard occurs, risk identifies the potential that negative consequences might happen (Paron and Di Baldassarre, 2014). Risk is a human-centred concept, which is applied when human beings and their property could be adversely affected in the foreseeable future (Lee and Jones, 2004). There are many definitions of risk that, in some way, converge towards a common perspective. Alexander (2000, p. 17) defined risk as "the likelihood, or more formally the probability, that a particular level of loss will be sustained by a given series of elements as a result of a given level of hazard impact". Similarly, according to the UNISDR, risk is defined as "the combination of the probability of an event and its negative consequences" (UNISDR 2009, p. 25). Often, it is quantified through the following conceptual equation (Alexander, 2000; Crozier and Glade, 2012; Kron, 2015; Pescaroli et al., 2014):

$$\mathbf{R = H \times V \times E} \quad \text{Equation 1}$$

where:

- *Hazard* [**H**] corresponds to the probability of occurrence to something adverse with a given magnitude in a specified period of time (Crozier and Glade, 2012);
- *Vulnerability* [**V**] is "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" (UNISDR 2009, p. 30) or "the propensity or predisposition to be adversely affected" (IPCC 2012, p. 5);
- *Elements at risk* [**E**] are defined as "the people, buildings and structures, infrastructure, economic activities, and services exposed to hazards" (Alexander, 2002, p. 309)

Exposure is defined as the spatial overlay of hazard and elements at risk, and represents "people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses" (UNISDR 2009, p. 15) or "the presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected" (IPCC 2012, p. 5).

The Equation 1 identifies separately the principal factors that contribute to risk, that are the probability of occurrence of a damaging event of a given magnitude (hazard), the valued attributes at risk (elements at risk) and the amount of damage expected from the specified event of a given magnitude (vulnerability) (Fig. 2).

Calculation of risk by multiplication means that the risk will be zero if one or more of the factors (hazard, vulnerability or elements at risk) is equal to zero. Fig. 3 shows the interdependences among the drivers of risk. If a natural hazard occurs in an unpopulated area, the risk is zero (a). If the same hazardous event happens in a well-prepared region with low vulnerability, risk is low (b). Alternately, risk is high if a natural hazard harms people and/or their possessions in a region with high vulnerability (c).

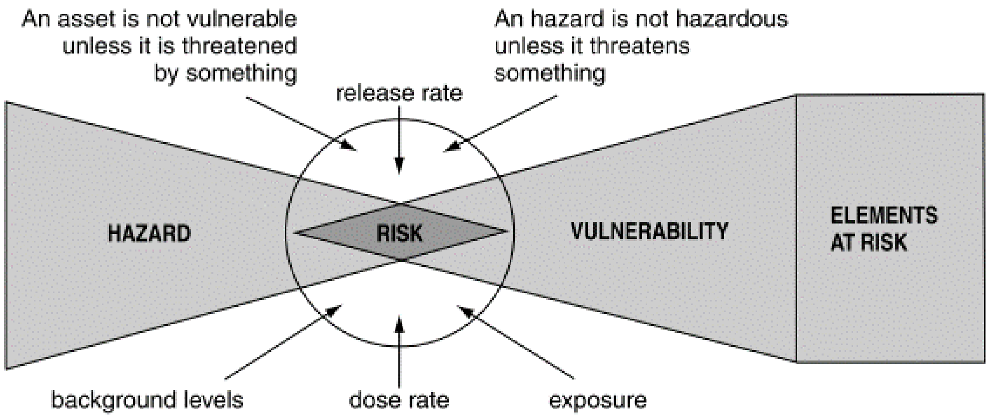


Fig. 2 - Conceptual relationship between hazard, element at risk and vulnerability (from Alexander 2002).

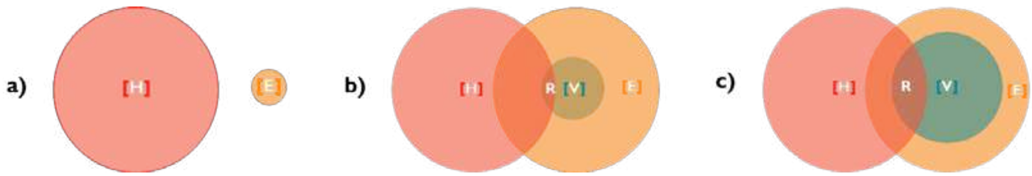


Fig. 3 - Dependency of Risk [R] on the variables Hazard [H], Element at risk [E] and Vulnerability [V] (adapted from Kron 2015).

Despite the risk is zero because natural hazards hit unpopulated areas, the estimation of the hazard, independent of existing human constructs, can help to guide future development decisions inasmuch hazard represents those processes, situations or actions that can cause potential damages, losses or other adverse effects to impacted elements (Crozier and Glade, 2012).

The consequences following the impacts of a generic hazard depend on the context in which they occur. They can be defined as a disaster, that is "a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" (UNISDR 2009, p. 9). Disasters are also defined as "severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery" (IPCC 2012, p. 5).

Nowadays, the consequences of natural hazards are expected to be worsen because of the effect of climatic changes (and consequent raising of extreme events), inappropriate land use, rapid and uncontrolled urbanization and environmental degradation (Alexander, 2000; IPCC, 2012a; Nones and Pescaroli, 2016a). Moreover, the interaction between natural hazards, and environmental and human drivers can make risk more complex, causing compound, interactive, interconnected and cascading risk and disasters (Pescaroli and Alexander, 2018) (Fig. 4).

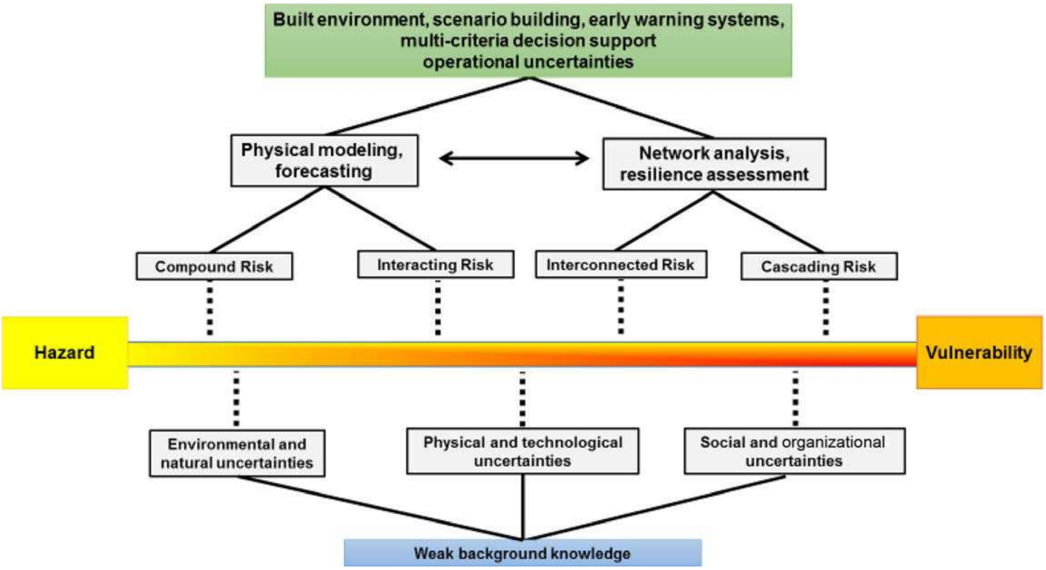


Fig. 4 - Overview of the relations of compound, interacting, interconnected, and cascading risk with hazard and vulnerability, uncertainties, and analytical tools (from Pescaroli and Alexander, 2018).

A combination of compounding drivers or events (compound risk) that happen at the same time (like floods in saturated soil, heat waves on wildfires) can lead to a potential worsening of the consequences of a hazardous phenomenon. Moreover, a natural hazard can, in turn, generate interacting hazards, that are events causally related to the triggering phenomenon (such as an earthquake that triggers a tsunami, storms that cause floods and landslides). The negative impact of natural hazards on society can be adversely exacerbated by the complex and strong interactions between human, environment, and technological systems. A natural hazard can provoke interconnected risk, due to physical interdependencies that allows societal interactions (i.e. a hazardous phenomenon that cuts off an electric grid). The impact of natural hazards on critical infrastructures, which represent vital elements to the preservation of social functions (Pescaroli and Alexander, 2016), cause a wide range of nonlinear secondary effects, generating cascading risk and disasters. Unexpected and cascading effects amplify the consequences related to the triggering hazardous event (Helbing, 2013; Nones and Pescaroli, 2016b; Pescaroli and Alexander, 2015). As the matter of fact, cascading effects are the dynamics that characterize disasters, during which primary phenomena can trigger a chain of effects that can, in turn, cause secondary consequences amplifying the magnitude of primary phenomena (Pescaroli and Alexander, 2015). By definition, cascading effects are non-linear, complex, and multidimensional and they can evolve constantly over time. In case of disasters, the impact of physical events or the development of a principal technological or human failure generate an escalation of secondary effects in other human or non-human systems that result in physical, social, or economic disruption. This escalation is more problematic than primary calamities because of their impacts on critical infrastructures, which represent vital elements to the preservation of social functions (Pescaroli and Alexander, 2016).

The potential damages due to the impact of a generic natural hazard can be direct and indirect (Merz et al., 2010; Pellicani et al., 2018). Direct damages are those that occur due to the physical contact of the hazard with humans, property or any other objects, whereas indirect damages are induced by the direct impacts and can occur – in space or time – even outside the hazardous event. Moreover, damages are classified as tangible if the damages can be quantified in monetary values, otherwise they are classified as intangible.

2.2 International Frameworks for Disaster Risk Reduction and Sustainable Development

In the last decades, the increased awareness of international community in disaster risk reduction is remarked by the ratification of international agreements, guidelines and global targets from local to global scales (Fig. 5).

In 1989, the *International Decade for Natural Disaster Reduction* (IDNDR) was launched by the United Nations with the intent to reduce loss of life, damages and social and economic disruption caused by natural disasters through global action, especially in developing countries (General Assembly of United Nation, 1989).

Thereafter, the United Nation General Assembly (UN/GA) organized the first *World Conference on Natural Disaster Reduction* in Yokohama in 1994. The expectation was to guide governments and policy makers to incorporate risk reduction measures into action, expecting to reduce the unacceptable negative effects of hazardous phenomena. From the beginning, it was clear that prevention and mitigation are more effectively than response. According to the UN/GA, progress in social and economic development will be threaten unless disaster risk reduction becomes part of plans and programmes from local to national scales (United Nations, 2005). As the matter of fact, the ten principles of the *Yokohama Strategy and Plan of Action for a Safer World* (IDNDR, 1994) and its strategy highlighted the need of investing in risk assessment, prevention and preparedness, and to "take urgent action to prevent as well as to reduce the effect of such disasters" (Table 2) (IDNDR 1994, p. 9).

The second *World Conference on Disaster Reduction* held in Kobe and Hyogo reviewed the former international guidelines and adopted the *Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters*. The UN/GA outlined objectives and goals with the expectation to reduce disaster losses and to achieve the internationally agreed development goals, including the Millennium Development Goal ratified by the Millennium Declaration (General Assembly of United Nation, 2000; UNISDR, 2005).

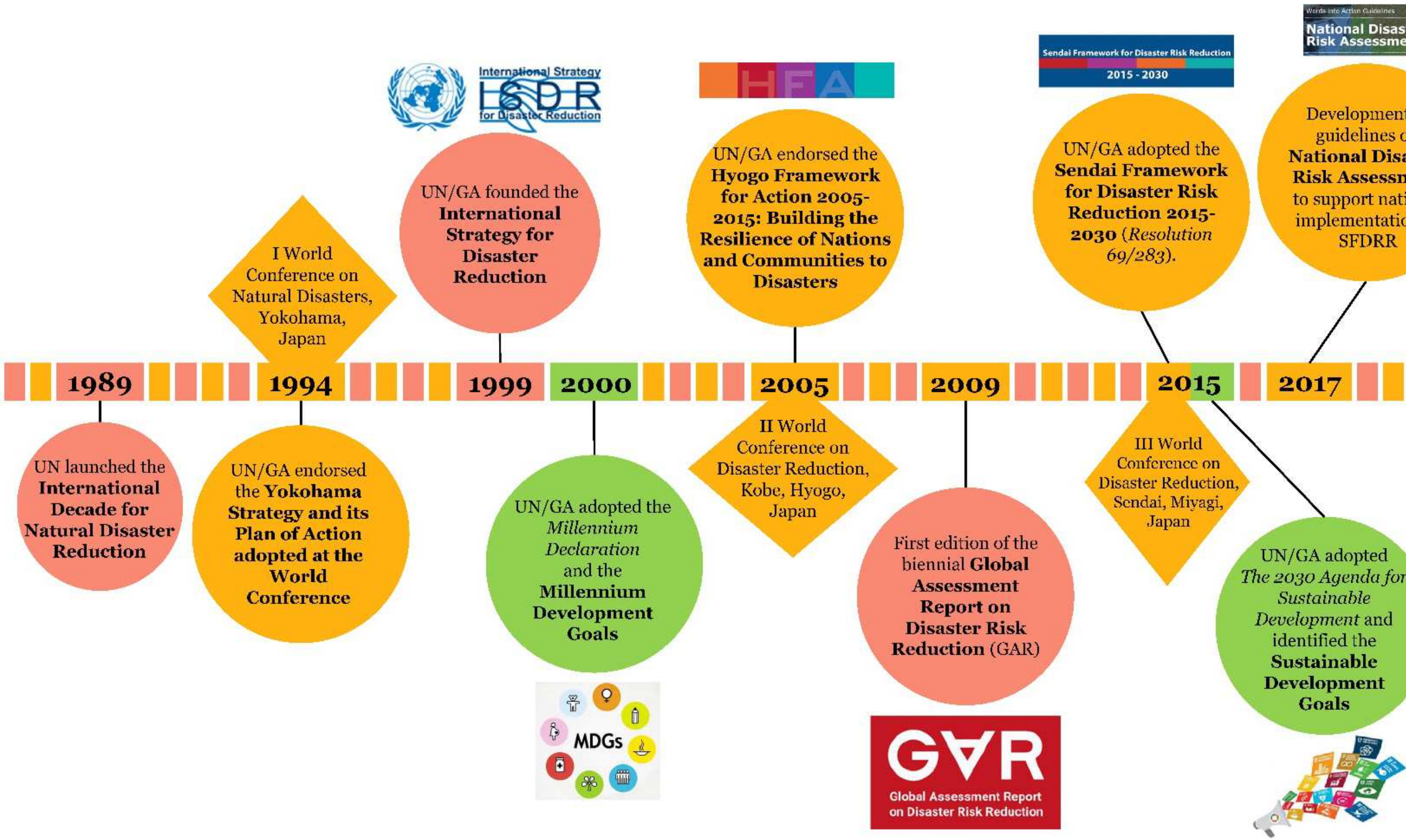


Fig. 5 - Thirty years of international commitments to disaster risk reduction (adapted from Aitsi-Selmi et al. 2015).

Table 2 - The ten principles of the Yokohama Strategy (IDNDR, 1994).

(1)	Risk assessment is a required step for the adoption of adequate and successful disaster reduction policies and measures.
(2)	Disaster prevention and preparedness are of primary importance in reducing the need for disaster relief.
(3)	Disaster prevention and preparedness should be considered integral aspects of development policy and planning at national, regional, bilateral, multilateral and international levels.
(4)	The development and strengthening of capacities to prevent, reduce and mitigate disasters is a top priority area to be addressed during the Decade so as to provide a strong basis for follow-up activities to the Decade.
(5)	Early warnings of impending disasters and their effective dissemination using telecommunications, including broadcast services, are key factors to successful disaster prevention and preparedness.
(6)	Preventive measures are most effective when they involve participation at all levels, from the local community through the national government to the regional and international level.
(7)	Vulnerability can be reduced by the application of proper design and patterns of development focused on target groups, by appropriate education and training of the whole community.
(8)	The international community accepts the need to share the necessary technology to prevent, reduce and mitigate disaster; this should be made freely available and in a timely manner as an integral part of technical cooperation.
(9)	Environmental protection as a component of sustainable development consistent with poverty alleviation is imperative in the prevention and mitigation of natural disasters.
(10)	Each country bears the primary responsibility for protecting its people, infrastructure, and other national assets from the impact of natural disasters. The international community should demonstrate strong political determination required to mobilize adequate and make efficient use of existing resources, including financial, scientific and technological means, in the field of natural disaster reduction, bearing in mind the needs of the developing countries, particularly the least developed countries.

Since the adoption of the Yokohama guidelines in 1994 and the Hyogo Framework for Action in 2005, most progress has occurred in disaster risk reduction from local to global scale. However, despite the raise of public and institutional awareness, natural hazards, in particular recurring small-scale and slow-onset ones, have continued to significantly impact communities and their assets, undermining efforts to achieve sustainable development. The growing concern of the international community derives from the awareness of the increased exposure of people and their assets, the raise of magnitude, frequency and complexity of hazardous phenomena exacerbated by climate change, and the evidence of the steady rise of losses (visible and hidden) and economic, social, health, cultural and environmental impacts in the short, medium and long term. Moreover, over the period 2005-2015 natural disasters have been a death tool of 840 thousand people, whereas the economic losses were more than $1.5 trillion. If compared with the previous decade (1994-2004), notwithstanding a slight increase in the number of calamities (4.200 vs 4.449 events), it was registered an increase of the number of loss of lives (+19.75%) and of the total economic damages (+44.69%) (data source: EM-DAT - CRED).

Table 3 - Priorities and Global Targets of the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015).

PRIORITIES	GLOBAL TARGETS
(1) Understanding disaster risk	**(a)** Substantially reduce global disaster mortality by 2030, aiming to lower the average per 100,000 global mortality rate in the decade 2020-2030 compared to the period 2005-2015. **(b)** Substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 in the decade 2020-2030 compared to the period 2005-2015.
(2) Strengthening disaster risk governance to manage disaster risk	**(c)** Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030 **(d)** Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030
(3) Investing in disaster risk reduction for resilience	**(e)** Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020. **(f)** Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of the present Framework by 2030
(4) Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction	**(g)** Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030

In the light of the above, in 2015 two international frameworks, which contain several major agreements underlining the importance of preventing risks due to potential hazardous phenomena, were adopted. The *Sendai Framework for Disaster Risk Reduction* (SFDRR), which is the successor instrument to the Hyogo Framework for Action, endorses *four priorities for action* to achieve *seven global targets* (Table 3) in the period 2015-2030. Both priorities and targets aim at reducing existing and preventing new disaster risk, and more effectively protecting people, assets and ecosystems. SFDRR was followed by the *2030 Agenda for Sustainable Development*, which identifies 17 *Sustainable Development Goals* (SDGs) to achieve sustainable development by 2030. Measures aimed at disaster risk to reduction are considered essential to achieve these goals.

2.2.1 Understanding disaster risk and general guidelines to risk assessment

In addition to the international frameworks already described, during last decades UN have disseminated several documents designed to multiple purposes, such as supporting governments to implement the SFDRR, better understanding disasters and their dynamics and designing risk assessment related to single or multiple hazardous phenomena (Fig. 6).

The guideline *National Disaster Risk Assessment* (NDRA) defines three stages and ten elements towards an effective risk assessment (Table 4), in order to ensure that measures and investments are based on the understanding of disaster risk in all its dimensions, such as hazard characteristic, vulnerability, exposure of persons and assets (UNISDR, 2017a). In accordance with the first *priority for action* of SFDRR (understanding disaster risk), NDRA outlines a set of recommendations for effectively reducing risk, aiming at making risk information available to people.

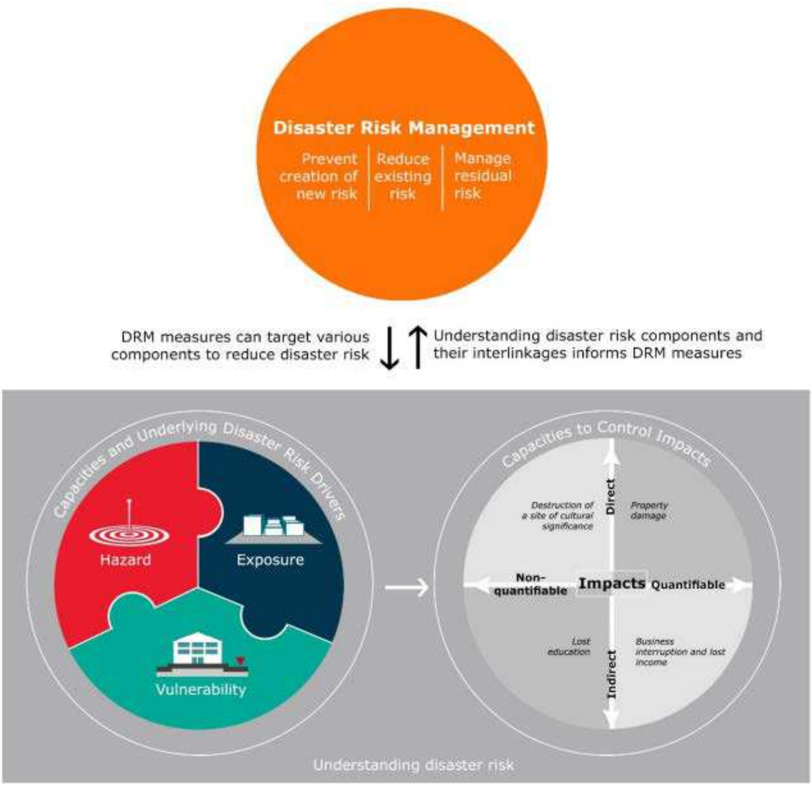


Fig. 6 - Holistic understanding of disaster risk towards an effective and comprehensive disaster risk management (from UNISDR 2017b).

Table 4 - The three stages and ten elements of the risk assessment process proposed by the guideline *National Disaster Risk Assessment* by United Nation (UNISDR, 2017a).

Elements	**Stage I Preparing and Scoping**
(1) Establishing a governance mechanism	A successful NDRA requires a system of institutions, operational modalities, policies and a legal framework to guide, manage, coordinate and oversee implementation.
(2) Defining the policy scope and technical scope of NDRA	Depending on the complexity, the scale of the area and its risk, the purpose and objectives of the risk assessment for producing relevant and usable information is defined. The study should define the policy and technical scopes and the boundaries set by the available technical, political and financial resources.
(3) Developing an NDRA data management plan	A strategy needs to be developed to efficiently organize and manage the data as they become available, as well as for distributing the results to participants and key stakeholders.
(4) Developing NDRA required capacities	The NDRA process requires strong administrative, technical and financial capacities.
(5) Developing terms of reference for NDRA	An NDRA is a project. Timeline, milestones and deliverables, roles and responsibilities of the stakeholders, as well as the budget should be clearly indicated.

Elements	Stage II Conducting Risk Analysis
(6) Utilizing various risk analysis methodologies	The methods (qualitative, semi-quantitative and/or quantitative) to use depends on the purpose the results should serve, the resources available and the significance of the risk.
(7) Key considerations in conducting risk analysis	(a) identifying and compiling existing input data, (b) assessing disaster risk management capacities and (c) determining the sources and drivers of risk, the direct and indirect impacts and the climate change impact.
(8) Preparing the outputs of risk analysis for communication with stakeholders	Presenting the results in a format that is understandable, relevant and useful to the stakeholders.

Elements	Stage III Using NDRA Results for DRM and Development Decisions
(9) Facilitating the process for evaluation and applying results in DRM decisions	Aware that the outputs of risk assessment are inputs to decision-makers, actions and investments for managing disaster risk, the results and findings are presented to the key stakeholders to ensure the outputs are understandable and are usable for the purpose that was originally defined in the scoping phase.
(10) Ensuring long-term sustainability of NDRA system	In accordance with the first priority for action of SFDRR (understanding disaster risk), it is necessary to produce risk information needed for prevention, mitigation, preparedness, response and recovery, in order to build a resilient future (for example defining NDRA updating time cycle, a financial strategy, site-specific hazard assessment for significant investments).

2.3 Managing the risk posed by natural hazards: the hazard management cycle

The hazard management aims at reducing potential losses consequent the impact of hazardous events, assuring prompt assistance to people involved, and achieving effective recovery (Carter, 2008; Crozier, 2012).

After and before the impact of a generic natural hazard, even if it does not become a so-called disaster, it is possible to identify the following cyclical phases (Fig. 7):

- **Response**, that represents the measures taken following the impact of natural hazard, directed toward saving life and protecting property;
- **Recovery**, that is the process by which communities and the nation are assisted in returning to their proper level of functioning following the occurrence of a hazardous phenomenon;

- **Mitigation**, that implies all the actions taken to reduce damage and loss, and to prevent some future negative effects;
- **Preparation**, that regards comprising measures, which enable governments, organizations, communities, and individuals to respond rapidly and effectively to hazardous situations.

Fig. 7 - The Hazard Management Cycle (adapted from Alexander 2000 and Crozier 2012).

If the occurrence of natural hazards is inevitable within a certain hazard-prone terrain, however the potential negative effects can be prevented or mitigated. In the light of the highlighted complexity related to the impact of natural hazards on society, it can be advantageous to invest in mitigation and prevention measures that can reduce, avoid or transfer the potential negative effects of natural hazards (Crozier, 2012).

For an administration, to justify where and how to spend the financial resources to mitigate the potential consequences of hazardous phenomena is challenging. First of all, it is necessary to define the most at-risk zones through their assessment. Aiming at risk assessment, the employment of models can be useful, inasmuch they can simulate several hazard scenarios to quantify how damaging a single or multiple natural hazard can be. Moreover, they can provide the picture of how events could impact the exposed elements within the hazard-prone areas.

3 LANDSLIDES: BASICS, RISK MANAGEMENT AND LEGISLATIVE FRAMEWORK

3.1 Landslides in Italy

Among European countries, landslide hazard is one of the most frequent natural hazard and a major threat to human safety and the environment, in particular in mountainous and hilly zones (Aleotti and Chowdhury, 1999; Crosta et al., 2005; Van Den Eeckhaut and Hervás, 2012). Landslides are usually connected to other natural hazards, such as extreme precipitation, earthquakes or floods. The compound nature of landslide risk can lead to an underestimation of their impact on society, with consequent reduction of the awareness and concern of both authorities and public about landslide hazard (Van Den Eeckhaut and Hervás, 2012).

Harmful landslide events are frequent in Italy because of its geomorphological and structural characteristics (Fig. 8). Italy is the European country that suffers the greatest human and economic losses due to landslides (SafeLand-Project, 2010a). After earthquakes, landslides are the Italian natural hazards, which cause the highest number of victims (Trigila and Iadanza, 2008). Up to 2017, the national Italian Landslide Inventory (IFFI) counted 620,808 landslides that affected the 7.9% of the national territory (Fig. 9) (Trigila and Iadanza, 2018). From 1279 to 2002, the recorded landslide events were 1,256, causing 10,111 victims. Among them, 1,102 landslide events occurred only in the twentieth century, with an estimated death toll of more than 5,000 (Guzzetti et al., 2005b). According to the periodic report "Polaris", provided by the Research Institute for Geo-Hydrological Protection of the National Research Council (CNR-IRPI), which concerns the impact of floods and landslides on population, during the period 1961-2010 Italian landslides caused 3,309 fatalities, 1,859 injuries and more than 150,000 people were displaced (CNR-IRPI, 2012). The last update highlights that, among the period 2000-2018, landslides caused 209 casualties, 545 injuries and the displacement of around 50,000 people (CNR-IRPI, 2019).

Short period intense rainfall and persistent precipitation are identified, also in Italy, as one of the main trigger of landslides (Fig. 10). Infiltration, soil characteristics, antecedent moisture and rainfall influence the capacity of the ground to be affected by heavy or prolonged precipitations, causing the increase of water pressure and the likelihood of landsliding (SafeLand-Project, 2010a; Trigila and Iadanza, 2018).

Fig. 8 - Italy in the Mediterranean Basin.

Despite disastrous landslides (high impact-low frequency events) are very common in Italy (Catenacci, 1992), the greater part of the economic cost of landslides is essentially due to the *normal-scale* phenomena (low impact-high frequency), which affect the country every year (Sorriso-Valvo, 2005).

In the next decades, the risk related to landslide phenomena is expected to rise because of climatic changes and increase in exposure in many areas of the world. An increase of landslide activity is expected as a consequence of increased rainfall, variation in the hydrological cycles and more extreme weather events (Christensen and Christensen, 2002; IPCC, 2012b). Moreover, the occupation of steep and unstable slopes has worldwide increased the number of people exposed to landslides (Moeyersons et al., 2004). Since landslide is one of the most frequent natural hazards, many researchers have been involved in the assessment of landslide hazard and risk (Lee et al., 2017). These studies can be useful for identifying landslide-prone areas, land use planning, land management, and disaster risk reduction (Pourghasemi et al., 2018).

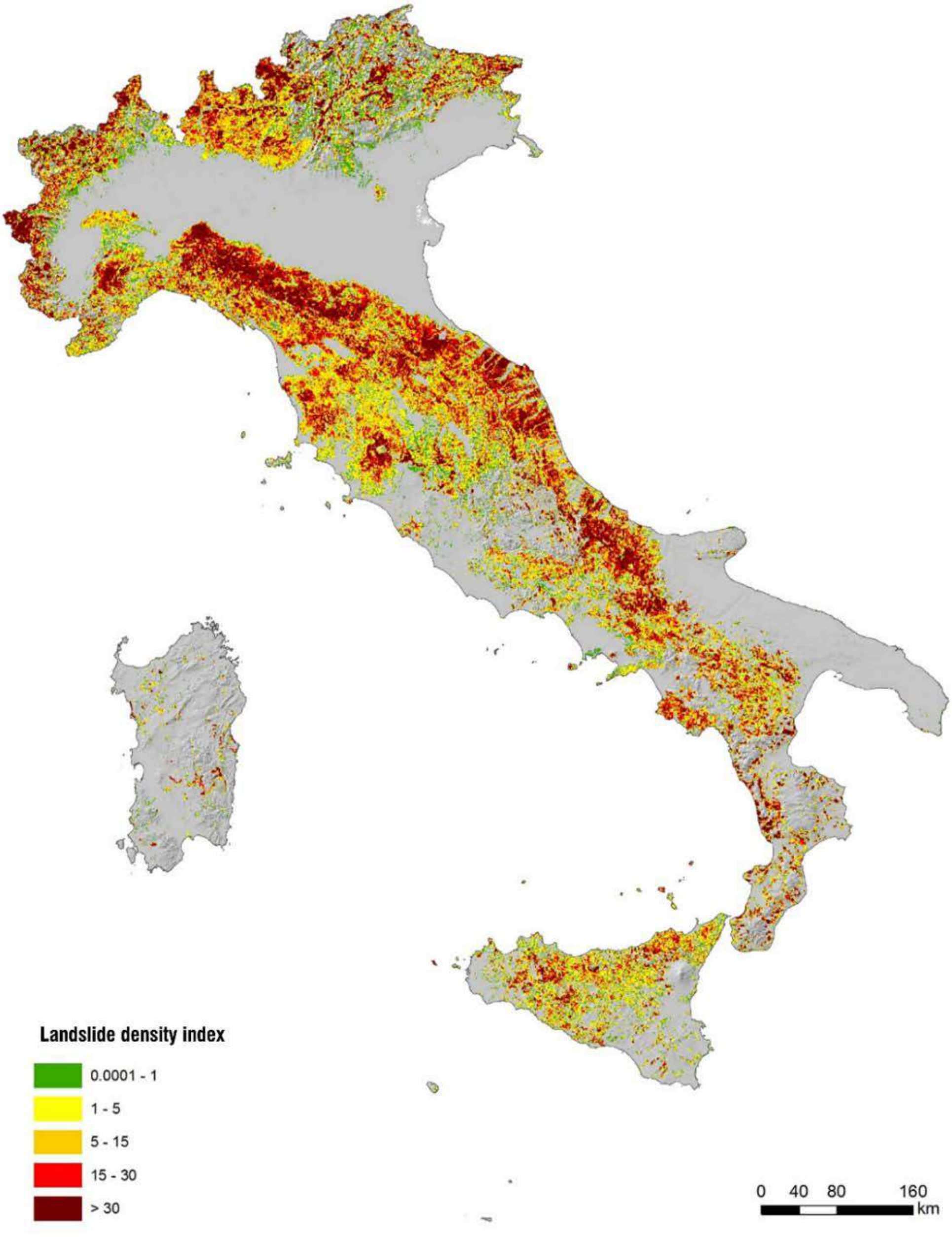


Fig. 9 - Italian landslide density index (Trigila and Iadanza, 2018)

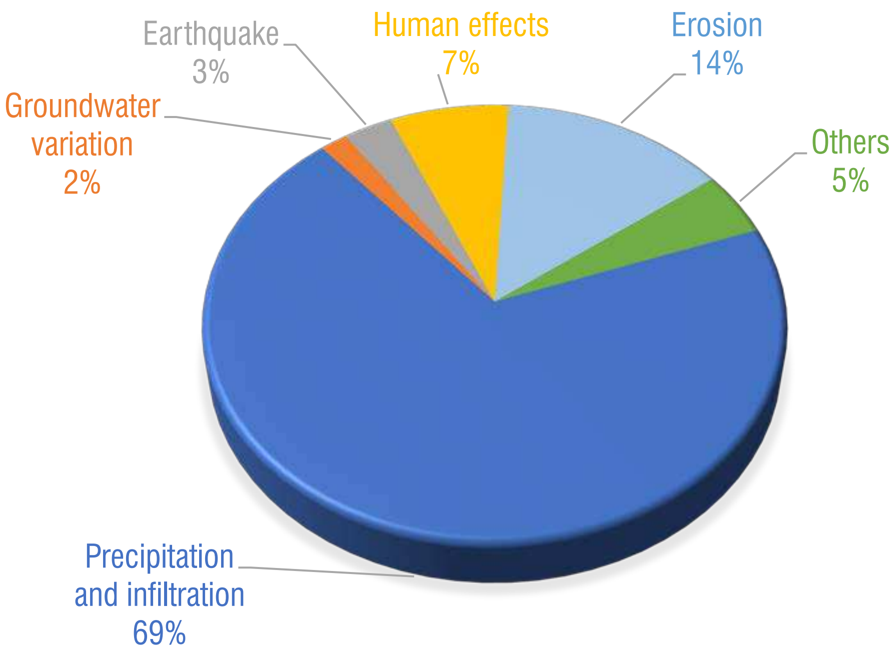


Fig. 10 - Landslide triggers in Italy (Source: AVI inventory).

3.2 Basics about landslides and their classification

The term landslide denotes a wide range of processes that result in the movement of a certain amount of materials (UNISDR, 2017b). A common terminology (Fig. 11) and a proper landslide classification are necessary towards a comprehensive risk management of landslide-prone terrains. Moreover, they are fundamental in the mass movement classification within landslide inventories, that is one of the crucial data of landslide hazard and risk assessment (Fell et al., 2008).

The main aspects describing landslides are geology, type of movement, rates of movement, activity, causes, consequences and the distribution of movement within landslides (WP/WLI, 1993).

Cruden and Varnes (1996) classified landslides according to the involved materials (*rock*, *debris* - soil composed predominantly by coarser fragments -, *earth* - soil composed mainly by fine particles - or a combination of them) and the type of movement, which represents how the mass is displaced (*fall*, *topple*, *slide*, *spread*, *flow* or their combination) (Table 5). Moreover, mass movements can involve anthropic fill and organic materials.

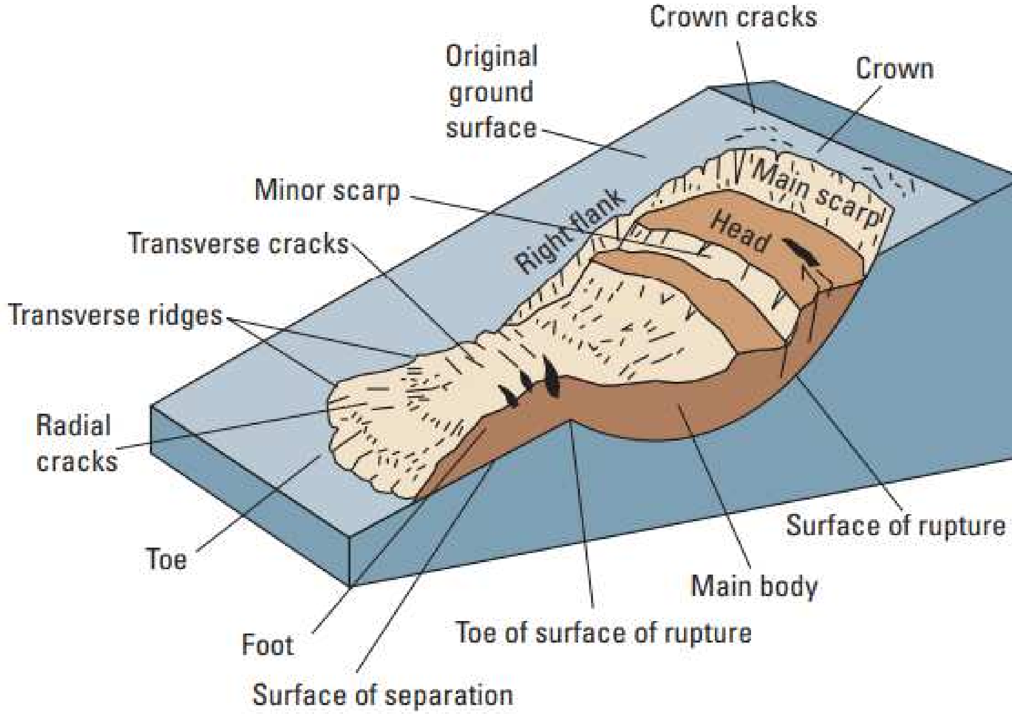


Fig. 11 - Most common nomenclature used to describe the unique parts of a landslide (from Cruden and Varnes 1996).

Landslide velocity (Table 6) and volume influence the destructiveness of landslide phenomena and their potential consequences on impacted elements. They can vary according to the type of movement, the involved material and the depth of moving mass (shallow or deep landslides) (Hungr et al., 2014). Landslide velocity ranges from few millimetres per year to several meters per second, whereas landslide volume ranges from a few cubic meters to millions of cubic meters.

According to the UNESCO Working Party on World Landslide Inventory (WP/WLI), the stage of activity can be described under three headings as described in Table 7 (WP/WLI, 1993).

Table 5 - Description of major type of landslides (Cruden and Varnes, 1996; USGS, 2004; Varnes, 1978)

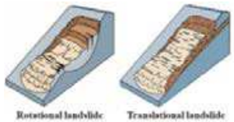
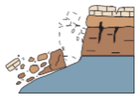
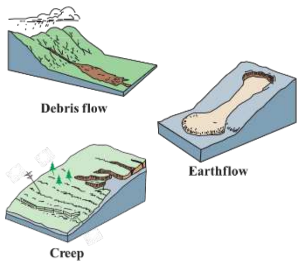
<table>
<tr><th colspan="3">TYPE OF MOVEMENT</th><th>DESCRIPTION</th></tr>
<tr><td colspan="2">**Slides**</td><td></td><td>Mass movements with a zone of weakness that separates the slide material from more stable underlying material. The surface of rupture is curved in rotational landslides, and roughly planar in translational ones.</td></tr>
<tr><td colspan="2">**Falls**</td><td></td><td>Abrupt movements of masses of geologic materials influenced by gravity, mechanical weathering and interstitial water. Separation occurs along discontinuities.</td></tr>
<tr><td colspan="2">**Topple**</td><td></td><td>Rotation of a unit or units about some pivotal point under the actions of gravity and forces exerted by adjacent units or by fluids in cracks.</td></tr>
<tr><td rowspan="5">**Flow**</td><td>**Debris flow**</td><td rowspan="5"></td><td>Rapid mass movement with <50% fines in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope.</td></tr>
<tr><td>**Debris avalanche**</td><td>A variety of very rapid to extremely rapid debris flow.</td></tr>
<tr><td>**Earthflow**</td><td>The slope material liquefies and runs out, forming a depression at the head.</td></tr>
<tr><td>**Mudflow**</td><td>Earthflow consisting of material that is wet enough to flow rapidly and that contains at least 50% sand-, silt-, and clay-sized particles.</td></tr>
<tr><td>**Creep**</td><td>Slow, steady, downward movement of slope-forming soil or rock.</td></tr>
<tr><td colspan="2">**Lateral spread**</td><td></td><td>Lateral extension accompanied by shear or tensile fractures which occurs on very gentle slopes or flat terrain.</td></tr>
<tr><td colspan="3">**Complex**</td><td>Combination of two or more principal types of movement.</td></tr>
</table>

Table 6 - Proposed landslide velocity classes (adapted from Cruden and Varnes, 1996; Lee and Jones, 2004).

Velocity class	Description	Velocity (mm/sec)	Typical velocity	Description
1	Extremely slow			No damage to structures built with precautions.
		$5 * 10^{-7}$	16 mm/year	
2	Very slow			Some permanent structures undamaged, or if they are cracked by the movement, they can be repaired.
		$5 * 10^{-5}$	1.6 m/year	
3	Slow			Roads and insensitive structures can be maintained with frequent and heavy maintenance work, if the movement does not last too long and if differential movements at the margins of the landslide are distributed across a wide zone.
		$5 * 10^{-3}$	13 m/month	
4	Moderate			Insensitive structures can be maintained if they are located a short distance in front of the toe of the displaced mass; structures located on the displaced mass are extensively damaged.
		$5 * 10^{-1}$	1.8 m/hr	
5	Rapid			Escape and evacuation possible; structure, possessions and equipment destroyed by the displaced mass.
		$5 * 10^{1}$	3 m/min	
6	Very rapid			Some lives lost because the landslide velocity is too great to permit all persons to escape; major destruction.
		$5 * 10^{3}$	5 m/sec	
7	Extremely rapid			Catastrophe of major violence; exposed buildings totally destroyed and population killed by impact of displaced material or by disaggregation of the displaced mass.

The state of activity of mass movements, illustrated in Fig. 12 and Fig. 13, can be *active* (currently moving), *reactivated* (again active after being inactive), *suspended* (moved within the last annual cycle of seasons, currently not moving) or *inactive* (moved more than one annual cycle of seasons ago).

Table 7 - A glossary of the activity of landslides (adapted from WP/WLI, 1993; Cooper, 2007).

STATE OF ACTIVITY		DISTRIBUTION OF ACTIVITY	STYLE OF ACTIVITY
A. Active B. Reactivated C. Suspended		i) Retrogressing ii) Advancing iii) Confined iv) Enlarging v) Diminishing vi) Moving	1) Single 2) Composite 3) Multiple 4) Successive 5) Complex
D. Inactive	D1. Dormant D2. Abandoned D3. Stabilised D4. Relict		

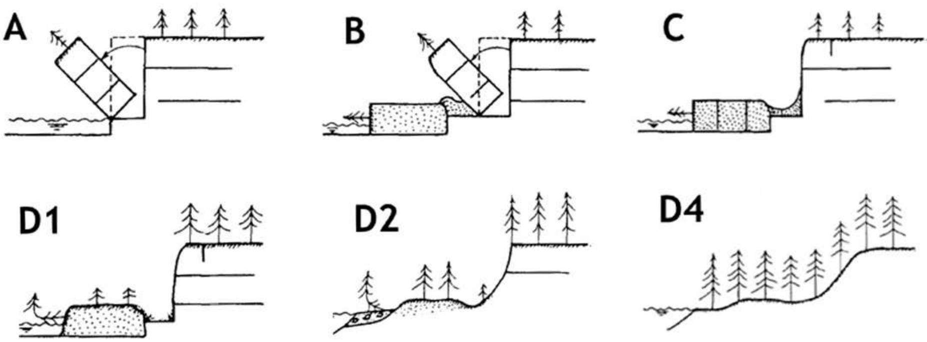


Fig. 12 - Different states of activity in the case of a topple: A) Active, B) Reactivated, C) Suspended, D1) Dormant, D2) Abandoned, D4) Relict (from WP/WLI, 1993).

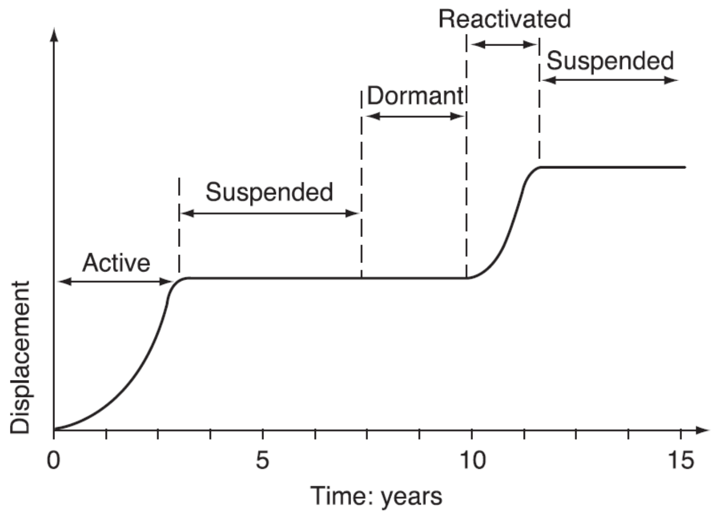


Fig. 13 - Landslide displacement in different states of activity (from Cruden and Varnes, 1996).

In turn, inactive landslides can be subdivided in *dormant* (the causes of movement apparently remain), *abandoned* (natural conditions are changed enhancing landslide stability), *stabilised* (artificial remedial measures have stopped the movement) or *relict* (landslides clearly developed under different geomorphological or climatic conditions). The distribution of activity indicates the direction of mass instability (Cooper, 2007). It is defined *retrogressive* if the rupture surface is extending in the direction opposite to the movement of the displaced material, *advancing* if the rupture surface is extending in the direction of movement, *confined* if there is a scarp but no rupture surface visible at the foot of the displaced mass, *enlarging* if the rupture surface of the landslide is extending in two or more directions, *diminishing* if the volume of displaced material is decreasing and *moving* if the displaced material continues to move without any visible change in the rupture surface and the volume of the displaced material.
The style of activity describes the type of movements (Cooper, 2007). It can be *single* (a single movement of displaced material), c*omposite* (a landslide that exhibits at least two types of movement simultaneously in different parts of the displacing mass), m*ultiple* (mass movement that shows repeated development of the same type of movement), s*uccessive* (the same type as a nearby landslide, but without sharing the displaced material or rupture surface with it) and c*omplex* (two types of movements in sequence).

3.2.1 Causes and consequences of landslides

The elements that affect slope stability are various and they can interact each other in a complex way. On the one hand, there are factors that predispose to landsliding; on the other hand, there are factors that have the potential to trigger mass movements (van Westen et al., 2006; Varnes and IAEG-CLOMMS, 1984). The conditioning (predisposing) factors, such as geology (lithology and structure), slope angle, geomorphology, groundwater condition, land use and vegetation, are those that favour landsliding and influence the type of landslide. The trigger are events that finally initiated landslides (Table 8) (Highland and Bobrowsky, 2008; Varnes and IAEG-CLOMMS, 1984).
The destructiveness of mass movements mainly depends on where they occur (either in natural environment or in built-up areas) and some characteristics, such as their

type, velocity and volume. In the natural environment, they can affect the topography of Earth's surface, the morphology and the quality of waters (in rivers and streams), groundwater flow, and the coverage of forests and grasslands. As an example, mass movements can negatively affect wildlife habitats and the soil productivity, causing, in a cascading and indirect way, economic and social negative effects. Moreover, large amounts of landslide material can also be destructive to aquatic life and the rapid deposition of sediments in water bodies often changes the water quality. However, under certain conditions, landslides can generate benefit on fish and wildlife habitats (Geertsema et al., 2008).

Table 8 - Triggering factors of landslides (from Highland and Bobrowsky 2008).

CAUSES		**DESCRIPTION**
Natural	**Water**	Slope saturation by water of ground mass is a primary cause of landslides. It can occur after heavy or prolonged rainfall, snowmelt, changes in groundwater level. Landslides and floods are closely associated: often debris flows and mudflows are mistaken for floods.
	Seismic activity	Earthquakes greatly increase the likelihood of landslides in hazard prone-areas. Ground shaking, liquefaction of susceptible sediments or shaking-caused dilation of soil materials allow rapid infiltration of water in the ground.
	Volcanic activity	Volcanic debris flows (also known as lahars) pose a serious threat to volcano surrounding. The rapid snow melt consequent to the volcanic eruption can form a surge of rock, soil, ash and water that rapidly accelerates on the steep slopes of volcanoes, reaching great distances and devastating anything in its path.
Anthropic		Cities expansion in hazard prone areas, disturb or change of drainage patterns, slopes destabilization, removal of vegetation, drainage of reservoirs, leakage of pipes, and improper excavation or levelling on slopes are some of the common human-induced factors that can generate landslides

Furthermore, landslides can cause the erosion of coastal cliff (Fig. 14). The occurrence of rock-and-soil falls or topples can be very harmful to people, building and infrastructure at the base of cliffs. The occurrence of landslide within a river can cause water accumulation behind the blockage that may suddenly be released and cause massive flooding downstream (Geertsema et al., 2008).

Fig. 14 - Rocky cliff occurred on the 7th July 2019 along the coastal stretch of Melendugno municipality (Apulia region, Southern Italy) (source: https://www.lagazzettadelmezzogiorno.it).

Looking at the interconnection within the natural environment, landslides are also known to generate other natural hazard, such as earthquakes, floods, tsunamis, and giant waves (Radbruch-Hall and Varnes, 1976).

Most concerns regard landslide effects in build environments, inasmuch they can affect either large basins (where many people and assets locate) or individual slope (where only one structure or part of a structure is affected) (Highland and Bobrowsky, 2008). Among the other built-up areas, landslides can harm human life (Fig. 15), and they can cause partial or complete damages to residential areas (affecting foundations, walls, property, and above-ground and underground utilities), lifelines (such as trunk sewer, water, or electrical lines and common-use roads) and commercial structures (in such a case experiencing an interruption in business) (Highland and Bobrowsky, 2008).

Their fast-moving (i.e. debris flow) or slow-moving (i.e. earthflow) nature can cause over time either sudden or slightly damages to the impacted structures. Moreover, their potential continuous moving precludes the reconstruction within the affected areas, unless mitigating measures are taken. Even then, such efforts are not always a guarantee of stability (Fig. 16).

The transportation industry is the most affected by landslide occurrence, involving large numbers of people around the world. Some example of negative effects of landslide along transportation corridors are cut and fill failures, collapses of roads from underlying weak and slide-prone soils and fill, blockages due to falls (leading to temporary or long-term closing consequent dirt, debris, and/or rocks), and maintenance problems consequent to slow creeps (Fig. 17).

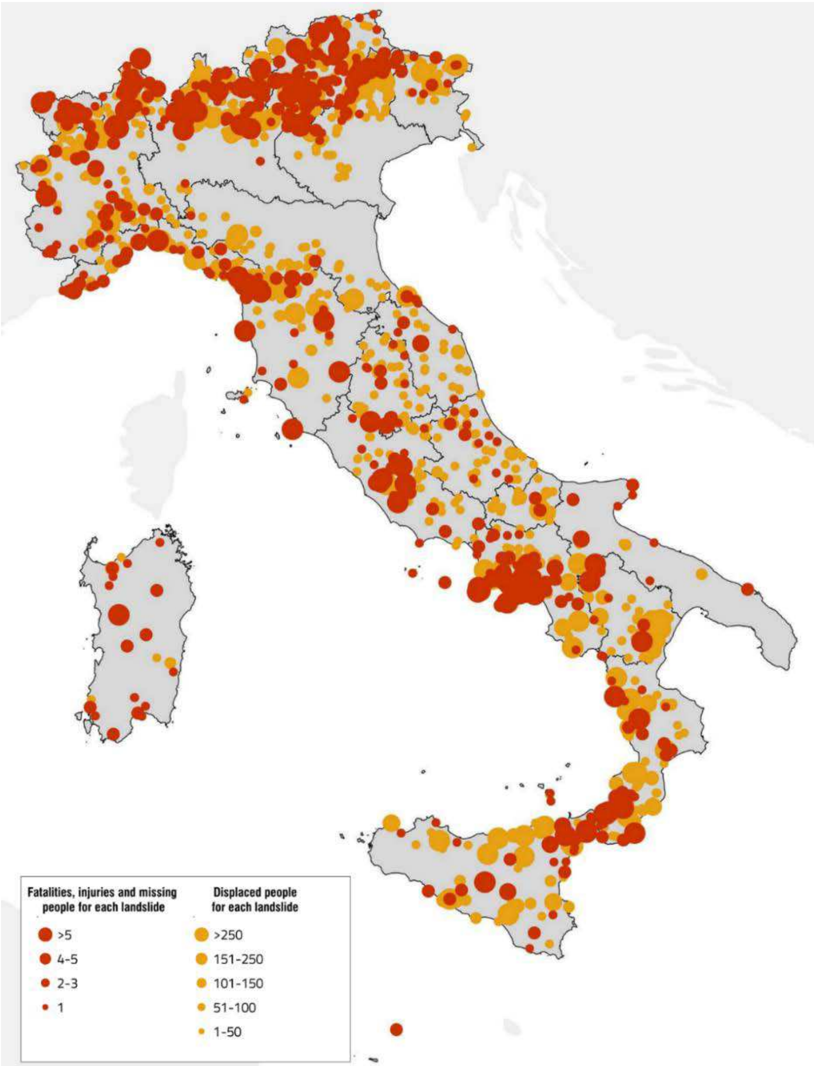


Fig. 15 - Map of the landslide events with fatalities, injuries, missing people and displaced people among the period 1961-2010 (from CNR-IRPI, 2012)

Fig. 16 - The debris avalanche that affected Sarno municipality and surrounding (Campania region, Southern Italy) in May 1998. There were more than 150 causalities; around € 500 million of economic losses were estimated (source: http://www.protezionecivile.gov.it).

Fig. 17 - Earthflow landslide in Montaguto (Campania region, Southern Italy) that, in 2010, affected the national road *SS 90* and the national railroad (source: http://www.irpi.cnr.it).

As the world's population continues to expand, people are increasingly vulnerable to landslide hazards. As the matter of fact, residential areas and human activities tend to move on new lands that might have been deemed too hazardous in the past, but are now the only areas that remain for a growing population.

Poor or non-existent land-use policies allow building and other construction to take place on land that might better be left to other uses (i.e. agriculture, open-space parks). Communities often are not prepared to regulate unsafe building practices and may not have the legitimate political means or the expertise to do so (Fig. 18).

Fig. 18 - The complex landslide of Stigliano municipality (Basilicata region, Southern Italy) that affect buildings and roads within a building expansion area of the ‘80s.

3.3 Landslide data collection and main Italian inventories

Landslide inventories are undoubtedly the main information when dealing with landslide hazard and risk management, considering valid the principle according to which the present and the past are the key to interpreting the future (Fell et al., 2008; Varnes and IAEG-CLOMMS, 1984). Inventories constitute a detailed register of spatial and time characteristics of past landslides within a given area (van Westen et al., 2008). Collecting data about past landslide occurrences may constitute a tedious procedure because mass movements are generally isolated and localised events, which need to be mapped

and individually described because of the diverse attributes of each landslide (Van Den Eeckhaut and Hervás, 2012).
In term of collected landslides, inventories should be as complete as possible to constitute a useful tool in risk management. The main required pieces of information regard an identification code, location information, landslide type, date of occurrence or last reactivation, state of activity and volume. Additional and complementary information can be landslide geometry, geology, hydrogeology, land use, triggering factors, consequences, mitigation measures, surveying methods and date, surveyor's name, bibliographical references, illustrations, ground or aerial photographs, and monitoring data (Fell et al., 2008; Van Den Eeckhaut and Hervás, 2012). AVI inventory, acronym of *Aree Vulnerate Italiane* (Areas Affected by Landslides and Floods in Italy), was the first comprehensive database of areas historically affected by landslides and floods in Italy built by collecting information from newspapers, in particular local ones (Fig. 19) (Guzzetti et al., 1994). It was commissioned by the Italian Department of Civil Protection to the National Group for Prevention of Hydro-geological Disasters (GNDCI) ("Gruppo Nazionale per la Difesa dalle Catastrofi Idrogeologiche" - GNDCI) of the National Research Council (CNR) to take a census of landslide and flood events occurred from 1919 to 1998.
Each hazardous event has a factsheet with several data, which were collected as complete as possible according to the exhaustiveness of newspaper information. Regarding landslide events, the main information regards administrative location, data of event occurrence, geographic coordinates, landslide typology, geology, predisposing and triggering factors, consequences and bibliography.
The current national and official database collecting information about landslide is the IFFI catalogue (Fig. 20), acronym of *Inventario dei Fenomeni Franosi in Italia* (Inventory of landslide events in Italy). It is realized by the Italian Institute for Environmental Protection and Research (ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale) in collaboration with regional administrations. It is considered an important basic knowledge tool useful in the landslide hazard and risk assessment, the preliminary design of soil protection interventions, and the design of Civil Protection

emergency plans. It is constantly updated and, up to now, 620,808 landslides have been recorded within the whole Italian territory.

Fig. 19 - Landslide events for each Italian municipality within the AVI inventory (from http://avi.gndci.cnr.it/).

The census of landslide phenomena is based on the collection of historical and archival data, aerial photo-interpretation, and soil surveys. To obtain homogeneous and comparable results at national level, a factsheet based on international standards of classification and terminology has been prepared for each mass movement. Each IFFI factsheet contains three types of information: basic (location, type of movement, state of activity), additional (i.e. geology, geomorphology, land use, causes, date of occurrence) and optional (i.e. consequences, mitigation interventions) (Fig. 21).

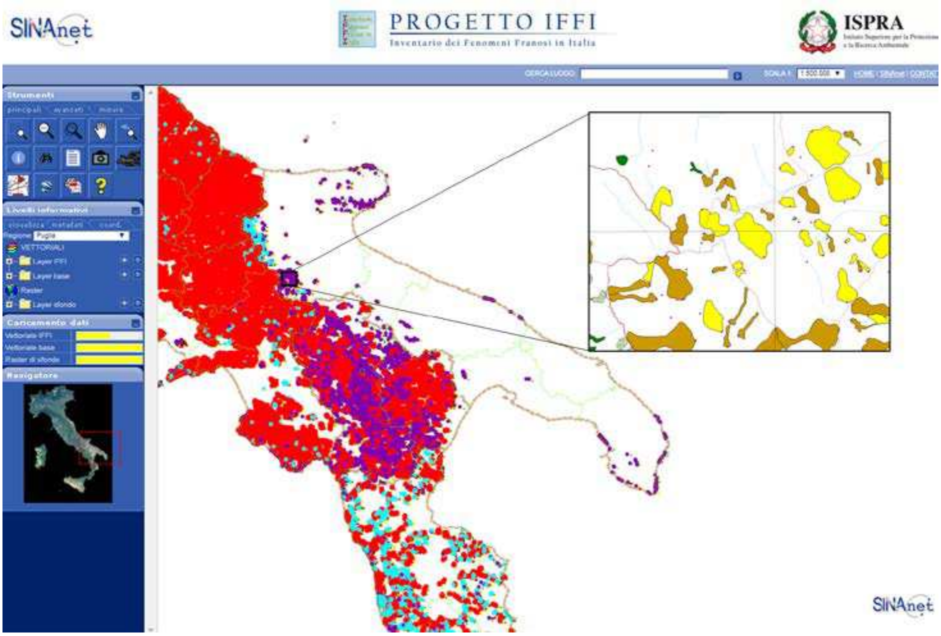


Fig. 20 - Landslide events within the IFFI catalogue (from http://www.progettoiffi.isprambiente.it/).

DATI ALFANUMERICI DEGLI ELEMENTI

DATI ALFANUMERICI DEGLI ELEMENTI RELATIVI ALLA CARTOGRAFIA IFFI

Frana 1

IDFrana	Regione	Provincia	Comune	Autorita' di Distretto	Tipo di movimento	Attivita	Litologia
0710036300	Puglia	Foggia	Bovino	Appennino Meridionale	Scivolamento rotazionale/traslativo	Relitto	flysch, calcareo-marnosi

Uso del suolo	Metodo usato per la valutazione del movimento e dell'attivita'	Danno	Area della frana (m^2)	Data evento (gg/mm/aaaa)	Causa	Interventi	Link RENDIS
	Fotointerpretazione	n.d.	1508941				

DATI ALFANUMERICI DEGLI ELEMENTI RELATIVI ALLA CARTOGRAFIA DI BASE

LIMITI REGIONALI

REGIONE	SHAPE_AREA
Puglia	19351895857,747963

LIMITI COMUNALI

NOMECOMUNE	SUPERFICIE	ISTAT
Bovino	84929653	16071007

RETICOLO TAVOLETTE

CODICE	FOGLIO
F174-ISO	174

Fig. 21 - Example of the IFFI factsheet for a landslide (from http://www.progettoiffi.isprambiente.it/).

3.4 A framework for landslide risk assessment and management

Since landslides are one of the most frequent and destructive geological hazards, many researchers have been involved in landslide risk assessment and management (Lee and Jones, 2004). Until the 1970's, landslide risk assessment and management were performed in a qualitative manner, mainly for urban planning purposes (Fell et al., 2005). In the last decades, even as a consequence of new available data, innovative approaches have been developed to assess landslide hazard and risk through quantitative methods, from the management of individual slopes to more global landslide risk management (Corominas et al., 2014; Fell et al., 2008, 2005; Hungr et al., 2005; SafeLand-Project, 2010b; Varnes and IAEG-CLOMMS, 1984). As the matter of fact, several innovative techniques based on remote sensing data and satellite imaginary interpretation have been recently developed in landslide hazard and risk management (SafeLand-Project, 2012a). Moreover, differential levelling, Global Navigation Satellite System (GNSS), total station, laser scanning (both airborne and terrestrial), high resolution space-borne imagery, photogrammetry and radar interferometry can be used in each step of landslide studies, such as to detect and map landslides over large hazardous areas, to characterize their failure mechanisms, to classify landslide type, state and style of activity, to monitor landslide activity through time-series analysis, and to evaluate the probability of occurrence within a given area in landslide hazard assessment (Hungr et al., 2005; Werner and Friedman, 2010).

A general-accepted framework for landslide risk management is shown in Fig. 22. Firstly, there is the need to define the scope of risk management. Next, the framework provides the evaluation of the susceptibility of a territory to landslides and the corresponding frequency (that is the annual probability) of occurrence (*hazard analysis* phase). Subsequently, the *consequence analysis* phase permits to identify and quantify the elements at risk and their vulnerability. After that, the *risk assessment* considers the outputs from *risk analysis*, which includes the previous hazard and consequence analysis phases. The landslide risk assessment aims at evaluating risks in comparison with value judgments and risk tolerance criteria, considering landslide risks either tolerable (and, consequently, accepted) or intolerable.

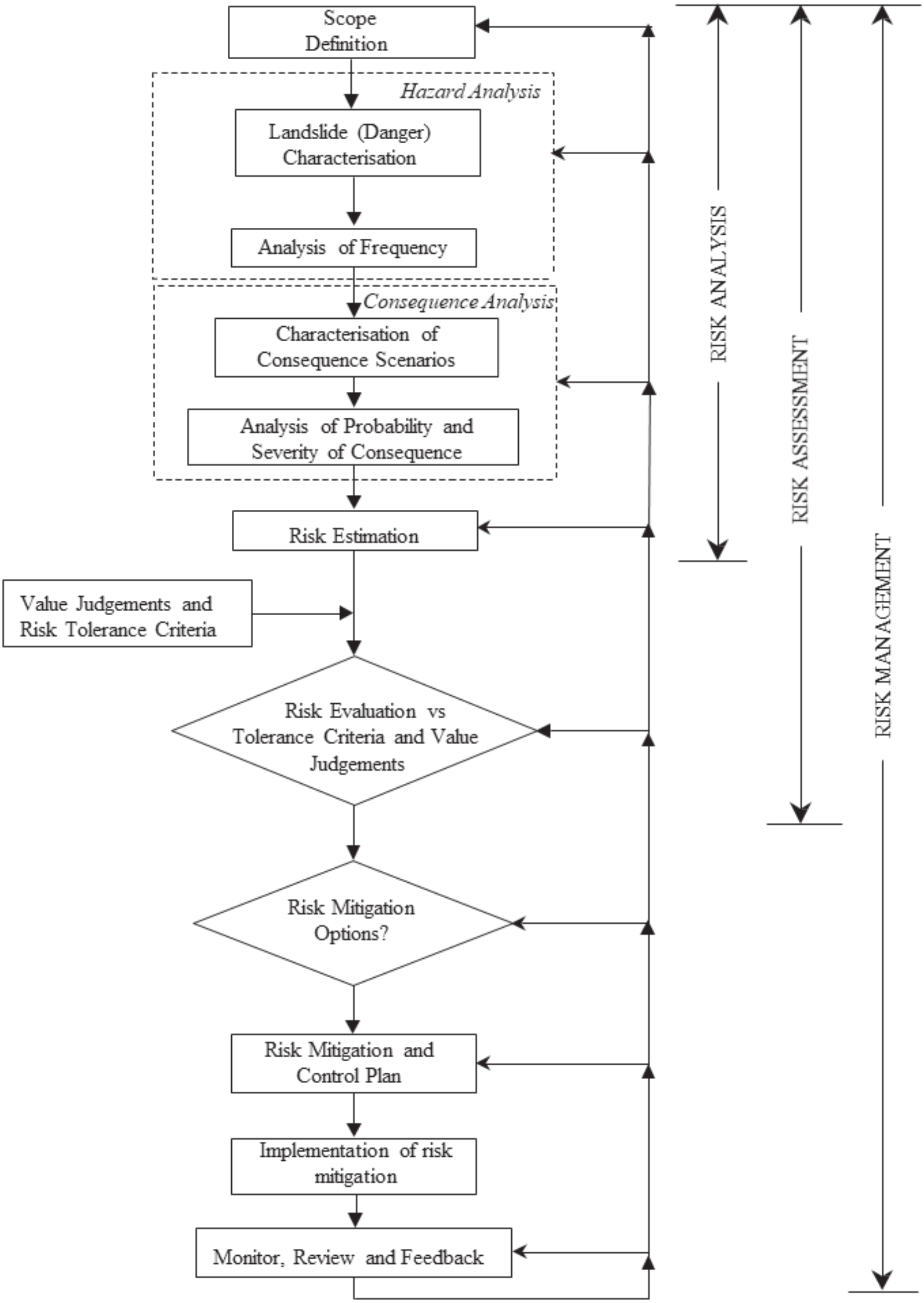


Fig. 22 - A framework for landslide risk management (from Fell *et al.*, 2005).

The outputs of risk assessment correspond to the input of risk management phase. Whether the level of risk is considered unacceptable, risk mitigation measures need to be implemented, aiming at reducing, avoiding or transferring the unacceptable risks (Aleotti and Chowdhury, 1999; Crosta et al., 2005; Fell et al., 2008; Sassa et al., 2005). In line with the prefigured scope and aware about the assumptions of the risk analysis, the outcomes of the framework of landslide risk management might help regulators and governments to decide whether the calculated risks are acceptable or whether risk mitigation measures are required. Sometimes, there is the need to assess relative risk values, instead of absolute values, in order to prioritize the implementation of risk reduction measures (Fell et al., 2005; Hungr et al., 2005).

3.4.1 Landslide mitigation measures

Mitigation measures need to be implemented whether the level of risk is intolerable. Landslide risk mitigation measures, which can vary according to the characteristics of landslide phenomena, can be classified in structural and non-structural. Moreover, they can focus on hazard, vulnerability or exposure reduction (Table 9). Concerning the hazard reduction, mitigation measures aim at lessening the frequency of landsliding through stabilization works, by implementing engineering works that reduce the probability of occurrence of landslides (i.e. through groundwater drainage, slope modification and anchors). Dealing with the vulnerability means implementing passive solutions, which reduce the degree of loss either increasing the resistance of elements at risk or lessening the probability of the mass movement to reach the element at risk. About reducing exposure of each element at risk, different measures can be employed, which aim at reducing the temporal and spatial probability of the element at risk (Hungr et al., 2005; SafeLand-Project, 2012b, 2011a; Turner and Schuster, 1996). Other strategies to mitigate risk can be risk avoidance, aiming at eliminating the cause of risk (i.e. seeking an alternative site or form of development). Alternatively, it is possible to transfer the risk. It happens when another authority (usually, insurance companies) accepts to take on responsibility for risk, taking out insurance policies to properties and people (Fell et al., 2005).

Table 9 - Classification of mitigation measures (SafeLand-Project, 2011a).

	Classification	Component of risk addressed	Brief description	Notes and other terms used
STRUCTURAL	Stabilization	Hazard (H)	Engineering works to reduce the landslide probability of occurrence	Preventive, remedial, hard, soft, active stabilization.
	Control	Vulnerability (V)	Engineering works to protect, reinforce, isolate the elements at risk from the landslide zone of influence	Preventive, hard, soft, passive stabilization.
NON STRUCTURAL	Avoidance	Elements (E)	Temporary and/or permanent reduction of exposure through: warning systems, emergency evacuation, safe sheltering, land-use planning and/or relocation of existing facilities	Reduction of the exposure of the elements at risk. Monitoring, early warning systems and civil protec-tion procedures, often described as reducing vulnerability, are essentially temporary, selective avoidance measures.
	Tolerance	Elements (E)	Awareness, acceptance and/or sharing of risk	Indirect reduction of the exposure of the elements at risk.

3.5 Methodological approaches to estimate landslide risk

Risk is often estimated by the product of probability of a hazardous phenomenon of a given magnitude and the consequences, which represent the sum of the product between physical vulnerability and the amount (or cost) of each element at risk (van Westen, van Asch and Soeters, 2006; Fell et al., 2008). Many factors influence the choice of the methodological approach, such as the landslide triggering phenomena, the elements at risk, the types of involved mass movements, the available data and those to be collected, the scale (such as individual, local, regional, national or global), and the available time and funds (Corominas et al., 2014; Glade et al., 2005; SafeLand-Project, 2010b; van Westen et al., 2006).

An analysis to estimate landslide risk can be qualitative, quantitative or their combination. Quantitative analyses are not necessarily more objective than qualitative ones, because risk components in all types of analysis are estimated and subject to assumptions.

Quantitative risk analyses are based on numerical values of the probability, vulnerability and consequences, and quantify the probability of a given level of loss and the associated uncertainties. They result in a numerical value of the risk, which can be represented by means of a risk curve, expressing the relation between hazard scenarios with different temporal probabilities and the corresponding expected losses (Corominas et al., 2014; Pellicani et al., 2014a; van Westen et al., 2010). Qualitative risk analyses use descriptive or numerical scales to describe the destructiveness of potential effects and the likelihood that those consequences will occur (Corominas et al., 2014; Fell et al., 2005). As explained in paragraph 3.3, whatever the method is, the main source to start the analysis is a landslide inventory. It constitutes a detailed register of spatial and time characteristics of past landslides within a territory (van Westen et al., 2008).

Van Westen et al. (2010) revisited landslide risk formulation in order to quantitatively assess the risk according to the following formulation:

$$\mathbf{R = P_s * P_t * V * A} \qquad \text{Equation 2}$$

where:

- P_s represents the component of spatial probability of landslide occurrence;
- P_t is the temporal probability of major, moderate and minor triggering events;
- V is the vulnerability
- A is the amount of elements at risk exposed to the hazard.

Equation 2 is based on the strong assumption that spatial and temporal probabilities are independent. From a geomorphological point of view, this is a strong assumption and it may not hold always and everywhere (Guzzetti et al., 2005a). However, the lack of understanding of the physical processes of landslide phenomena permits to consider this assumption as an acceptable first-approximation. It makes mathematically manageable and more feasible to work with the problem of assessing landslide hazard (Guzzetti et al., 1999). The following sub-paragraphs review some methodological approaches to estimate the components of risk formulation.

3.5.1 Hazard analysis

Hazard is considered as a condition with the potential for causing negative consequences (Fell et al., 2008). Landslide hazard can be defined as the probability of occurrence, within a specific period of time of a potentially damaging mass movement within a given area (Varnes and IAEG-CLOMMS, 1984).

Hazard, thus, has spatial and temporal components. It is a function of the topography and other factors that influence the spatial propensity to landslide activity (susceptible factors), and the analysis of temporal probability of landslide occurrence (Corominas et al., 2014; UNISDR, 2017b; van Westen et al., 2006). In addition, some authors also have been included the magnitude (or intensity) of the hazardous event in hazard analysis, as a component to evaluate damages related to landslides (Guzzetti et al., 2006, 2005a; Wu and Chen, 2013).

Landslide hazard assessment can be affected by uncertainty due to the significant spatial variability of slope material, the slope response under various external perturbations, anthropogenic activities and uncontrolled land-use, and climate change that increases the susceptibility of surface soil to instability because of abandoned agricultural areas, deforestation and climatic variability (IPCC, 2012b; UNISDR, 2017b). Moreover, the classification obtained by the assessment methods depends on the aspects emphasized by the researchers (Aleotti and Chowdhury, 1999; Lee et al., 2017). Therefore, there is the need to highlight the model assumptions, which affect hazard and risk assessment, and models should be validated through landslide inventory of past hazardous events.

The first component of hazard analysis is the landslide susceptibility, that can be considered as a relative indication of the spatial probability, and permits to determine zones prone to landslide events (van Westen et al., 2006). Some aspects, such as scope of mapping, mapping unit, scale of investigation, type of involved landslides, data required, and trigger phenomena, affect both the choice of the methodological approach and the result of susceptibility assessment (Erener and Düzgün, 2012). Aware about the uncertainness of susceptibility assessment, Fell et al. (2008) defined generally reasonable the following assumptions about susceptibility evaluation:

- areas that experienced mass movements are likely to experience landslides in the future;
- areas with similar characteristics (such as topography, geology and geomorphology) as the areas that have experienced past landslides are also likely to experience landsliding in the future.

The methods to assess landslide susceptibility are divided in qualitative, quantitative and a combination of them. Moreover, they can be categorized into heuristic, statistical, and deterministic models (Pourghasemi et al., 2018). Each technique has advantages and limitations, as described in the numerous examples and reviews of landslide susceptibility mapping methods (Aleotti and Chowdhury, 1999; Erener and Düzgün, 2012; Guzzetti et al., 2005a, 1999; Hungr et al., 2005; Pellicani et al., 2014a; Pourghasemi et al., 2018; van Westen et al., 2006; Varnes and IAEG-CLOMMS, 1984).

Most hazard analyses are basically focused on susceptibility assessment. Although susceptibility maps are fundamental in the landslide hazard assessment, they may be insufficient in risk management, as the temporal occurrence and the magnitude of the events are not included (Corominas et al., 2003).

Adding the temporal dimension to the susceptibility maps in order to produce real hazard maps is challenging (van Westen et al., 2006). The difficulties in determining temporal probability of landsliding are mainly associated to the absence of historical landslide records related to the triggering events (such as rainfall and earthquakes), scarcity of input data, or the absence or insufficient length of historical records of the triggering events, which does not allow to establish the quantitative relationship of the occurrence of landslides with important triggering factors (Corominas et al., 2014; van Westen et al., 2006).

Based on the availability of inventories that include spatial and time information about past landslide occurrences, literature provides different approaches to assess temporal probability of landslide. Probabilistic models, such as continuous-time models (Poisson model) and discrete-time models (Binomial model), are the most used in the prediction of occurrence of geological hazards (Haneberg, 2000; Keaton, 1994). In truth, hazard processes are deterministic, that means that every hazardous event has a cause. Moreover, probabilistic approaches assume that the rate of landslide occurrence will remain the same in future under the given geo-environmental conditions (Coe et al., 2004; Jaiswal and Westen, 2009). However, probabilistic models are able to incorporate our uncertainty regarding our knowledge of natural processes (Crovelli, 2000).

An application of Poisson and binomial models to assess landslide exceedance probability (and, thus, landslide temporal probability) in a landslide-prone area with a comprehensive inventory about past landslide was proposed by Coe et al. (2004). Guzzetti et al (2005) applied the Poisson model in a landslide-prone area located in central Italy. The multi-temporal inventory used in the temporal probability assessment was based on the interpretation of multiple sets of aerial photographs, and geological and geomorphological field mapping. Authors estimated the frequency of landslide occurrence through the count of the number of landslides shown in the multi-temporal inventory within a slope unit (Guzzetti et al., 2006). Then, the Poisson probability model was adopted to determine the exceedance probability of having one or more landslides in each slope unit, for different return periods.

Both the previous applications aimed at estimating the exceedance probability of experiencing one or more landslides within a unit area (slope unit, grid cell unit). Other authors estimated temporal probability of landsliding based on rainfall thresholds, which are commonly defined as the line that fits the minimum intensity or duration of rainfall required to initialise shallow landslides (Caine, 1980; Crosta, 1998; Reichenbach et al., 1998). Thus, the Poisson model has been also applied in the assessment of the exceedance probability that the amount of rainfall within a unit area overcomes one or more times the corresponding rainfall threshold (Jaiswal et al., 2010; Jaiswal and Westen, 2009).

3.5.2 Assessing landslide vulnerability and exposure

Consequences represent the sum of the product between physical vulnerability and the amount (or cost) of each element at risk. As the matter of fact, mass movements can adversely affect different elements (such as population, properties, infrastructures, public services) within a landslide-prone area. A comprehensive list of elements at risk, which not includes the moving elements (population, vehicles, etc.), is reported in Table 10.

Landslides vulnerability assessment should consider multiple dimensions including both physical and socioeconomic factors (UNISDR, 2017a). Physical landslide vulnerability, defined as the degree of damage of the elements within an area affected by a landslide with a given magnitude, is expressed as an index that ranges on a scale of 0 (no loss) to 1 (total loss) (Crozier and Glade, 2012; Fell et al., 2008). It is a function of the intensity of the landslide event and the resistance levels of the exposed elements. As the matter of fact, some methodological approaches to estimate vulnerability are based on relationship between these factors, resulting in vulnerability damage (or fragility) functions (Corominas et al., 2014; Lee and Jones, 2004; SafeLand-Project, 2011b).

In contrast to other natural processes, the quantification of landslide vulnerability is considered a difficult task because it depends on the complex nature and magnitude of mass movements, and the vulnerability characteristics of the elements at risk that are involved (Alexander, 2005; Fuchs et al., 2007; Lee and Jones, 2004). Moreover, for moving elements, the landslide vulnerability varies according to the temporal probability of being present during the mass movement (Glade et al., 2005; Lee and Jones, 2004).

Table 10 - Classification of elements at risk (adapted by Alexander, 2005)

Infrastructure	Buildings and rural production
Roads	**Houses**
unasphalted rural roads	single family homes
asphalted rural roads	semi detached (duplex) and terraced (row) housing
main roads	blocks of apartments (flats)
divided highways (dual carriageways)	urban insulae (historic or modern city block)
limited access freeways (motorways)	farmhouses
urban access roads (asphalted)	farm outhouses, stalls, barns, etc.
private drives	villas and isolated dwellings
Railways	prefabricated buildings
main lines	**Public buildings**
branch lines	town halls and public administration offices
sidings	hospitals and clinics
buildings (stations, etc.)	sports centres, stadia and sports fields
Bridges	cemeteries
major road, rail, pipeline bridges and viaducts	churches and chapels
minor bridges	schools and other educational institutions
culverts	fire and ambulance stations
Electricity transmission	armed forces barracks and police stations
low-tension lines, on poles	**Architectural heritage**
high-tension lines, on pylons	historic buildings
transformers, switching stations and substations	fortifications
Telephone	monuments
low-tension lines, on poles	**Commercial buildings**
cellular telephone repeaters and their electricity supplies	shops and stores
Pipelines	office blocks
water supply: main pipelines and distribution networks	warehouses and storage areas
sewer lines	factories
methane gas: main pipelines and distribution networks	artisans' premises and small businesses
septic tanks and their feeder systems	mechanics' premises and engineering works
Other	heavy industrial plants and refineries
canals, navigable rivers and drainage channels	**Agriculture**
water towers and tanks	tilled fields
gas and oil storage facilities	market gardens
airfields, airports	

Concerning the exposure assessment, it identifies the elements at risk, either static (buildings, roads, etc.) or moving (people, vehicles, etc.), that are present in areas potentially involved in mass movements (Corominas et al., 2014). Assessing the exposure of elements at risk means evaluating the proportion of the assets that are located in the hazardous areas. As the matter of fact, exposure of each element at risk can be assessed by superimposing landslide hazard zones on maps of population density, the built environment and infrastructures (UNISDR, 2017b).

3.6 Legislation concerning hydro-geological hazard and risk assessment and mitigation in Italy

Hydro-geological risk, that is the term concerning flood and landslide risk in Italy, has a long history in national regulation (Table 11). Before the end of ‘80s, national laws just indirectly accounted to the management of flood and landslide risk. As the matter of fact, several Royal Decrees (such as No. 3918/1877, No. 523/1904, No. 3267/1923, etc.) posed constraints aiming at soil, river and forest protection. After the World War II, the attention paid by Italian government to the hydro-geological events that devastated Italian territory can be assessed by the numerous legislation acts (91) and associated funds (around 17 billion Euro) between 1945 and 1990 (Catenacci, 1992; Sorriso-Valvo, 2005). In particular, after the disastrous flood in 1967 that harmfully impacted Florence and its surrounding (Tuscany, Central Italy), the Law No. 632/1967 “Autorizzazione di spesa per l'esecuzione di opere di sistemazione e difesa del suolo” (“Approval of the costs for the execution of accommodation and soil protection works”) established the Interministerial Commission for the study of hydraulic engineering and soil protection.

The risen awareness of Italian government about hydro-geological risk pointed out the enactment of national Law No. 183/1989 “Norme per il riassetto organizzativo e funzionale della difesa del suolo” (“Rules for the organisational and functional rearrangement of soil protection”). It is the first comprehensive Italian law on land management and soil protection, which laid the bases for the management of floods and landslides. It defined the establishment of hydrographic basins and related national, interregional and regional Basin Authorities, in charge of programming and planning land policies through Basin Plans dealing with flood and landslide risks.

Table 11 - Main Italian laws concerning landslide hazard and risk management.

Year	Name
1877	Royal Decree No 3917/1877 Legge "Majorana Calatabiano" (First forestry law)
1904	Royal Decree No 523/1904 "Legal provisions regarding hydraulic works of different categories"
1923	Royal Decree No 3267/1923 "Reorganisation and reform of legislation on forests and mountain land"
1967	Law No. 632/1967 "Approval of the costs for the execution of accommodation and soil protection works"
1989	Law No. 183/1989 "Rules for the organisational and functional rearrangement of soil protection"
1993	Law No. 493/1993 "Conversion into law, with amendments, of Decree-Law No 398 of 5 October 1993, concerning provisions for the acceleration of investment in support of employment and for the simplification of procedures in the building sector"
1998	Law No. 267/1998 "Conversion into law, with amendments, of Decree-Law No. 180 of 11 June 1998 on urgent measures to prevent hydro-geological risks and in favour of areas affected by landslide disasters in the Campania region"
1998	Prime Minister's Decree of the 29 September 1998 "Act of guidance and coordination for the identification of the criteria relating to the compliances referred to in Article 1, paragraphs 1 and 2, of Decree-Law No. 180 of 11 June 1998"
2006	Legislative Decree No. 152/2006 "Environmental standards"
2014	Decree-Law 91/2014 "Urgent dispositions for the agricultural sector, environmental protection and the energy efficiency of school and university buildings, the relaunching and development of businesses, the reduction of electricity tariff costs, as well as for the immediate definition of obligations deriving from European legislation"
2015	Law No. 221/2015 "Environmental regulations to promote green economy measures and to contain the excessive use of natural resources"
2015	Prime Minister's Decree of the 28 May 2015 "Identification of criteria and methods for establishing priorities for the distribution of economic resources to hydro-geological risk mitigation interventions"
2016	Ministerial Decree No. 294/2016 "Rules concerning the allocation and transferring to the District Basin Authorities of personnel and instrumental resources, including headquarters, and financial re-sources of the Basin Authorities, as per Law no. 183/1989"
2018	Prime Minister's Decree of the 4 April 2018 "Identification and transfer of personnel, instrumental and financial resources of the Basin Authorities (as provided by Law no. 183/1989) to the District Basin Authorities under the competence and determination of the endowment of the District Basin Authorities, pursuant to Article 63, paragraph 4, of Legislative Decree no. 152 of 3 April 2006 and Decree no. 294 of 25 October 2016"

After the establishment of Basin Authorities (Law No. 493/1993), the normative process speeded up because of the disastrous landslide that hit the municipality of Sarno

(Campania, Southern Italy) and surroundings, that occurred the beginning of May in 1998, causing hundreds of victims (Fig. 16). As a consequence of this harmful event, the national government promulgated the Law No. 267/1998 "Conversione in legge, con modificazioni, del decreto-legge 11 giugno 1998, n. 180, recante misure urgenti per la prevenzione del rischio idrogeologico ed a favore delle zone colpite da disastri franosi nella regione Campania" ("Conversion into law, with amendments, of Decree-Law No. 180 of 11 June 1998 on urgent measures to prevent hydro-geological risks and in favour of areas affected by landslide disasters in the Campania region"). It required each Basin Authority to evaluate the hydro-geological risk using simple and rapid procedures, drafting the so-called PAI, "Piani per l'Assetto Idrogeologico" (*Hydro-geomorphological Setting Plan* - HSP) up to 30 June 1999. The Prime Minister's Decree of the 29 September 1998 "Atto di indirizzo e coordinamento per l'individuazione dei criteri relativi agli adempimenti di cui all'art. 1, commi 1 e 2, del decreto-legge 11 giugno 1998 n.18" ("Act of guidance and coordination for the identification of the criteria relating to the compliances referred to in Article 1, paragraphs 1 and 2, of Decree-Law No. 180 of 11 June 1998") indicated the general criteria and methods for the identification of landslide and flood risks at basin scale. Moreover, it addressed the need to identify areas at landslide and flood hazard and risk through the acquisition of available information, in order to zone and assess risk levels, and to plan risk mitigation measures. The output of a hydro-geological risk assessment corresponds to a risk zonation in four risk classes, one for landslide risk and one for flood risk, ranging from R1 (moderate risk) to R4 (very high risk). Different compatible uses were defined within each risk class.

In 2006, the Legislative Decree No. 152/2006 "Norme in materia ambientale" ("Environmental standards"), according to the E.U. 2000/60 Directive about water resources management, reorganised the existing Basin Authorities covering the whole national territory in 8 District Authorities. The districts become 7 with the Law No. 221/2015 "Disposizioni in materia ambientale per promuovere misure di green economy e per il contenimento dell'uso eccessivo di risorse naturali" ("Environmental regulations to promote green economy measures and to contain the excessive use of natural resources") (Fig. 23).

Fig. 23 - Italian Hydrographic District after the Law No. 221/2015.

Nowadays, the coordination functions and tasks in the field of soil protection, water protection, and water resource management are assigned to the District Authorities (defined as Competent Authority) within their respective hydrographic district according to the Ministerial Decree No. 294/2016 "Disciplina dell'attribuzione e del trasferimento alle Autorità di bacino distrettuali del personale e delle risorse strumentali, ivi comprese le sedi, e finanziarie delle Autorità di bacino, di cui alla legge 18 maggio 1989, n. 183" ("Rules concerning the allocation and transferring to the District Basin Authorities of personnel and instrumental resources, including headquarters, and financial resources of the Basin Authorities, as per Law no. 183/1989"), the Prime Minister's Decree of the 4 April 2018, and following the abolition of the national, interregional and regional Basin Authorities (Legislative Decree No. 152/2006).

3.6.1 Legislation concerning funding landslide mitigation measures

The ongoing criteria to finance mitigation measures for hydro-geological risk in Italy are defined by the Prime Minister's Decree of the 28 May 2015 "Individuazione dei criteri e delle modalità per stabilire le priorità di attribuzione delle risorse agli interventi di mitigazione del rischio idrogeologico" ("Identification of criteria and methods for establishing priorities for the distribution of economic resources to hydro-geological risk mitigation interventions") (Fig. 24). Application for funding concerning structural mitigation interventions are submitted through the *ReNDiS* platform "Repertorio Nazionale degli interventi di Difesa Suolo" (National Database of Soil Protection Interventions) by regions, municipalities, or other authorized institutions. This national platform was founded in 2005, aiming at providing an updated picture about the works and economic resources involved in soil protection, shared by all administrations at local, regional and national level.

The process of funding is the same for flood and landslide mitigation measures. It varies according to the category of the designed mitigation measure. The types of interventions proposed for funding are classified in:

a. Interventions with autonomous effectiveness (local measures);
b. Overall large area interventions (large-scale measures);
c. Integrated measures to mitigate hydro-geological risks and to protect and restore ecosystems and biodiversity (complex large-scale measures).

To whom concerns the procedure of intervention funding, it is divided in three phases:

(1) Eligibility (through criteria) for funding;
(2) Classification (through criteria) of the eligible measures;
(3) Verification of time schedule and building feasibility.

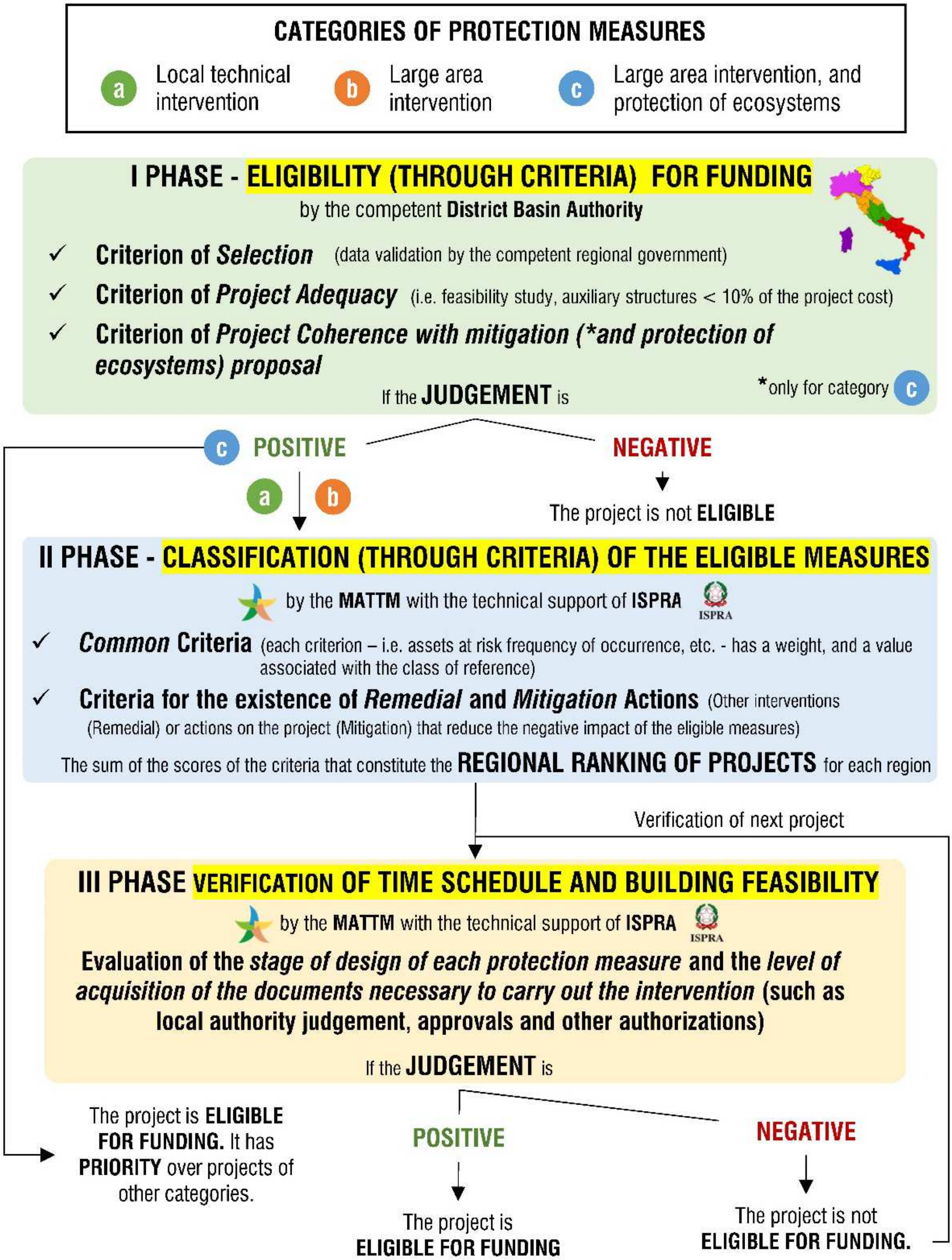


Fig. 24 - Framework of mitigation measures funding in Italy.

The first phase (1) is carried out for all the categories by the competent District Basin Authority that provides a judgement, either positive or negative. The aim of the first phase is to evaluate the proposed intervention in comparison with the main objective of funding, that is soil protection. Judgment is assigned following three criteria.
The first is the *criterion of selection*, that compares the position of the proposed intervention with the hazardous and risk zones reported in the HSP designed by the competent Basin Authority. The proposed intervention will be rejected if it is outside the hazard and risk zones of the HSP.
Moreover, the competent regional administration authority validates the data about the proposed project submitted by the organisation that proposes the mitigation measures (usually, municipalities and provincial administrative offices).
The second criterion aims at evaluating the *project adequacy*; it is based on the analysis of all report and technical documents concerning the intervention. The third criterion regards *the project coherence with mitigation proposal* (and, just for the intervention belonging to the category (c. - Fig. 24), it is the need to evaluate the protection and recovery of ecosystem and biodiversity).
If all the criteria are respected, the competent District Basin Authority gives a positive judgement, and the intervention is defined *eligible*. The project belonging to categories (a.) and (b.) continues the analysis to the second and third phases, whereas the projects that belong to the category (c.) become immediately *eligible for funding* and take priority in comparison with projects of other categories.
The second phase (2) aims at regionally ranking the interventions. It is carried out by the Ministry of the Environment and Protection of Land and Sea (MATTM - Ministero dell'Ambiente e della Tutela del Territorio e del Mare) with the technical support of ISPRA institute. The project ranking is carried out through two kinds of criteria: *common criteria* and criteria for the existence of *remedial* and *mitigation* action. Each criterion has a weight, values that vary according to a class of reference, and weighted values, that are a combination of the corresponding weight and value (Table 12).

Table 12 - Table of the criteria for ranking regionally the eligible interventions (annexed to the Prime Minister's Decree of the 28 May 2015).

Criterion	Weigh	Class	Value	Weighted Value
Regional priority	20	Very High	4	20
		High	3	15
		Medium	2	10
		Low	1	5
Project to be completed	10	Yes	1	10
		No	0	0
Number of people at direct risk	60	> 50.000	8	60
		10.000 - 50.000	7	52,5
		5.000 - 10.000	6	45
		1.000 - 5.000	5	37,5
		500 - 1.000	4	30
		100 - 500	3	22,5
		50 - 100	2	15
		< 50	1	7,5
		0 (no estimation)	0	0
Assets at high risk	30	Buildings	4	30
		Lifelines	3	22,5
		Protected natural areas	1	7,5
		No assets at high risk	0	0
Frequency of hazardous events (for landslides)	30	Slow landslide	1	15
		Rapid landslide	2	30
Assessment of expected economic losses	10	Yes	1	10
		No (no estimation)	0	0
Reduction of number of people ad direct risk	30	> 50.000	8	30
		10.000 - 50.000	7	26,5
		5.000 - 10.000	6	22,5
		1.000 - 5.000	5	18,75
		500 - 1.000	4	15
		100 - 500	3	11,2
		50 - 100	2	7,5
		< 50	1	3,7
		0 (no estimation)	0	0
Existence of remedial and mitigation action	5	Yes	1	5
		No	0	0

Among the common criteria, the “heaviest” is the number of people at direct risk, followed by the asset at high risk, the reduction of people at direct risk, the frequency of the hazardous events and the regional priority (Fig. 25). It should be noted that the frequency of the hazardous event for landslide phenomena is assessed as the velocity of landslide phenomena (rapid or slow) and not as the frequency of occurrence of landslide. The output of second phase is the regional ranking of project for each region.

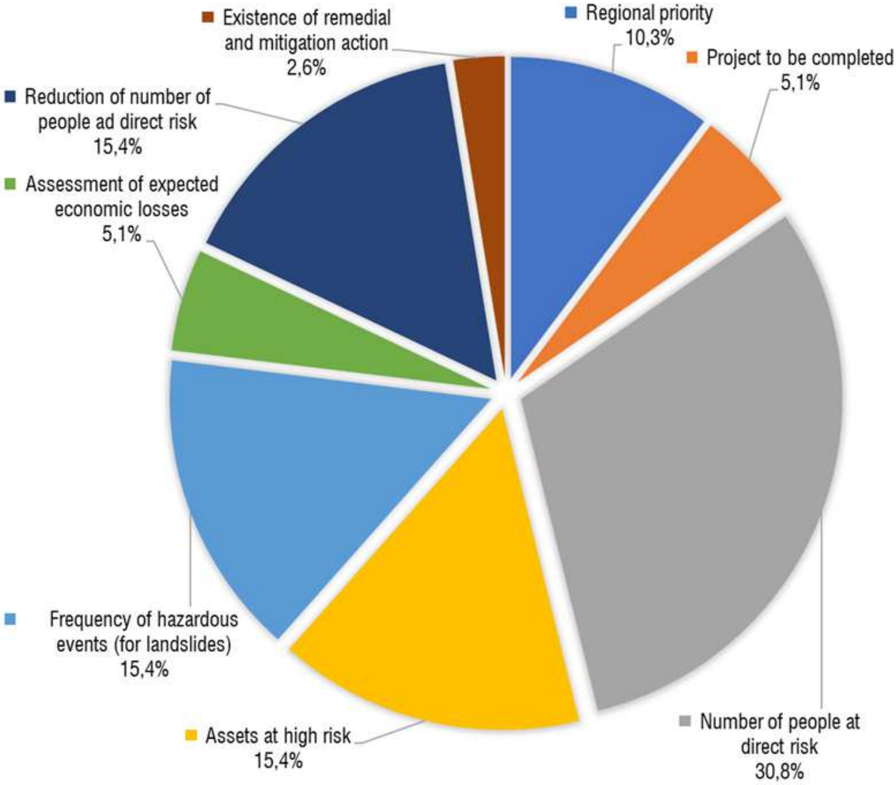


Fig. 25 - The weight percentage of the ranking criteria (II phase).

As the second phase, the third (3) one is carried out by the MATTM with the technical support of ISPRA institute. It regards the verification of time schedule and building feasibility, and it is performed by evaluating the stage of project and the level of acquisition of the documents necessary to carry out the intervention (i.e. local authority judgement, approvals and other authorizations). If the judgment is positive, the intervention is considered eligible for funding, otherwise the funding procedure carries on towards the evaluation of next project of the regional ranking.

Thus, once the regional ranking is defined, the regional governors are responsible for the prompt construction of the funded interventions. As the matter of fact, according to the Decree-Law 91/2014 “Disposizioni urgenti per il settore agricolo, la tutela ambientale e l'efficientamento energetico dell'edilizia scolastica e universitaria, il rilancio e lo sviluppo delle imprese, il contenimento dei costi gravanti sulle tariffe elettriche, nonché per la definizione immediata di adempimenti derivanti dalla normativa europea” (“Urgent dispositions for the agricultural sector, environmental protection and the energy efficiency of school and university buildings, the re-launching and development of businesses, the reduction of electricity tariff costs, as well as for the immediate definition of obligations deriving from European legislation”), the regional governors are nominated special commissaries in charge for the prompt completion of the procedures associated to the funded mitigation measures. The governors, in turn, can nominate an implementing authority responsible for performing the rule of special commissaries in their place.

4 THE CASE STUDY OF THE DAUNIA AREA (APULIA REGION, SOUTHERN ITALY)

4.1 Framing the Daunia area

In the Italian peninsula, there are several areas historically and chronically affected by landslides, in particular rainfall-induced ones. The Daunia area (Fig. 26), that is a geographical area located in the North-Western part of the Apulia region (Southern Italy), is among them (Catenacci, 1992).

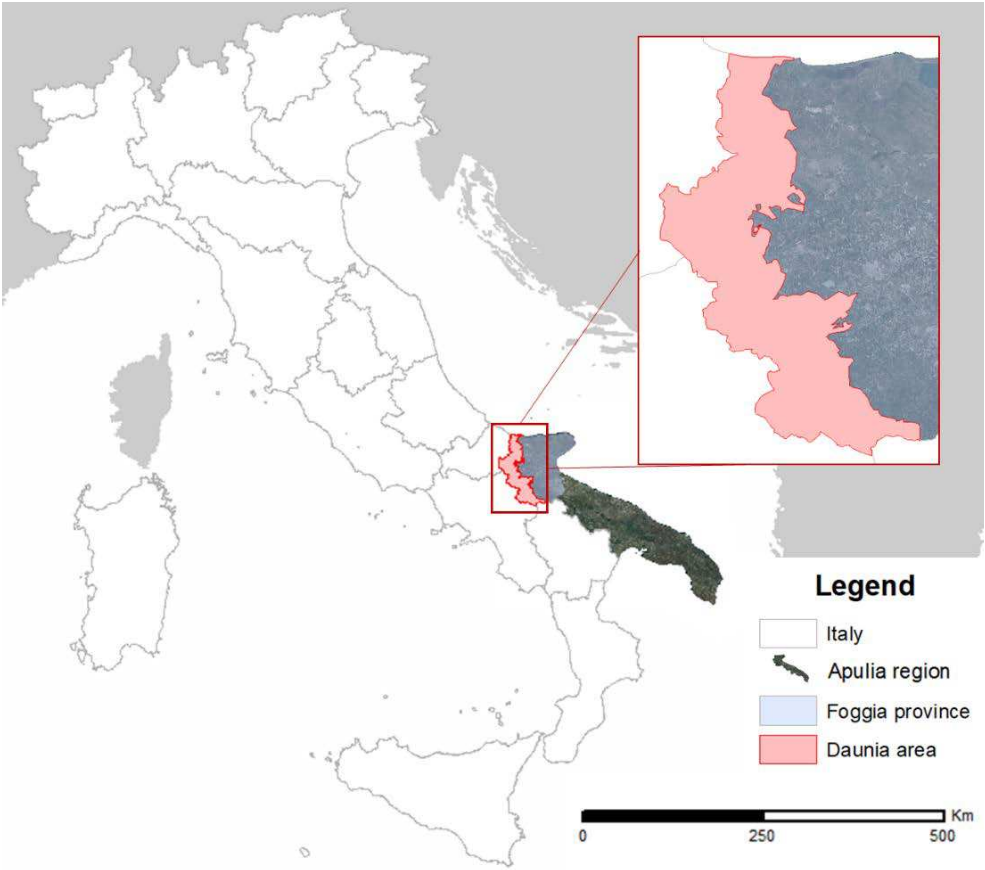


Fig. 26 - Daunia area within Apulia region (Southern Italy).

As highlighted by the report of the Regional Landscape-Territorial plan (PPTR) of Apulia region, the Daunia area is affected by numerous and various forms of soil and underground instability. Even if they are mainly expressions of the natural dynamics of the territory, they constitute threats to its integrity and usability, as well as an obstacle to the socio-economic development of the population (Regione-Puglia, 2015). Moreover, the HSP of Apulia region and the Territorial Coordination Plan of Foggia province highlight the geomorphological evolution of the landscape of this area, associated to the occurrence of small and large landslides that are favoured by lithology, the steepness of the slopes, the inadequate tree cover, seismic activity and climatic condition (AdB-Puglia, 2004; Provincia-di-Foggia, 2009).

The Daunia area includes 31 municipalities located in the Foggia province (Table 13).

Table 13 - Municipalities within the Daunia area (Apulia region, Southern Italy).

Municipality	Area (sq. km)	Inhabitants (ISTAT 2018)	Population density
Accadia	30,45	2.338	77
Alberona	49,44	956	19
Anzano di Puglia	10,88	1.225	113
Biccari	106,54	2.760	26
Bovino	84,21	3.256	39
Candela	97,43	2.784	29
Carlantino	34,43	957	28
Casalnuovo Monterotaro	48,27	1.507	31
Casalvecchio di Puglia	31,67	1.838	58
Castelluccio Valmaggiore	26,59	2.102	79
Castelnuovo della Daunia	61,61	1.276	21
Celenza Valfortore	64,61	1.530	24
Celle di San Vito	18,36	160	9
Chieuti	61,28	1.675	27
Deliceto	76,01	3.725	49
Faeto	26,12	628	24
Monteleone di Puglia	36,84	1.019	28
Motta Montecorvino	20,28	712	35
Orsara di Puglia	83,68	2.704	32
Panni	32,61	774	24
Pietramontecorvino	72,31	2.671	37
Rocchetta Sant'Antonio	72,46	1.820	25
Roseto Valfortore	49,87	1.075	22
San Marco la Catola	28,66	965	34
San Paolo di Civitate	91,01	5.740	63
Sant'Agata di Puglia	116,15	1.908	16
Serracapriola	144,16	3.877	27
Torremaggiore	210,12	17.069	81
Troia	168,12	7.100	42
Volturara Appula	52,22	401	8
Volturino	58,17	1.679	29

Cold winters and mild summers, and abundant precipitation from November to February, characterize this area. The total annual rainfall average is around 800 mm, whereas the annual average temperature is around 12 °C, monthly ranging from 2 °C to 21 °C (Pellicani et al., 2014a).

The altitude of the Daunia area ranges from the sea level (corresponding to the Adriatic coastline) up to 1.152 m asl at Mt. Cornacchia. The western part of the Daunia area, named *Subappennino Dauno*, is the most affected by landslide phenomena. This latter geographic area has no clear borders. However, it corresponds to the boundary between the Daunia mountains on the western side, and the surrounding area of the Tavoliere plain on the eastern side. As the matter of fact, in terms of land use, the arable crops characterize the lower slopes of the Tavoliere plain, whereas the slopes at higher altitudes are occupied by a fragmented mosaic of deciduous forests and areas with herbaceous vegetation used as pasture.

Moreover, most of the urban settlements of the western side are located in the upper part of hills, all above 400 metres amsl (Fig. 27). These urban centres, separated by steep valleys that are characterised by landslide instability phenomena, preserve the typical structures of the fortified boroughs of the Middle Age. On the eastern side, towards the Tavoliere plain, the landscape tends to assume a mainly flat conformation and the urban settlements are more extended.

From a geological point of view, the Daunia area is related to the geological history of the Southern Italian Apennines (Fig. 28). The geological-structural setting of the area is characterised by a wide variety of formations with very different mechanical properties (rocky successions versus clays), interacting to each other and often heavily folded and faulted. As the matter of fact, the alternation of fractured rock layers and fissured clays is a common feature of the slopes located in Daunia area, driven by the intense tectonic actions occurred during the Apennines' orogeny (Cotecchia et al., 2015).

According to the lithological and tectonic characteristics, it is possible to distinguish two different stratigraphic sequences: the Daunia Unit in the East, and the Fortore Unit in the West (Dazzaro and Rapisaldi, 1996).

Fig. 27 - A typical urban settlement of Daunia area (Sant'Agata di Puglia).

The Daunia Unit is formed by an Oligocene-Miocene succession of clayey and calcareous strata (Red Flysch and Numidic Flysch Formations), a calcareous-marly turbidite succession (Faeto Flysch Formation), and a clay and marly-clay formation (Toppo Capuana Formation). The Fortore Unit consists of Red Flysch and Numidic Flysch Formations, superimposed by pseudo-transgressive terrigenous Miocene deposits (San Bartolomeo Flysch and Toppo Capuana Formations) (Dazzaro and Rapisaldi, 1996; Patacca and Scandone, 2007).

The fissuring and the very poor strength properties of the clay part control the mechanical behaviour of the soil. As a consequence, the landscape is characterised mainly by clayey slopes with medium steepness of around 12° that, locally, increases up to 45° in presence of rocky strata (Pellicani et al., 2014a).

Climatic conditions of Daunia area, associated to the lithological, structural, and geomorphological characteristics, predispose the frequent landslide phenomena. Rainfalls and earthquakes are identified as the main triggering factors of landslides. Furthermore, the landslide occurrence has been exacerbated by the rapid expansion of built-up areas on unstable areas of last decades, and human activity, such as deforestation or excavation of slopes. These landslides start their dynamics in the lower part of the slopes, where the clayey successions outcrop. Then, mass movements affect the rocky blocks on which the urbanised areas are located because of their retrogressive evolution.

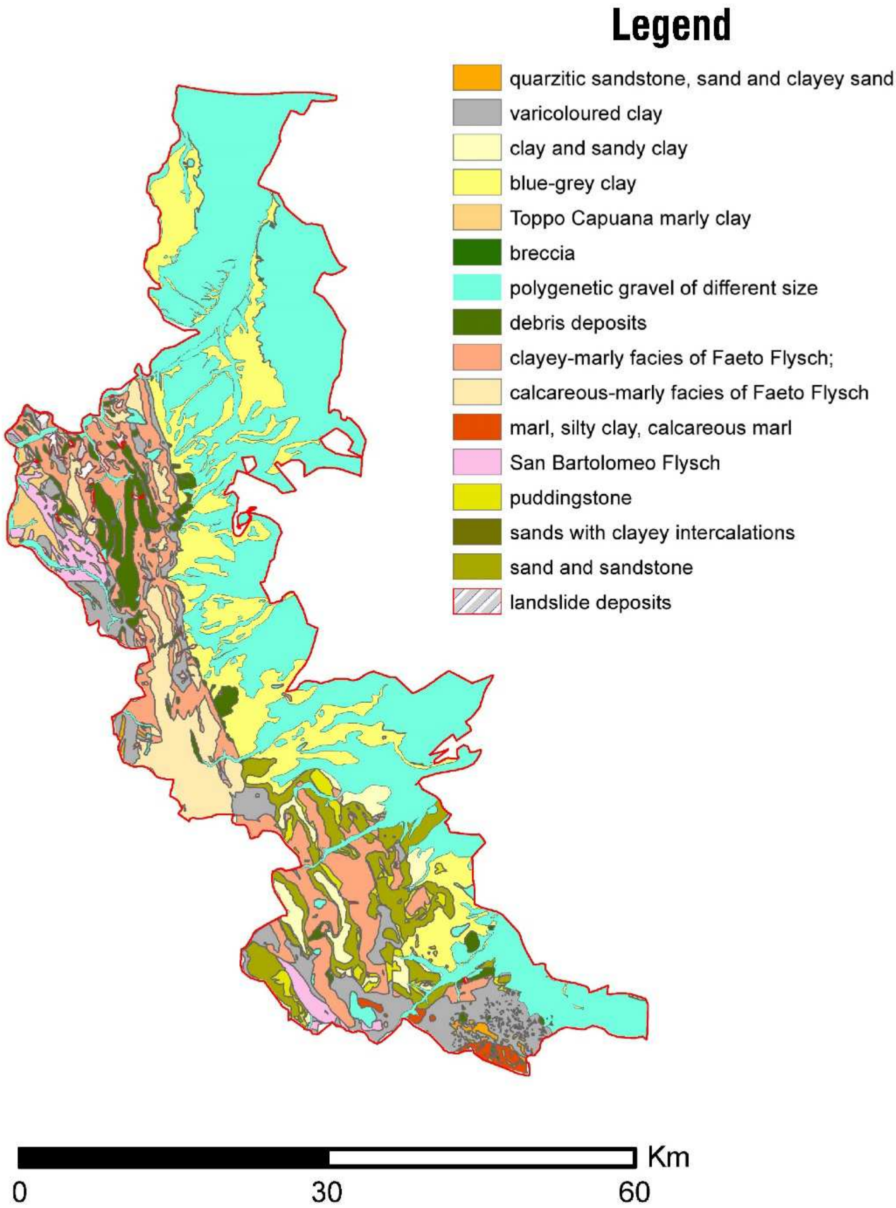


Fig. 28 - Lithological map at 1:100.000 scale (derived by the Official Geological Map of Italy).

Regarding their consequences, landslides are a major source of damage to properties in urban areas. As shown in Fig. 15, landslides have a low impact on human life and health (CNR-IRPI, 2012). Most concerns are related to the effects on road infrastructures and residential building.

4.2 Existing landslide inventories for the Daunia area

As a result of the harmfulness of landslide events in the Daunia area and the necessity to carry out landslide hazard and risk assessment, several landslide databases that collect information of past mass movements have been collected over time.
As already explained in paragraph 3.3, national landslide inventories, such as the AVI and the IFFI catalogues, registered several hazardous events occurred within the overall Italian territory. In particular, the AVI project refers to the events occurred in the period 1918-1998. Information about hazard characteristics, location, data of occurrence, triggering factors and consequences were derived mainly from newspapers and technical reports (Guzzetti et al., 1994).
For the 31 municipalities of Daunia area, the AVI catalogue registered 224 landslides, that correspond to the 75% of landslides registered within the Foggia province according to the same catalogue. The triggering factors were not always identified. Just 58 landslides on 224 have this information, identifying rainfall as the main trigger (67%), followed by anthropic actions (10%), and earthquakes (5%). Among the 224 landslides of Daunia area registered in around 65 years (1931-1995), 154 landslides have spatial information, whereas 91 events have temporal information, of which 31 with information on the precise date of occurrence. Landslides with both spatial and temporal information are 74, of which 19 with the day of occurrence (Table 14).
Concerning the IFFI inventory, which includes information collected by previous projects and other data from photo-interpretation, journals and technical reports, the Daunia area counts 542 mass movements (corresponding to the 80% of landslide phenomena of Foggia province inventoried in the same catalogue). More than half of mass movements has information about mitigation measures and involved areas, whereas almost all landslides have information about the type of movement, landslide activity,

geology, predisposing and triggering factors, and consequences. However, no one has information about the time of landslide occurrence (Fig. 29).

Table 14 - Landslide with both spatial and temporal (date of occurrence) information of the AVI inventory for the Daunia area.

Municipality	Date of occurrence	Sheet no.	Triggers	N (UTM)	E (UTM)	Type of landslide
San Marco La Catola	24/02/1931	4597655	Rainfall	4597655	500534	/
Alberona	14/12/1933	4587022	Rainfall	4587022	510289	Complex
Alberona	24/02/1934	4587022	Rainfall	4587022	510289	/
Sant'Agata di Puglia	03/04/1935	4556154	/	4556154	531846	/
Volturara Appula	12/01/1953	4594430	Rainfall	4594430	504912	Complex
Castelnuovo della Daunia	28/01/1955	4602798	Rainfall	4602798	509528	/
Troia	21/01/1957	4579344	Rainfall	4579344	526377	/
Faeto	19/01/1963	4575708	Rainfall	4575708	513518	/
Celenza Valfortore	22/02/1963	4597150	Rainfall	4597150	495428	/
Bovino	17/09/1966	4571210	Rainfall	4571210	534838	Earth flow
Celenza Valfortore	27/07/1976	4601302	Rainfall	4601302	498101	/
Troia	29/12/1976	4576904	Rainfall	4576904	523350	/
Deliceto	04/01/1977	4560912	Rainfall	4560912	531863	/
Sant'Agata di Puglia	09/01/1977	4560198	Rainfall	4560198	531488	/
Celenza Valfortore	27/01/1977	4601081	Rainfall	4601081	498481	/
Sant'Agata di Puglia	26/02/1979	4555892	Rainfall	4555892	532131	/
Monteleone di Puglia	01/03/1979	4555077	Rainfall	4555077	522506	/
Biccari	14/02/1994	4587197	Rainfall	4587197	517450	/
San Paolo di Civitate	24/08/1995	4625316	Rainfall	4625316	518832	/

Given the importance of the issue, other local studies aiming at collecting landslide information within the Daunia area have been carried out. For example, in 2009 the Basin Authority of Apulia region produced a landslide inventory map by using stereoscopic aerial-photo-interpretation of aerial photographs at scale 1:33.000, flown in 2003 by the Italian Military Geographical Institute (Pellicani et al., 2014a). The map collects around 1.330 landslides with spatial information, classifying the occurred mass movements. However, the inventory map has no information about landslide activity and the date of occurrence, since landslides were not detected in different years (Fig. 30).

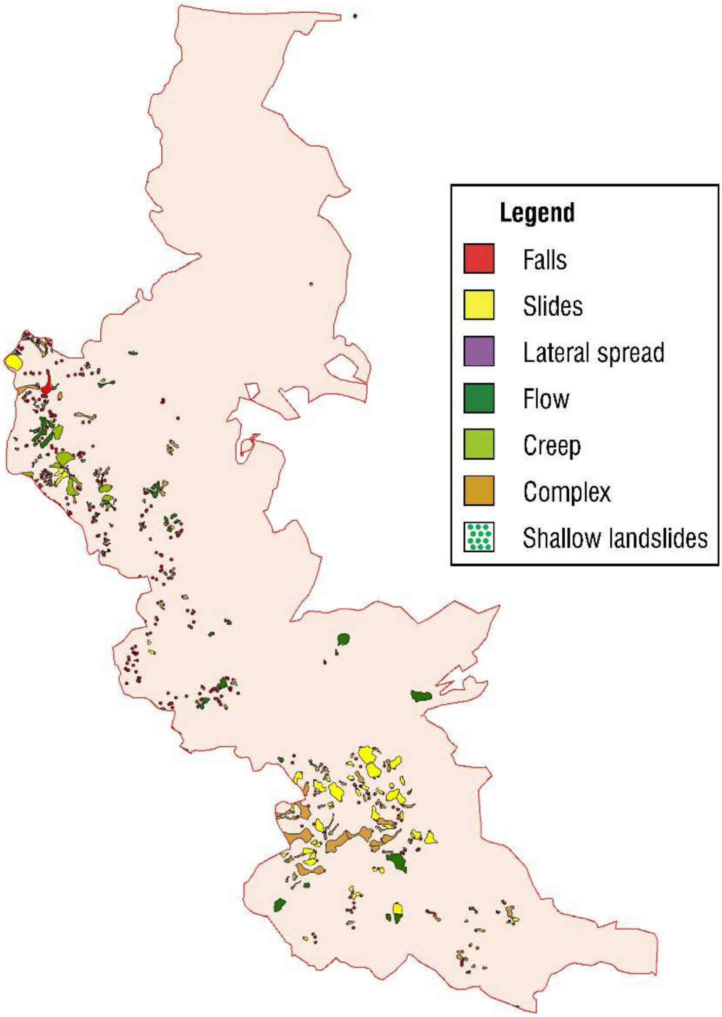


Fig. 29 - Landslides (542) reported in the IFFI catalogue.

Another landslide database was developed in 2015 as part of "Soglie Pluviometriche" project (namely "Rainfall Thresholds") by the Research Institute for Geo-Hydrological Protection of the Italian National Research Council (CNR-IRPI) in collaboration with the Civil Protection office of Apulia region. As described in the final report of the project (Parise et al., 2015), the landslide database was created with the aim of defining an empirical rainfall threshold for the Daunia region about the potential initialisation of shallow rainfall-triggered landslides. The spatial and temporal data, and triggering factors of past landslides were collected mainly from newspapers, local report, and previous databases. As a result, the registered shallow landslide events have accurate spatial and temporal information of rainfall-triggered landslides for the investigated period (1950-2014). However, the researchers involved in the landslide data collection for this project considered only the shallow landslides and the amount of precipitation measured by the nearest rain gauge that initialised the mass movements. Therefore, the database considers just a part of overall landslide events, counting 92 landslides occurred in the Daunia area.

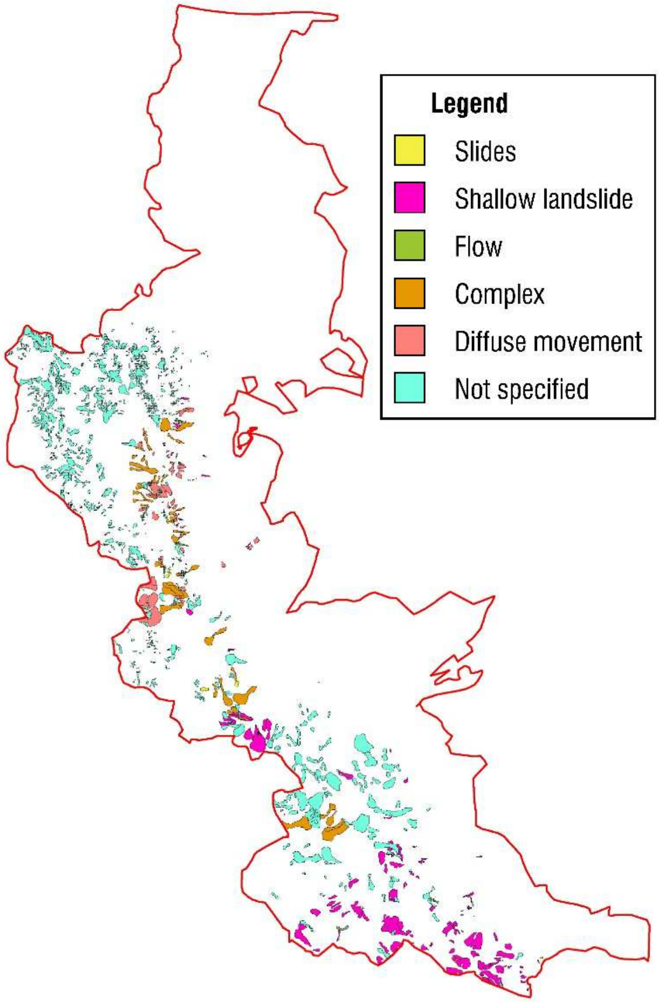


Fig. 30 - Landslide inventory map produced by the Basin Authority of Apulia region in 2009, that reported around 1.330 landslides.

4.3 Landslide hazard and risk assessment in the Daunia area: Hydro-geomorphological Setting Plans

One of the main objectives of each HSP concerning landslide phenomena is the definition of the areas of potential evolution of existing landslides and areas where new landslides may potentially occur. As highlighted in the paragraph 3.6, the Prime Minister's Decree of the 29 September 1998 only gave general suggestion for the assessment of landslide and flood hazard and risk. Consequently, different procedures to assess them have been adopted by the different competent Italian Basin Authorities within their jurisdiction.

This paragraph, among the Basin Authorities included in the District Basin of Southern Italy, focuses on the procedures developed by the only Regional Basin Authority of Apulia region and the National Basin Authority of Liri-Garigliano and Volturno (Fig. 31). These were chosen because they cover the southern part of Daunia area, which is the most impacted by landslide phenomena and will be studied in detail afterwards (Fig. 32).

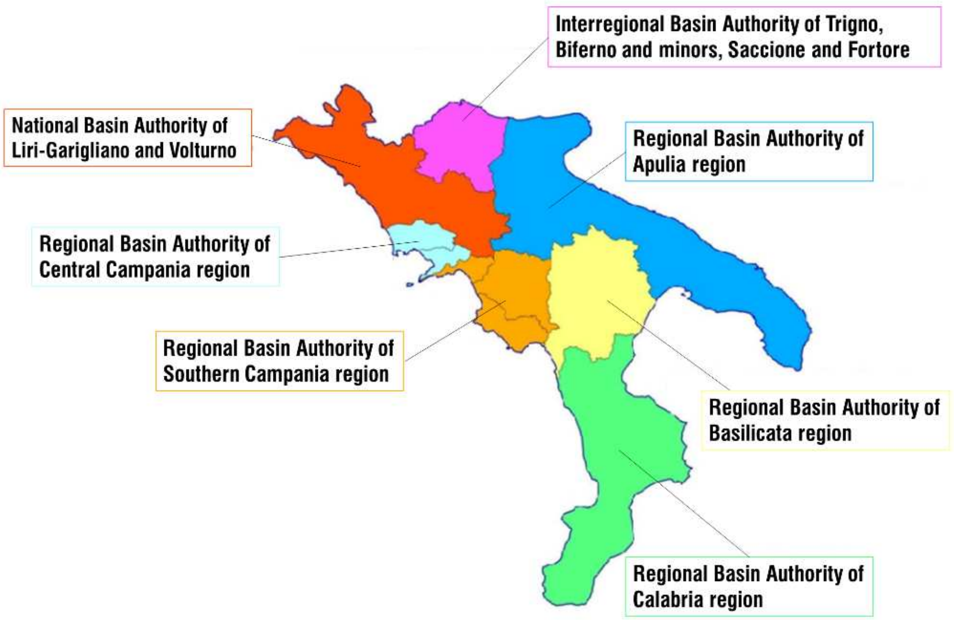


Fig. 31 - The District Basin Authority of the Southern Apennines and former competent Authorities.

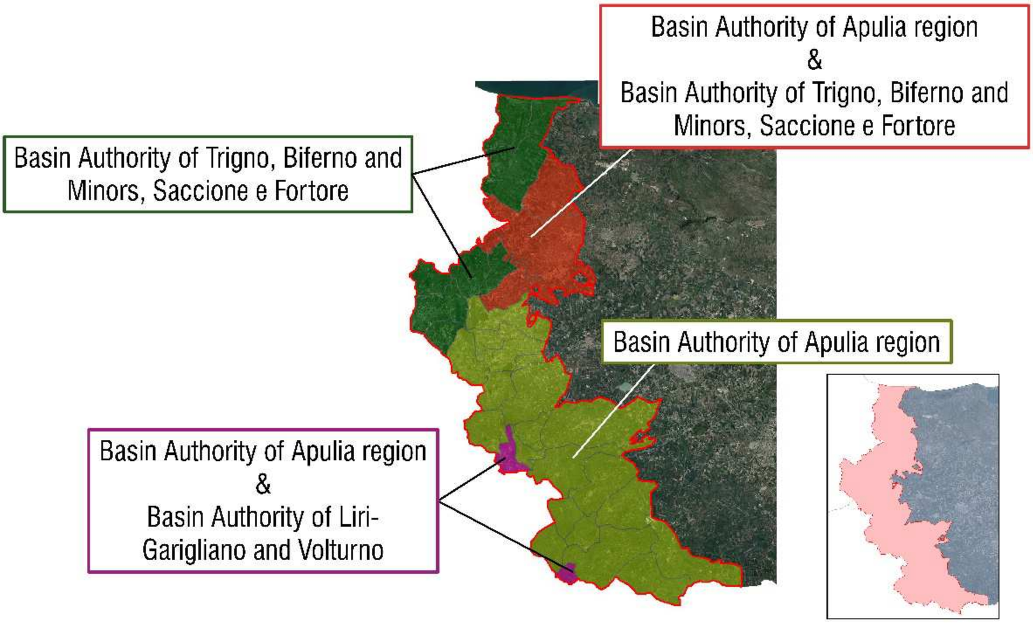


Fig. 32 - The Basin Authorities of the Daunia municipalities before the Legislative Decree No. 152/2006.

Nowadays, according to the existing legislation, the coordination functions and tasks in the field of soil protection, water protection, and water resource management is assigned to the District Basin Authority of the Southern Apennines. The area under the control of the District Authority is about 68.200 square kilometres and embraces seven Basin Authorities (national, interregional and regional) and seven regions (Abruzzo, Basilicata, Calabria, Campania, Lazio, Molise and Apulia). However, the assessment of landslide and flood hazard and risk is currently different in each administrative basin of the District Authority of the Southern Apennines, because these approaches were developed by the previous competent seven Basin Authorities and they have not yet been standardised in the administrative area of the District Basin.

4.3.1 Landslide hazard and risk assessment by the Apulian Basin Authority

Most of the municipalities of the Daunia area were administratively located within the Basin Authority of Apulia region. Its basin is about 20.000 square kilometres and embraces three regions (Apulia, Campania and Basilicata regions), 10 provinces

(Foggia, Benevento, Avellino, Salerno, Potenza, Bari, Matera, Taranto, Brindisi and Lecce) and 297 municipalities.

The methodological approach to assess hazard and risk within the administrative limits of Apulian Basin Authority is described in the Apulian HSP report, published in 2004 (resolution No. 25 - 15/12/2004), and its technical implementing rules adopted in 2005 (resolution No. 39 - 30/11/2005). As described in the HSP report and its technical implementing rules of Apulian Basin Authority, a simplified method that intersected classes of susceptibility and classes of element at risk was performed, obtaining four classes of risk (Table 15 and Table 16).

Table 15 - Landslide risk assessment according to the methodological approach of the Apulian Basin Authority.

Risk class		**Class of spatial hazard**		
		PG3	PG2	PG1
Element at risk	E5	**R4**	**R3**	**R2**
	E4	**R4**	**R3**	**R2**
	E3	**R3**	**R2**	**R1**
	E2	**R2**	**R2**	**R1**
	E1	**R2**	**R1**	**R1**

Table 16 - Description of classes of susceptibility, element at risk and risk according to the regional Basin Authority of Apulia region.

Class of spatial hazard	Description
PG1	Low and medium landslide susceptibility areas (medium and low hazard)
PG2	High landslide susceptibility areas (high hazard)
PG3	Areas with very high landslide susceptibility (very high hazard)
Class of element at risk	**Description**
E1	Absence of human settlements, activities and environmental heritage.
E2	Sports facilities, intensive crop farming.
E3	Power grids, aqueducts, sewerage systems, waste water treatment systems and minor roads.
E4	National, provincial and municipal roads (the only way to connect to the town) and railways.
E5	Urban areas, industrial areas, isolated buildings, dams and water reservoirs, recreational facilities and camping sites.
Risk class	**Description**
R1	Marginal social, economic and environmental damage.
R2	Potential minor damage to buildings, infrastructure and environmental heritage that does not affect human safety, the operability of buildings and the functioning of economic activities.
R3	Potential problems for the human safety, functional damages to the buildings and infrastructures, with the consequent inactivity of the same, the interruption of the functionality of the socio-economic activities and significant damages to the environmental heritage
R4	Potential human fatalities and serious injuries, serious damage to buildings, infrastructure and environmental heritage and destruction of socio-economic activities

The methodological approach to assess landslide hazard and risk developed by the Apulian Basin Authority highlighted the difficulties in evaluating temporal probability of landsliding and the vulnerability of elements at risk. As the matter of fact, regarding hazard assessment, Apulian Basin Authority just focused on the evaluation of spatial

probability of landsliding, not considering the assessment of temporal probability of landsliding. Moreover, vulnerability is not included in risk evaluation.
The susceptibility assessment adopted by the Apulian Basin Authority was based on:

1. a landslide inventory of past landslides, based on the information from existing databases (i.e. AVI, IFFI) and from technical reports of local administrations;
2. two thematic information layers (geology and slope angle) of predisposing factors, with different classes (for geology, many lithotypes were considered; for slope angle each class has a range of 5°).

The thematic information layers were intersected with the landslide inventory, thus obtaining the weight associated to the classes (if landslides intersect the class of reference, the weight becomes greater). The weights were subsequently grouped into two classes, and the territory was divided into three zones of landslide hazard (from the less to the most hazardous PG1, PG2 and PG3), where PG3 zone refers to areas very high susceptible to landsliding and to all the areas already affected by past landslides, according to AVI and IFFI catalogues. (Fig. 33 and Fig. 34).
Regarding risk assessment, the Apulian Basin Authority defines risk classes by combining hazard classes and classes of elements at risk (Fig. 35 and Fig. 36). However, it would be more correct to use the term 'exposure' instead of risk, reminding that the exposure is the spatial overlay of hazard and classes of elements at risk.
Finally, according to the technical implementing rules of its HSP, landslide hazard classes (and, consequently, landslide risk classes) might be modified periodically through "plan variants", which permit to modify the perimeters of the zones at different landslide susceptibility, for example after the occurrence of a hazardous event.

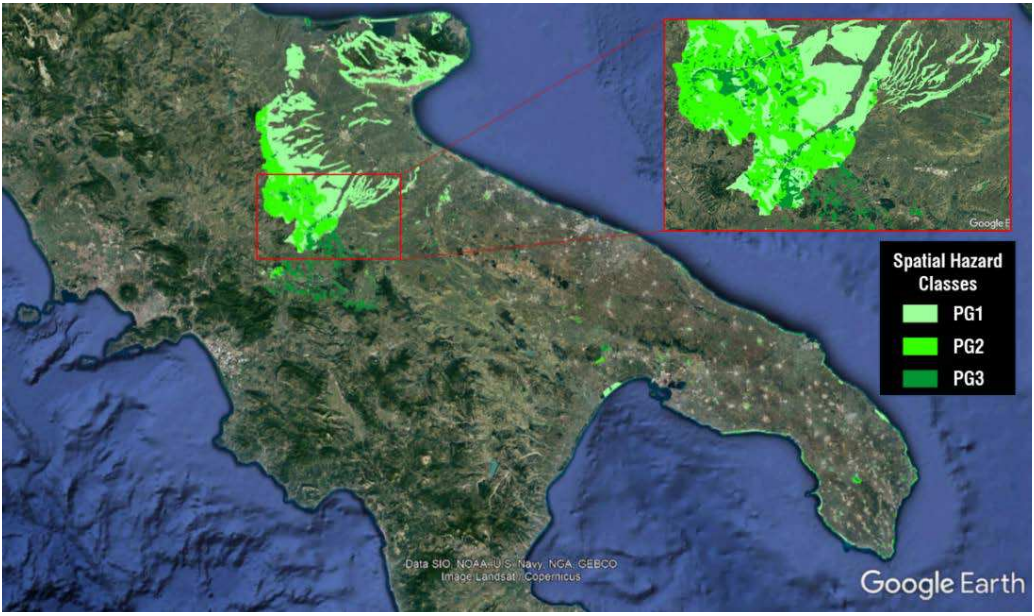


Fig. 33 - Landslide hazard (susceptibility) classes defined by the HSP of the Apulian Basin Authority, with a focus on the southern part of the Daunia area.

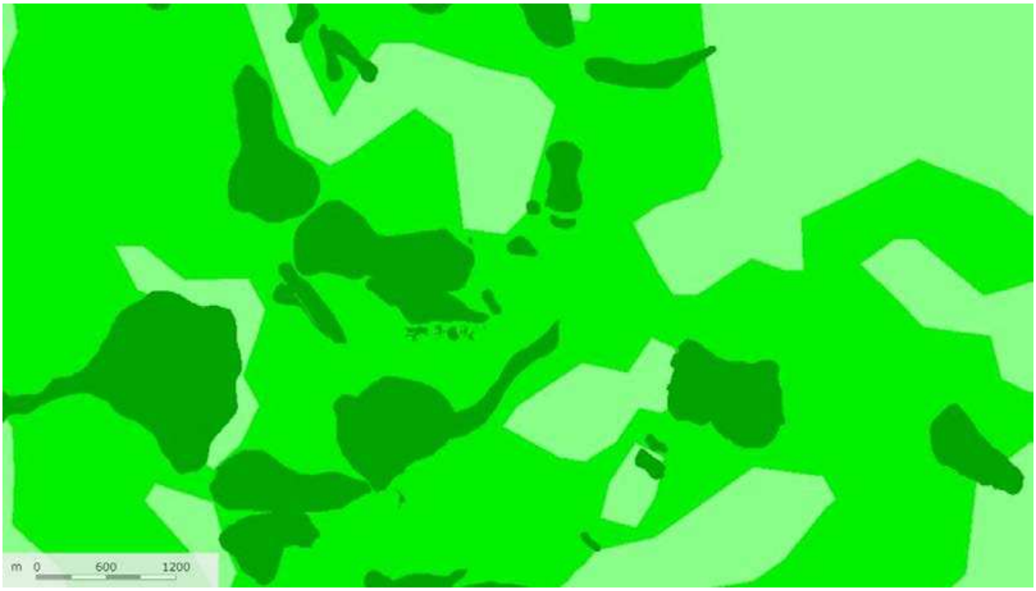


Fig. 34 - Landslide hazard classes for the municipality of Deliceto and surrounding, defined by the HSP of the Apulian Basin Authority.

Fig. 35 - Landslide risk classes for the municipality of Deliceto and surrounding: R2 (rose), R3 (orange) and R4 (red), defined by the HSP of the Apulian Basin Authority.

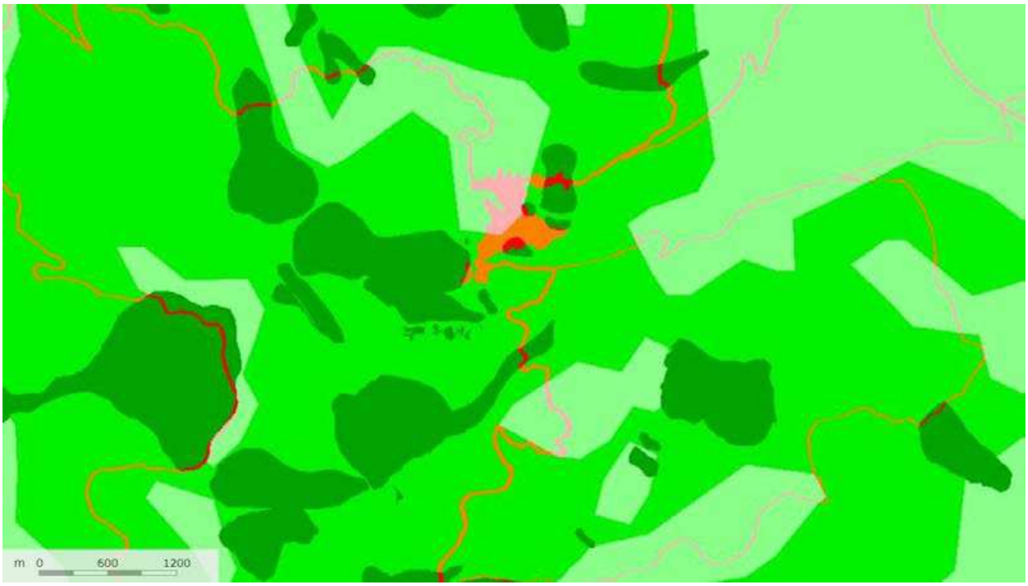


Fig. 36 - Landslide hazard and risk classes around the municipality of Deliceto, defined by the HSP of the Apulian Basin Authority.

4.3.2 Landslide hazard and risk assessment developed by the National Basin Authority of Liri-Garigliano and Volturno

Before the Legislative Decree No. 152/2006, the administrative area of the National Basin Authority of Liri-Garigliano and Volturno embraced five regions (Apulia, Abruzzo, Campania, Lazio and Molise). Some municipalities of the Daunia area (Sant'Agata di Puglia, Faeto, Anzano di Puglia and Roseto Valfortore) were administratively located partly within the area of competence of the regional Basin Authority of Apulia region, partly in the area of competence of the national Basin Authority of Liri-Garigliano and Volturno.

The methodological approach to assess landslide hazard and risk within the national Basin Authority of Liri-Garigliano and Volturno is described in its HSP report, published in 2003 (resolution No. 1 - 25/02/2003) and technical implementing rules adopted in 2006 (resolution No. 1 - 05/04/2006). It is based on a landslide inventory, which was obtained by a geomorphological study of the territory. Following Varnes' classification (Varnes and IAEG-CLOMMS, 1984), the (spatial) landslide hazard was considered at high or medium class according to landslide typology and activity (see Table 5, Table 6 and Table 7). Then, a class of intensity (high, medium or low) was associated to each mass movement occurred within its administrative area according to the expected velocity of mass movement (Table 17). Combining landslide hazard and intensity, classes of consequences were assessed (Table 18).

Table 17 - Landslide intensity classes associated to landslide velocity (see Table 6) by the National Basin Authority of Liri-Garigliano and Volturno.

Landslide intensity class	**Description**
High	Expected velocity from rapid to extremely rapid
Medium	Expected velocity from slow to moderate
Low	Expected velocity from extremely slow to slow

Table 18 - Hazard and consequences assessment carried out by by the National Basin Authority of Liri-Garigliano and Volturno.

Landslide intensity class	Hazard	Consequences
High	High	High
Medium	High	High
	Medium	Medium
Low	High	Moderate
	Medium	Low

Finally, for the urbanized areas, six classes of landslide risk were assessed combining landslide intensity, hazard and consequences (combination in Table 19, definition in Table 20).

Table 19 - Landslide risk assessment according to the methodological approach of the national Basin Authority of Liri-Garigliano and Volturno.

	Landslide intensity class	High	Medium		Low	
	Hazard	High	High	Medium	High	Medium
Consequences	High	**R4**	**R4**	**R3**		
	Medium		**R3**	**R2**		
	Moderate				**R2**	**R1**
	Low				**R1**	RPb

Table 20 - Description of landslide risk classes for the national Basin Authority of Liri-Garigliano and Volturno.

Risk class	Description
RPa (R4)	Areas where the risk is potentially high and need to be addressed more in detail.
R4	Areas at high risk, with potential losses of human lives or injuries, serious damage to buildings, infrastructure and environmental heritage, and potential destruction of socioeconomic activities.

R3	High risk area in which possible problems for the safety of persons, functional damage to buildings and infrastructures, interruption of socio-economic activities and significant damage to the environmental heritage are possible.
R2	Medium-risk area in which minor damages to buildings, infrastructure and environmental assets that does not compromise human safety, the usability of buildings and the functionality of economic activities are possible.
R1	Moderate risk area where social, economic and environmental damages are marginal.
RpB	Area where risk is potentially low; more detailed scale studies are required.

Moreover, six classes of "attention" were associated to the unurbanized areas (Table 21). Fig. 37 shows the result of hazard and risk zonation within one of the municipality of the study area.

Table 21 - Description of warning classes according the HSP of the national Basin Authority of Liri-Garigliano and Volturno.

Risk class	Description
APa	Unurbanized area with potentially high level of attention, where more detailed scale studies are required.
A4	Area of high attention, not urbanized, potentially affected by landslide phenomena expected at high intensity.
A3	Medium-high attention area, not urbanized, either in an area with active landslide expected at high intensity or in an area classified at high seismicity with quiescent landslide.
A2	Area of medium attention, non-urbanized, located within a quiescent landslide expected at high intensity
A1	Area of moderate attention, not urbanized, within a landslide expected at intensity low
APb	Potentially low attention area, more detailed scale studies are required

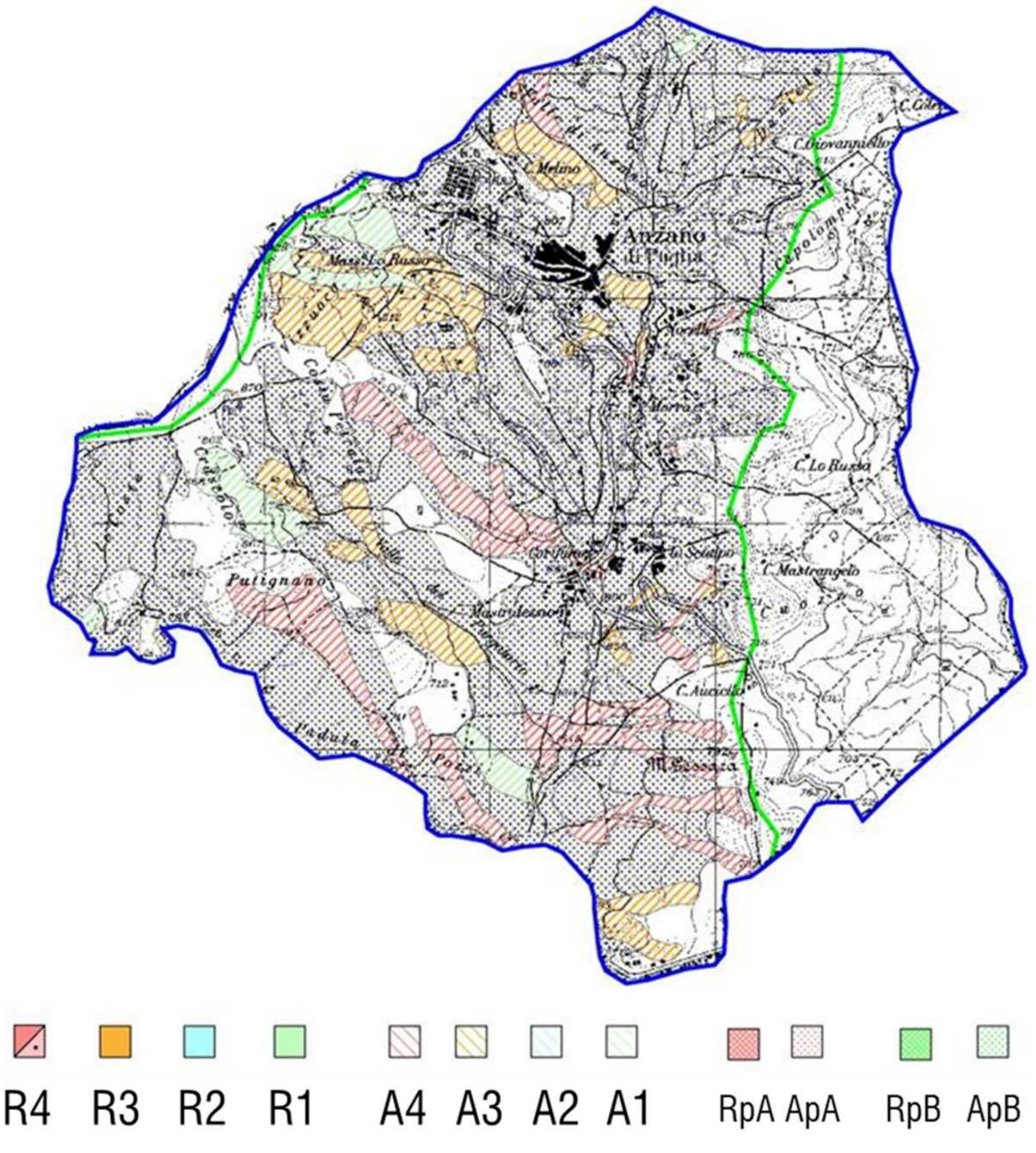


Fig. 37 - Risk zones for the municipality of Anzano di Puglia assessed by the national Basin Authority of Liri-Garigliano and Volturno.

4.4 Mitigation measures financed within the Daunia area

According to the *ReNDiS* catalogue, that is the Italian Register of Mitigation Measures, 277 projects (corresponding to € 312,768,910.33) have been financed from 1999 to 2018 in the Apulia region (Fig. 38).

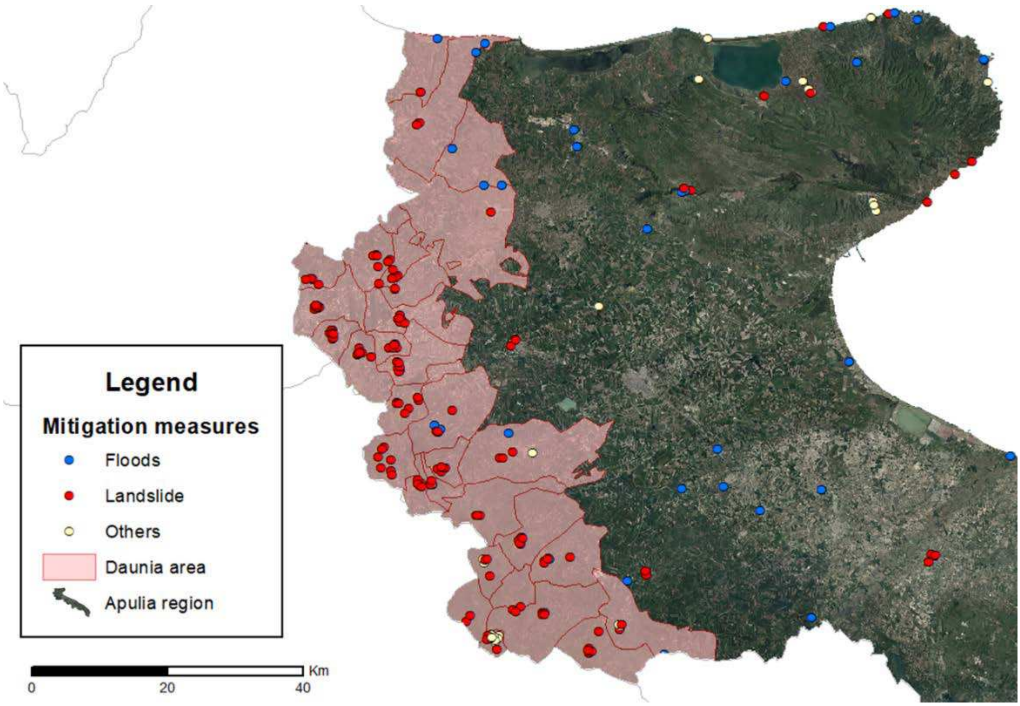


Fig. 38 - Location of mitigation measures within the Daunia area (data from ReNDiS catalogue).

They have concerned mainly mitigation of floods (91 project, corresponding to € 120,605,277.65) and landslides (170 projects, corresponding to € 173,723,667.47). The Foggia province is the most financed with 199 projects (corresponding to € 210,146,027.16), of which 161 have been financed in the Daunia area (corresponding to € 158,033,825.21) (Fig. 39).

Regarding landslide mitigation projects, almost the 85% (146 projects) of Apulian mitigation projects (170) are located in the Daunia area, with a yearly cost of mitigation measures normalized by area equal to 38.57 €/(ha*year) (Fig. 40), around eight times more than the cost for Apulia region, corresponding to 4.94 €/(ha*year).

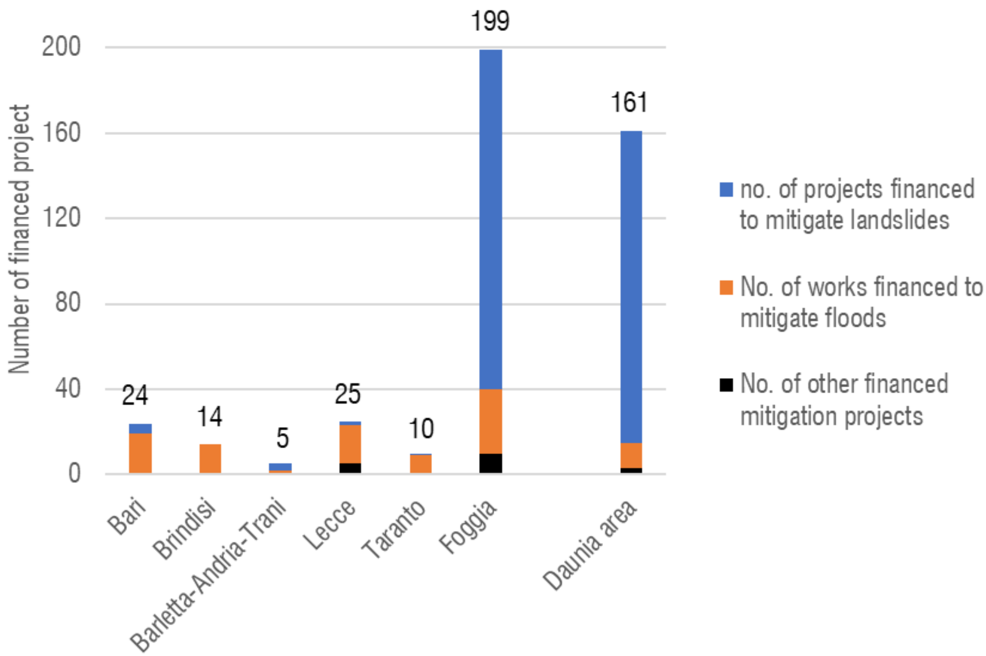


Fig. 39 - Number of financed mitigation projects for each Apulian province and for the Daunia area from 1999 to 2018.

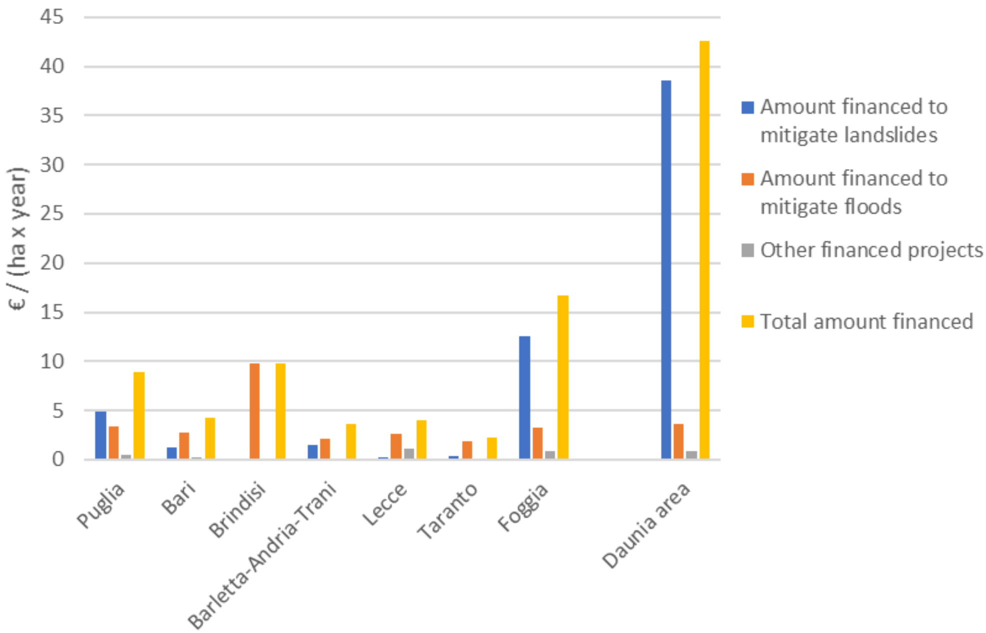


Fig. 40 - Yearly cost of mitigation projects normalised by area compared with the cost for the Daunia area.

4.5 Highlighting the limits of current data and risk methods towards a novel risk assessment

The section shows the main limits of available data, as well as the limitation of the current methodological approaches to assess hazard and risk within the southern part of the Daunia area (Fig. 41). This area is among the most impacted by landslide phenomena: many landslide events, indeed, have been registered for this part of the Foggia province, and many mitigation projects have been financed during the last years (Table 22).

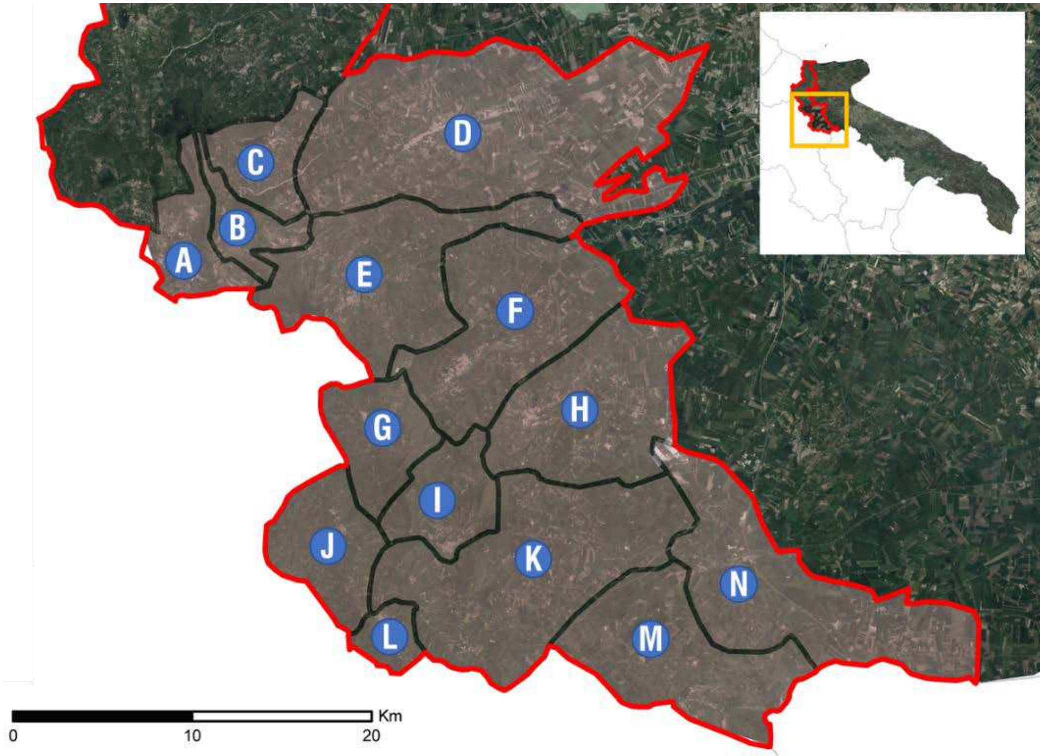


Fig. 41 - Framing the study area within the Daunia area.

Table 22 - Generalities about the 14 municipalities within the study area (Daunia area, Foggia province, Apulia region, Southern Italy). The column "Basin Authority" defines the competent Basin Authority that was in charge to assess flood and landslide hazard and risk before the Legislative Decree No. 152/2006 (a=Regional Basin Authority of Apulia region; b=National Basin Authority of Liri-Garigliano and Volturno).

Code	Municipality	Basin Autority	Landslides (IFFI catalogue)	Number of financed projects (1998-2018)	Cost of landslide mitigation measures in € / (ha x year)
I	Accadia	a	7	3	€ 29.35
L	Anzano di P.	a+b	4	4	€ 120.38
F	Bovino	a	36	4	€ 11.58
N	Candela	a	10	5	€ 27.63
C	Castelluccio Val.re	a	12	6	€ 74.60
B	Celle di San Vito	a	16	7	€ 162.58
H	Deliceto	a	30	5	€ 46.78
A	Faeto	a+b	9	5	€ 59.22
J	Monteleone di P.	a	10	1	€ 13.35
E	Orsara di Puglia	a	15	2	€ 9.86
G	Panni	a	21	3	€ 27.38
M	Rocchetta Sant'Antonio	a	13	5	€ 23.64
K	Sant'Agata di P.	a+b	14	5	€ 14.17
D	Troia	a	4	4	€ 16.02

As already highlighted, the current coordination functions and tasks in the field of soil protection, water protection, and water resource management are assigned in Italy to District Basin Authorities, which include the areas of the former competent Basin Authorities within new administrative boundaries. Despite the administrative coordination has become the same, different methodological approaches towards the assessment of landslide hazard and risk are currently implemented in their boundaries. As in the case of the Distinct Basin Authority of the Southern Apennines, different procedures have been applied. Therefore, different evaluations have been carried out within the municipalities of the same District Basin, and in few cases even within the same municipal administrative boundaries (as in the case of the municipalities of Sant'Agata di Puglia, Faeto and Anzano di Puglia).

As stated in the paragraph 4.3, the methodological approaches to assess landslide hazard and risk carried out by the competent Basin Authorities within the Daunia area do not include the assessment of landslide temporal probability within the hazard module, as well as a magnitude analysis of landslide events. Moreover, they do not assess the vulnerability of elements at risk, not including its evaluation in the risk formulation.

This is mainly due to the lack of inventories with comprehensive information about spatial, temporal and magnitude attributes about past landslides. As the matter of fact, even if some temporal and magnitude aspects exist in the available inventories, complete information is available just for a few mass movements. Thus, the current available data limit the hazard evaluation to susceptibility assessment. Moreover, data are not sufficient to carry out a landslide temporal probability assessment (Table 23), as well as to consider the magnitude of the occurred landslide events and vulnerability within hazard and risk assessment.

Assessing the temporal probability of landsliding is important because it would show the frequency of hazardous phenomena, which is also a criterion of funding in Italian legislation. However, given the widespread limitation in Italian territory about its assessment, the funding criterion is based on landslide velocity instead of frequency of landslide events, as shown in Table 12.

Table 23 - Landslide occurred within the Daunia area with spatial, temporal and magnitude aspects according to the available landslide inventories.

Landslide Inventory	Period of record	Time of record (year)	Recorded landslides	Landslide with spatial and temporal attributes	Magnitude information
AVI	1918-1998	80	224	74	Description
IFFI	Not specified		542	0	Description
Apulian Basin Authority map	Not specified		1320	0	Not specified
CNR-IRPI catalogue	1950-2014	64	92	92	Not specified

Moreover, the procedures to assess hazard and risk are diverse in the same administrative area, sometimes even within the same municipality. Therefore, inequalities in hazard and risk evaluation, as well as in the allocation of mitigation funds, might arise. In the light of above, the attempt of this work is to improve hazard evaluation, aiming to assess landslide risk at regional scale in monetary terms. Chapter 5 would illustrate in-deep the novel method carried out for assessing hazard (including temporal probability of landsliding in the hazard module) and risk at local and regional scales in monetary terms, aiming at their assessment within the southern part of Daunia area (Fig. 42).
For the hazard assessment, according to Equation 2, two aspects have been considered: “when” or how frequently a landslide will occur (landslide occurrence in an established period *t*), and “where” a landslide will occur (spatial occurrence). As first step towards the assessment of landslide temporal probability, because of the scarce information available in the current landslide inventories, a new inventory has been collected, aiming at providing complete spatial, temporal and magnitude information about each landslide occurred within the study area. The paragraph 5.1 will show the methodological approach carried out in order to collect new landslide data from official paper documents collected by the Apulian administrative office *Difesa del Suolo* (namely, Soil Defence).

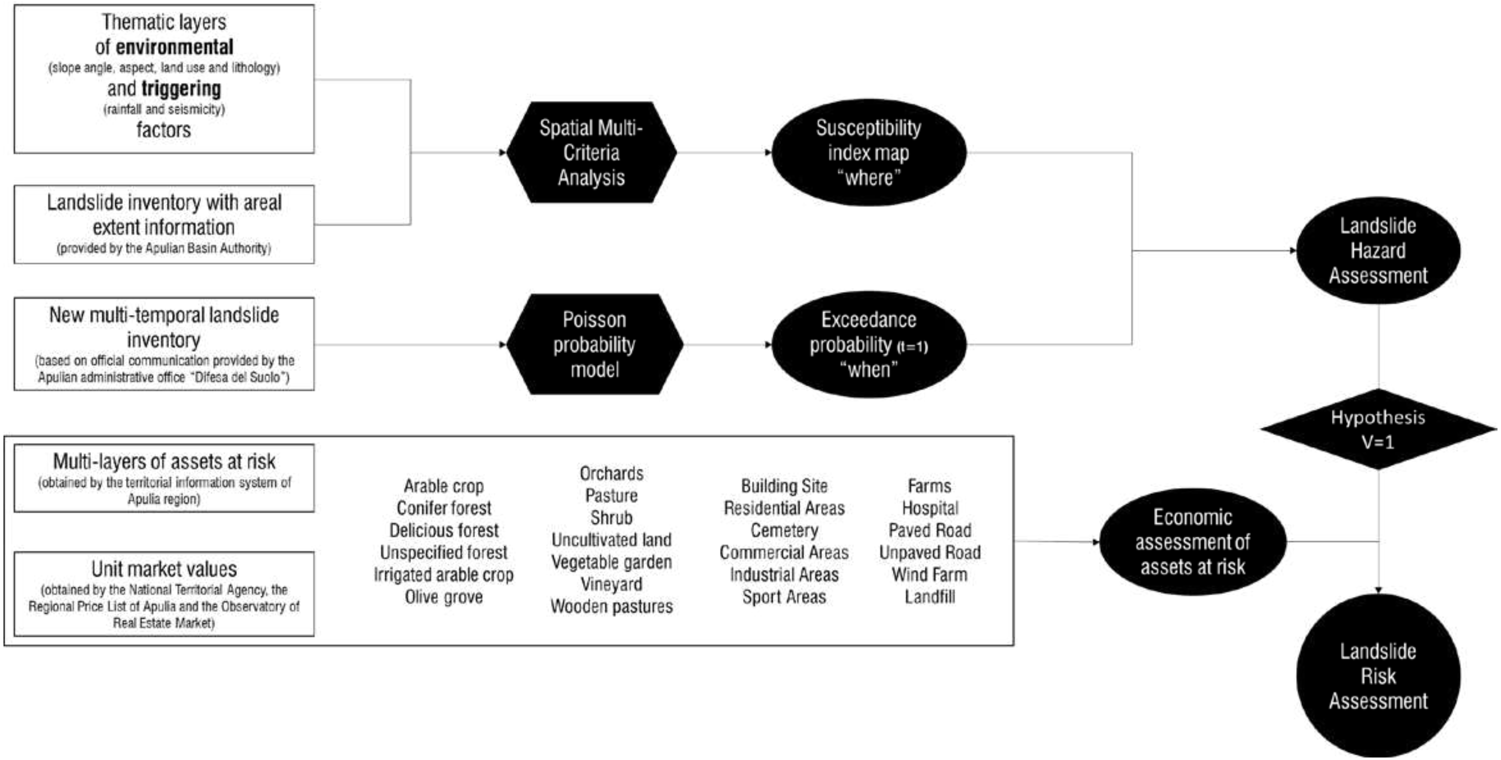


Fig. 42 - Diagram exemplifying the work flow adopted to assess landslide risk in monetary terms for a period of one year. Rectangles indicate the input data, hexagons identify the adopted models. Ellipses identify intermediate results whereas the circle defines the final result.

Consequently, the temporal probability has been evaluated applying a Poisson probability model, counting the number of landslide events within slope units and assessing the landslide temporal probability for different period *t*.
In order to assess landslide hazard, based on the assumption of independency between spatial and temporal probabilities, the result of temporal probability evaluation for a period of one year has been combined with a susceptibility map, generated by Pellicani, Westen and Spilotro (2014) using a Spatial Multi-Criteria Evaluation (SMCE) procedure in a Geographic Information System (GIS).
Successively, the resulting hazard map has been combined with the map of assets concerning the main elements at risk. Hereafter, a quantitative risk assessment has been carried out by evaluating the exposed assets (or consequences) in monetary terms for each slope unit and for each municipality within the study area. As a result, the economic risk assessment has been carried out. It shows a ranking of the municipalities most-at-risk, as well as the slope units most-at-risk within each municipality. Finally, a comparison between the economic risk for a period of one year, due to the potential occurrence of landslides, and the cost of landslide mitigation measures has been carried out.
It should be noted that the methodological approach does not include the magnitude of landslide events, as well as an estimation of the vulnerability considered as V=1. Therefore, since exposure is defined as the spatial overlay of hazard and elements at risk, and although it should be more correct to use the term “exposure assessment” rather than “risk assessment”, the two terms will be used as having the same meaning.

5 BUILDING A NEW APPROACH TO ASSESS THE LANDSLIDE RISK IN MONETARY TERMS

5.1 The new landslide inventory to assess landslide temporal probability

As first step towards the temporal probability assessment, a new database with spatial, temporal and magnitude class information for the southern part of the Daunia area are has been built, aiming at a comprehensive reconstruction of past landslide events. To build the new database, official paper documents collected by the Apulian administrative *Difesa del Suolo* office have been considered. The regional *Difesa del Suolo* office is in charge of planning structural mitigation interventions in the field of soil protection. In particular, it contributes to the selection of structural mitigation measures aimed at reducing the flood and landslide risks according to current legislation.

The paper documents collected by the regional office are mainly composed by warnings from municipalities and technical surveys made by either local or regional authorities (i.e. local technical office, administrative office of Apulia region involved in public works, Basin Authorities' reports). They concern the occurrences of landslide and flood events from the end of '90s up to now. Thus, data collection of past landslide events allowed framing the landslide movements occurred in Daunia area that caused damages, even included the smallest ones. The pieces of information collected for each landslide event were location of hazardous events (coordinates, location, streets, etc.), date of occurrence, triggering factors, types of movement and consequences of landslide impact.

The different nature of the available documents affects the exhaustiveness of the information. As a result, it was not always possible to precisely reconstruct either the spatial position or the date of occurrence. Therefore, classes of spatial and temporal accuracy (high H, medium M or low L) were associated to each landslide event.

The spatial information was considered with high accuracy (H) if coordinates were reported in the analysed document. Similarly, high accuracy was assigned to landslide movements either if their description permitted to identify the exact location, or if multi-temporal satellite images showed the mass movement. Alternatively, medium accuracy

(M) was assigned when the impacted area with some information of the spatial context was described. Finally, low spatial accuracy (L) was assigned to mass movements with generic description about the position.

Concerning the temporal accuracy, a high accuracy (H) was assigned when the day of occurrence was specified, otherwise accuracy was considered either medium (M) (if the period - in days - was addressed) or low (L) (when it was possible to identify the week or the month of landslide occurrence).

The analysed documents were undoubtedly focused on the consequences of occurred landslides, inasmuch the communications to the Apulian office of Soil protection aimed to declare the state of emergency or to request funding application. Thus, starting from the description of each landslide, the attempt was to associate a magnitude to each landslide (Table 24) in order to include the magnitude of events within the database (Fig. 43).

Table 24 - Magnitude class associated to each recorded landslide.

Magnitude class	Description
M1	Small landslides with no damages (i.e. temporary interruption of minor roads caused by small amounts of debris/mud on the roadways) or negligible damages (i.e. small collapses, small damages to structures).
M2	Landslides that cause road instability (i.e. small subsidence), large amounts of debris/mud on the roadway and damages (i.e. collapse of walls) with track width reduction, and negligible damage to build environment.
M3	Landslides that cause major damages (i.e. partial collapse of roads, building and road destruction), or interruption of vital services (damage to other infrastructure - i.e. aqueducts, sewages).

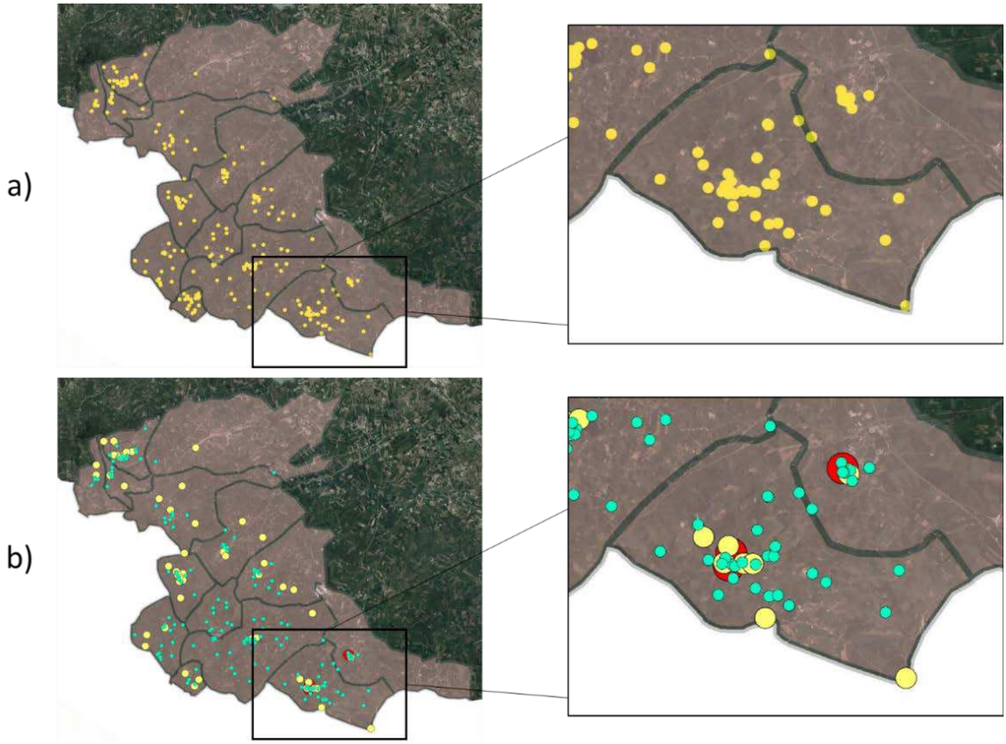


Fig. 43 - (a) New database of collected landslide events; (b) database with different magnitude classes: blue M1, yellow M2, and red M3.

5.2 Method for the assessment of landslide temporal probability

The new multi-year landslide inventory allowed counting the number of landslide events within slope unit, carrying out the assessment of landslide temporal probability within the study area. Following the method described by Crovelli (2000), the aim was to assess the possible occurrence of landslides during a specified future time *t* in an area.

The assessment was made through the Poisson probability model, which is a continuous-time model consisting in random-point events that occur independently in ordinary time (Guzzetti et al., 2005a). The Poisson model assigns probabilities to the occurrence of future landslide events for different times *t*, based on the statistics of past landslide events.

The Poisson probability model is based on the following assumptions (Crovelli, 2000):

- the numbers of events (landslides) which occur in disjoint time intervals are independent;
- the probability of an event occurring in a very short time interval is proportional to the length of the time interval. The probability of more than one event in such a short time interval is negligible.
- the probability distribution of the number of events remains the same for all time intervals of a fixed length.

The main assumptions of the Poisson continuous-time model regard the time independence of the landslide events among them, and the mean recurrence of events that will remain the same in the future, as it was observed in the past. In the light of climate change and of the complex causes of mass movements, it is important to know that these assumptions may not completely hold for the occurrence of landslides. Thus, the consequences of these assumptions should be considered when interpreting (and using) the results of the probability model. However, given a lack of understanding of the physical processes that control landslides, the Poisson model represents the best first-approximation model in attempting to model their occurrence. A first-approximation model is often applied in mathematical modelling when the assumptions are not completely satisfied by the physical process. Usually the first-approximation model is easy to work with and is mathematically tractable (Crovelli, 2000).
In the Poisson model, the probability that one or more landslides will occur during a future time *t* (exceedance probability), that is $P\{N(t)\geq 1\}$, is given by the following equation:

$$P\{N(t) \geq 1\} = 1 - e^{-t/\mu} \qquad \text{Equation 3}$$

where:

- $P\{N(t)\geq 1\}$ is the exceedance probability that one or more landslide will occur during a specific time *t*;
- μ represents the future mean recurrence interval, that is the time interval between future landslides;

- t is the period of time in the future for which the exceedance probability is calculated (i.e. t = 1 year for Annual Exceedance Probability).

The mean recurrence interval of future landslide events μ was assumed to correspond to the historical mean recurrence interval of the occurred landslide events.
To assess the historical mean recurrence interval, the number of landslide events occurred within each slope unit was counted. According to Xiao et al. (2013), a slope unit represents a territorial unit between ridge and valley, moderately homogeneous in terms of slope gradient and aspect. In the study area, slope units were derived applying an object-based image analysis to a Digital Elevation Model (DEM), generated through the interpolation of contour lines with a 5 m interval and elevation points extracted from the Apulia Regional Technical Map at scale 1:5.000.
Dividing the time of the database record (in years) by the landslide events counted in each slope unit, the historical mean recurrence interval (μ) was assessed. In turn, the Exceedance Probability was calculated within each slope unit adopting a Poisson probability model (Equation 3) for different future periods *t*.
The following economic risk assessment has been carried out combining the result of the susceptibility assessment and the output of the assessment of the exceedance probability for a period of one year (AEP). If no landslide events were counted within a slope unit, the AEP of experiencing one or more landslides would be zero. Consequently, where no landslide events are registered, landslide hazard and risk would be nullified. In order to consider landslide susceptibility where mass movements were not counted, reducing and not nullifying the hazard value in slope units without landslide events, a minimum value of 0.5 was assigned to slope units without counted landslide events. Consequently, the exceedance probability applying Poisson equation was calculated based on that value.
The main assumptions of the methodological approach to assess temporal probability of landsliding are described in Table 25.

Table 25 - The main assumptions of the methodological approach to assess landslide temporal probability.

Assumption		Explanation
1	Exceedance probabilities for different periods *t* were calculated by the application of the Poisson probabilistic model.	The Poisson probability model is a temporal probability method. Despite hazardous phenomena are deterministic, that means that every hazardous event has a cause, probabilistic models are able to incorporate our uncertainty regarding our knowledge of natural processes.
2	The historical mean recurrence interval is equal to the future mean recurrence interval.	As addressed by many authors, the past and present landslides are the key to the prediction of future frequency of landslide events (Coe et al., 2004; Fell et al., 2008). As the matter of fact, probabilistic approaches assume that the rate of landslide occurrence will remain the same in future under the given geo-environmental conditions (Jaiswal and Westen, 2009). However, in the light of climate change, this assumption may not hold for landslide events induced by rainfall. Thus, given a lack of understanding of the physical processes that control landslides, the Poisson model represents the best first-approximation model in attempting to model their occurrence (Crovelli, 2000).
3	A value of 0.5 was associated to slope units where no landslide events were counted.	The combination between spatial and temporal probabilities would be zero if no landslide events have occurred within slope units. Assuming a value 0.5 if no landslide events were counted within a slope unit means that the proposed method would not nullify landslide hazard and risk in areas that result susceptible to mass movements, even if landslide events were not recorded. The value of landslide event equal to 0.5 for the slope units where no landslide events have been recorded supposes that one landslide events might occur in an amount of time equal to twice time the investigated interval (42 years).

5.3 Towards the evaluation of landslide risk in monetary terms at local and regional scale

The results of the temporal probability assessment has been combined with a susceptibility map, that can be seen as an indication of the spatial probability of landsliding (van Westen et al., 2006). It corresponds to the result of a spatial multi-criteria evaluation (SMCE) procedure, generated by Pellicani, Westen and Spilotro (2014).

The susceptibility index map was obtained by combining two main groups of indicators (environmental and triggering factors), which are a set of thematic layers that has an influence on the occurrence of landslides. Thus, they can be utilised as causal factors in the prediction of future landslides. Because of their relevance for landslide initiation, the selected environmental factors were slope angle, aspect, land use and lithology, while rainfall and seismicity were considered as triggering factors. All factors were standardised and normalised to a range of 0-1. Then, according to their relative influence on slope instability, they were weighted implementing different procedures (i.e. direct method, pairwise comparison and rank ordering). Finally, environmental and triggering factors were combined, obtaining the susceptibility index map.

The main data used in the evaluation of the predisposing factors were:

- a DEM, generated through the interpolation of contour lines with a 5 m interval and elevation points extracted from the Apulia Regional Technical Map at scale 1:5.000;
- a *lithological map*, produced by integrating the Geological Map of Italy at 1:100.000 scale with historical geological sheets at 1:25.000 scale;
- a *land use map*, obtained from the territorial information system (SIT - Sistema Informativo Territoriale) of the Apulia Region;
- a *landslide inventory provided by the Basin Authority of Apulia region*, realized through the interpretation of stereoscopic aerial-photos, using aerial photographs at scale 1:33.000 flown in 2003 by the Italian Military Geographical Institute.

The Slope angle map was obtained by the DEM through an algorithm that calculates automatically the maximum rate of change between each cell and its neighbours in the steepest downhill direction. Even from the DEM, the Aspect map was generated by using an algorithm that identifies the downslope direction of the maximum rate of change in value from each cell to its neighbours.

Regarding land use map, the 58 land use types, available from the territorial information system of Apulia region, were merged into six classes (urban area, crops, pasture, shrubs, forests, bare and water bodies). Analysing the relationship among the six classes and the past landslide events through a bivariate statistical analysis, the relative importance of the land use classes in landslide processes were determined.

The latter environmental layer, the lithology indicator map, was composed by 16 lithological units. Correlating the landslide events with the lithologies, the definition of the higher landslide-prone unit was obtained.

The two layers regarding triggering factors considered in the susceptibility index map were rainfall and seismicity. The former, that is the main triggering factor in this area, was obtained by interpolating data of past rainfall events published by Civil Protection Authority of Apulia region. Although earthquake-triggering landslides are less frequent than rainfall events in the study area, a seismicity layer based on the peak ground acceleration was considered in the susceptibility analysis.

The final map obtained by the spatial assessment was the landslide susceptibility index map, which contains values for each grid cell (20 m x 20 m) that range between 0 (no susceptibility) to 1 (very high susceptibility) (Fig. 44).

In order to build the landslide hazard map, the susceptibility map was combined with the results of temporal probability assessment associated to the future period t of 1 year, obtaining a cell grid (20 m x 20 m) with values ranging between 0 and 1.

To facilitate the following exposure analysis, the hazard map was subdivided into hazard classes with a threshold at 1%. Consequently, the hazard value associated to the cells of each hazard class was the mean value of the considered class. As an example, the hazard value associated to the cells of the hazard class between 0.01 and 0.02 was 0.015, cells of the hazard class from 0.02 and 0.03 were assumed equal to 0.025, and so on. The first hazard class, that refers to the cells with value ranging between 0 to 0.01, was excluded from the analysis as at a level of hazard too low to be considered.

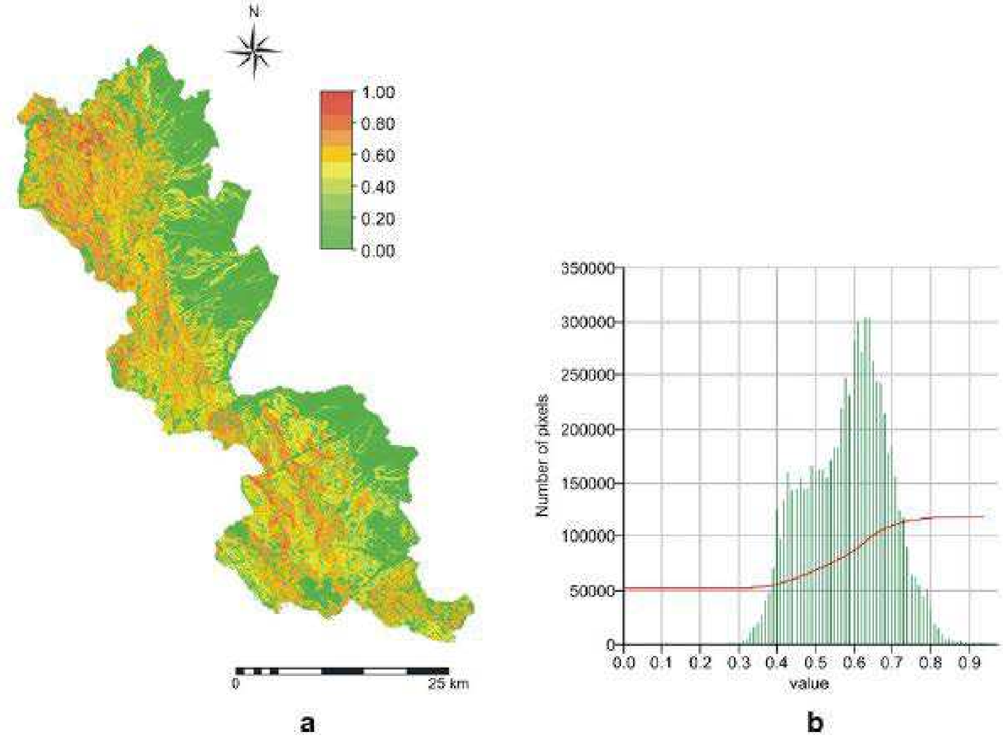


Fig. 44 - Landslide susceptibility composite index map standardised to 0–1 range; b) histogram and cumulative curve of landslide susceptibility index map (from Pellicani, Van Westen and Spilotro, 2014).

Hereafter, to carry out the quantitative assessment of the landslide exposure in monetary terms, the hazard map has been combined with asset maps concerning the main elements at risk. Exposure assessment regarded just direct and tangible losses, not including the evaluation of population and cultural heritage exposure. The layers regarding the assets at risk were obtained by the territorial information system (SIT - Sistema Informativo Territoriale) of the Apulia Region, updated to 2011. The considered 25 assets were: arable crop, conifer forest, delicious forest, unspecified forest, irrigated arable crop, olive grove, orchards, pasture, shrub, uncultivated land, vegetable garden, vineyard, wooden pastures, building site, residential areas, cemetery, commercial areas, industrial areas, sport areas, farms, hospital, paved road, unpaved road, wind farm and landfill.

The economic risk was evaluated at slope unit level and municipal level. For each asset, the areal extent within each hazard class was obtained, and it was combined with the

mean hazard class value and the unit market values or unit construction costs of the considered asset.
The unit market values of agricultural assets (expressed in Euros per hectare), updated to 2012, were obtained from the National Territorial Agency for each municipality. Concerning residential and commercial buildings, the unit market value (expressed in Euros per square meter), updated to 2018, was acquired from the Observatory of Real Estate Market instituted by the National Territorial Agency for each municipality. The unit market of building site (expressed in Euros per square meter) was assumed equal to the minimum value of residential areas for each municipality. Concerning the unit economic values (expressed in Euros per square meters) of industrial areas, hospitals, cemeteries, sports areas, landfills and farms, they were obtained by Pellicani, Van Westen and Spilotro (2014). Authors used the fixed values for the entire region, defined in 1988 by the National Territorial Agency, updated by calculating the inflation rate. For paved and unpaved roads, the unit construction costs were obtained from the Regional Price List of Apulia region updated to 2019. Finally, the economic value of wind farms was evaluated for each municipality, starting from the report about the industrial wind farms in the Apulia region updated to 2010 (LIPU-Puglia, 2010), and assessing the mean wind energy cost per square meter for each municipality.
As a result of landslide exposure assessment, the monetary consequences have been assessed at slope unit level and municipal level.

6 *RESULTS AND DISCUSSION*

6.1 Description of new landslide inventory carried out for the Southern part of Daunia area

The lack of detailed data about the temporal occurrence of landslide events limits the implementation of existing methodological approaches able to evaluate temporal probability of landsliding. As the matter of fact, many methods involved in landslide hazard and risk assessment just focus on spatial probability of landsliding (susceptibility). As described in this work, the analysis of the paper documents collected by the regional administrative office of Apulia region *Difesa del Suolo* allowed to obtain data useful for the evaluation of the temporal occurrence of landslide phenomena. Thus, data useful for this aim might exist even if they are not collected properly.

A new multi-temporal landslide inventory has been carried out for the southern part of the Daunia area (Fig. 41). For the 14 municipalities investigated, the regional administrative *Difesa del Suolo* office collected 212 paper documents that regard mass movements occurred between February 1998 and December 2018. Therefore, the recording time interval of the database is 21 years.

As shown in Fig. 45, these paper documents can be subdivided in:

- warning of municipalities (121), which are mainly communications about the occurrence of mass movements within the administrative area of each municipality, and fund requests to face the emergency phases;
- on-site investigation (68), that were carried out by local technical offices (27), the competent Basin Authority (2), regional technical offices (34) and other institutions (5);
- other documents (23), such as communications sent by the Prefect of the Foggia province to the administrative office *Difesa del Suolo*, warning from residents and legal acts.

The results of the analysis of the paper documents are summarized in Table 26. From the 212 analysed paper documents, 562 landslide events have been identified.

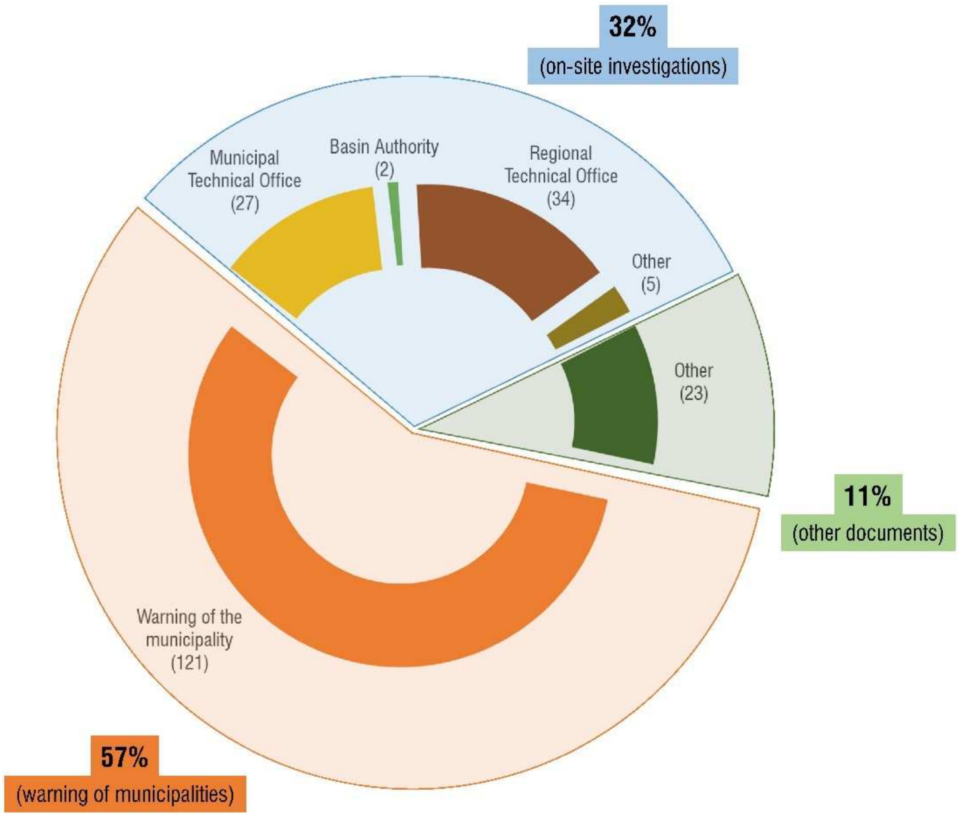


Fig. 45 - Communications collected by the regional administrative *Difesa del Suolo* office concerning landslide events occurred within the 14 municipalities of the study area.

Among them, 493 events have complete information about spatial, temporal and magnitude aspects, so they are useful to carry out the temporal probability assessment (Fig. 46). The number of landslides recorded is 236. Thus, many reactivations of mass movements have occurred during the 21 years of analysis (1998-2018). The municipalities that experienced the major number of landslide events were Rocchetta Sant'Antonio (145), Sant'Agata di Puglia (101) and Panni (53) (Fig. 47).

As many paper documents concern warning of municipalities and funding request for the emergency phase, municipalities sent them to the regional *Difesa del Suolo* office immediately after the landslide events. As a result, more than the 90% of overall landslide events (454) have a good temporal accuracy (high and medium). Moreover, even the on-site investigations identified the date of the landslide events inasmuch they have been carried out to describe more accurately the situation after the events.

Table 26 - Summary of some results of the new landslide inventory for the analysed 14 municipalities of the Daunia area.

Municipality	Landslide inventory description			Spatial accuracy			Temporal accuracy			Magnitude		
	No. of overall landslide events	No. of landslide events with complete information	No. of landslides	L	M	H	L	M	H	M1	M2	M3
Accadia	21	17	16	100%	-	-	-	-	100%	100%	-	-
Anzano di P.	37	34	18	88%	12%	-	-	70%	30%	62%	38%	-
Bovino	36	23	12	39%	39%	22%	19%	6%	75%	78%	22%	-
Candela	12	10	8	10%	60%	30%	42%	-	58%	70%	10%	20%
Castelluccio Val.re	37	35	23	43%	37%	20%	-	37%	63%	43%	57%	-
Celle di San Vito	19	14	8	79%	21%	-	42%	26%	32%	71%	29%	-
Deliceto	26	21	16	67%	14%	19%	19%	35%	46%	57%	43%	-
Faeto	8	6	6	33%	50%	17%	25%	25%	50%	67%	33%	-
Monteleone di P.	42	37	18	78%	19%	3%	3%	-	97%	78%	22%	-
Orsara di Puglia	23	19	14	84%	5%	11%	9%	30%	61%	58%	42%	-
Panni	53	48	20	79%	6%	15%	10%	20%	71%	21%	79%	-
Rocchetta Sant'Antonio	145	144	36	64%	11%	26%	3%	30%	67%	71%	22%	7%
Sant'Agata di P.	101	83	39	63%	17%	20%	-	1%	99%	96%	4%	-
Troia	2	2	2	-	50%	50%	100%	-	-	50%	50	-
TOT	**562**	**493**	**236**	**66%**	**17%**	**17%**	**8%**	**21%**	**71%**	**69%**	**29%**	**2%**

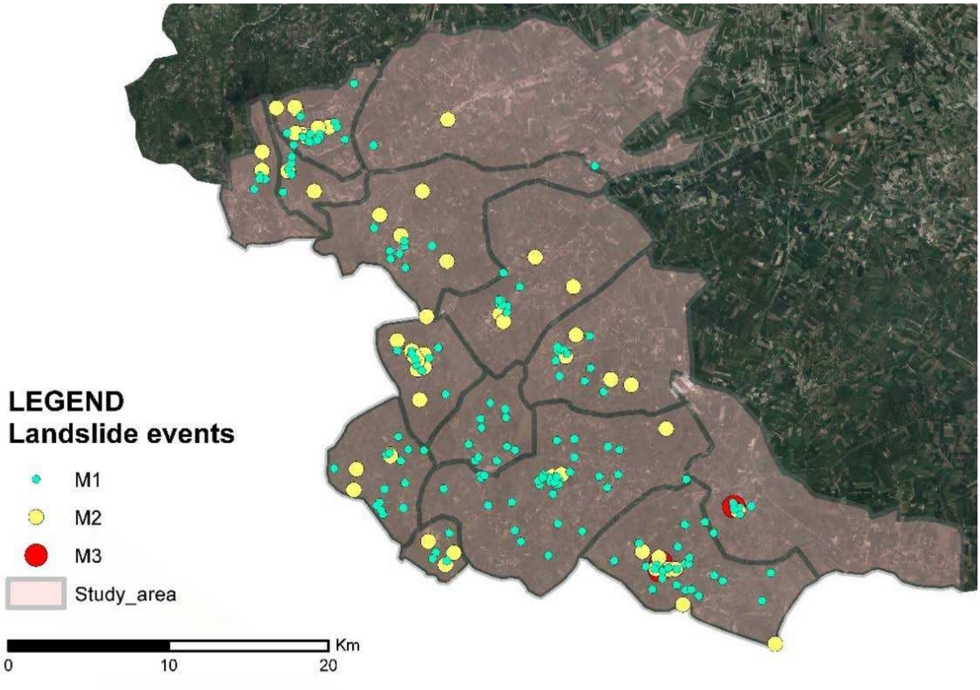


Fig. 46 - Location of the 493 landslide events of the new database inventory with magnitude information.

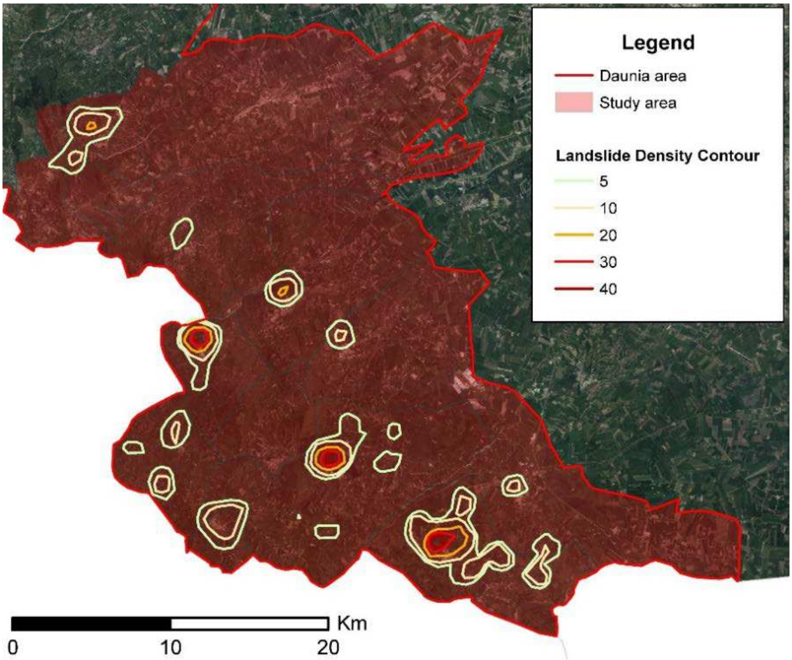


Fig. 47 - Landslide density contours that show the areas with the major number of landslide events.

Concerning the spatial accuracy, just about the 34% (166 landslide events) resulted with high and medium accuracy. The descriptions of paper documents have been interpreted in order to extract information about the location of landslide events. The focus of these documents was often on the damages and the fund request to face the emergency phase. About the location, they reported just a brief description, rarely associated with accurate spatial information (i.e. geographic coordinates). Thus, in particular with landslide events occurred in the countryside that impacted local roads, the reported descriptions were just sufficient to locate them within the impacted area (in broad and non-specific terms) using Technical Regional Maps and satellite images.

In few cases, as shown in Fig. 48, the comparison of multi-temporal satellite images provided by Google Earth allowed deriving spatial information of the occurred events with a high accuracy. As an example, Fig. 48 shows the landslide event registered on the 7th March 2009 in the municipality of Panni (in a very high susceptible area - PG3). It was described by the Technical Regional Office as follow: "After the precipitation of previous days, a landslide fell down in the rural area *Alvanello* on the municipal road *Bosco-Cotizzi*. The crown of the mass movement might affect a farm and the provincial road no. 138".

As the proposed hazard assessment was carried out at regional scale, the lack of detailed information about the exact location of landslides has a low influence on the hazard analysis. Therefore, even if with low spatial accuracy, all the landslide events with information about spatial, temporal and magnitude aspects (493) have been considered in the hazard and risk assessment.

As to the triggering factors, they were clearly identified for almost all landslide events according to the description and the available attachments. As a result, referring to the overall identified landslide events (562) occurred within the investigated period 1998-2018, around the 95% of the landslide events (532) were associated to the occurrence of rainfall events.

Fig. 48 - Example of high spatial accuracy for a landslide occurred in the municipality of Panni.

Because of the lack of detailed descriptions in the paper documents, the new inventory has limitations as to the identification of landslide typology. This information results attainable just for the 15% (85 landslides) of inventoried mass movements. Thus, starting from the available descriptions and following the Varnes' classification (Table 5), five typologies of mass movements were recognized: slides (7 %), earthflows (58 %), complex movements (13 %), rockfalls (13 %), debris flows (9 %). Moreover, just in some case, as in the rockfall occurred in Rocchetta Sant'Antonio on the 14th January 2009 in the locality "Versante Murgia del Diavolo" where the amount of movement material was estimated in around 5 m^3, a description of the amount of the moving mass was reported. Thus, no information about landslide extent was reported in the new database.

Concerning the landslide damages, the collected landslide events have affected mainly road infrastructures (Fig. 49). They have impacted municipal roads in urban environments 80 times, municipal roads in the countryside 266 times, and provincial and national roads 75 times. Moreover, many documents highlight that landslides have affected buildings 36 times, whereas they have impacted, among others, water treatment plants, local water networks and sewage lines 12 times.

With the purpose of defining the magnitude of occurred landslide events, the different rate of destructiveness of occurred landslide events was inferred from the description of their consequences. In this way, a class of magnitude (Table 24) was assigned to each landslide event. Table 26 shows that around the 68% (337) of the 493 events has a low magnitude, corresponding to a class magnitude M1, the 29% (143) belongs to the class magnitude M2, and only 13 landslide events were identified at the class magnitude M3.

Fig. 49 - Landslide impacts on provincial and municipal roads of the Daunia area (source: reports of on-site investigations provided by Apulian Administrative office).

6.2 Temporal probability assessment

The 493 landslide events inventoried for the period 1998-2018 (21 years) were used as input of the temporal probability assessment. As briefly descripted in the previous chapter, the exceedance probabilities for periods *t* were assessed through the Poisson probabilistic model. First at all, landslide events were counted in each slope unit (Fig. 50). Consequently, the mean recurrence interval (μ) of equation 3 was estimated in each of them.

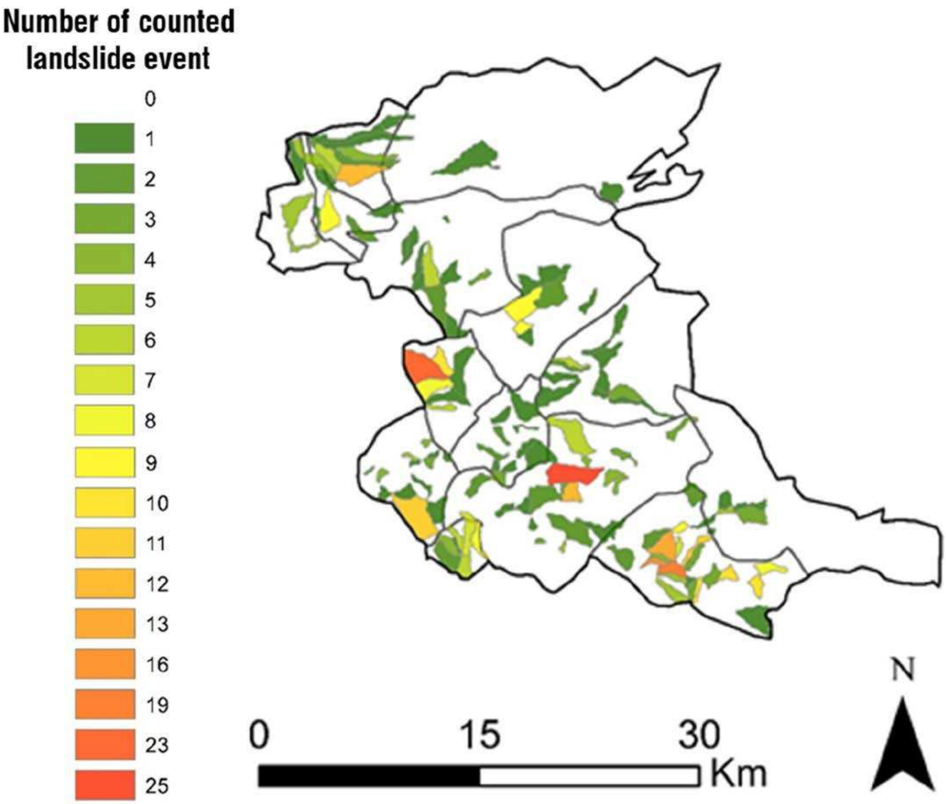


Fig. 50 - Slope units classified according to the number of landslide events counted within each slope unit of the study area.

Table 27 shows the exceedance probabilities, that are the probabilities of experiencing one or more landslide events in the future time *t*, assessed by the Poisson equation. As the matter of fact, they are associated to the number of landslide events counted within each slope unit, applying Equation 3.

Table 27 - Input (density of landslide events) and output (exceedance probability of experiencing one or more landslides during a period *t*) of the Poisson probability model.

Density of landslide events	**Mean Recurrence Interval (μ)**	**Exceedance Probability**			
no. of counted landslide events	(years)	*t=1* year	*t=5* year	*t=10* year	*t=20* year
0,5*	42	2,35%	11,22%	21,19%	37,89%
1	21	4,65%	21,19%	37,89%	61,42%
2	10,5	9,08%	37,89%	61,42%	85,11%
3	7	13,31%	51,05%	76,03%	94,26%
4	5,25	17,34%	61,42%	85,11%	97,78%
5	4,2	21,19%	69,59%	90,75%	99,15%
6	3,5	24,85%	76,03%	94,26%	99,67%
7	3	28,35%	81,11%	96,43%	99,87%
8	2,63	31,68%	85,11%	97,78%	99,95%
9	2,33	34,86%	88,27%	98,62%	99,98%
10	2,1	37,89%	90,75%	99,15%	99,99%
11	1,91	40,77%	92,71%	99,47%	100,00%
12	1,75	43,53%	94,26%	99,67%	100,00%
13	1,62	46,15%	95,47%	99,80%	100,00%
14	1,5	48,66%	96,43%	99,87%	100,00%
15	1,4	51,05%	97,19%	99,92%	100,00%
16	1,31	53,32%	97,78%	99,95%	100,00%
17	1,24	55,49%	98,25%	99,97%	100,00%
18	1,17	57,56%	98,62%	99,98%	100,00%
19	1,11	59,54%	98,92%	99,99%	100,00%
20	1,05	61,42%	99,15%	99,99%	100,00%
21	1	63,21%	99,33%	100,00%	100,00%
22	0,95	64,92%	99,47%	100,00%	100,00%
23	0,91	66,55%	99,58%	100,00%	100,00%
24	0,88	68,11%	99,67%	100,00%	100,00%
25	0,84	69,59%	99,74%	100,00%	100,00%

* The value 0.5 was assigned to the slope unit where no landslide events were counted.

As shown in Fig. 51, the probability of having one or more landslides increases with time *t.*

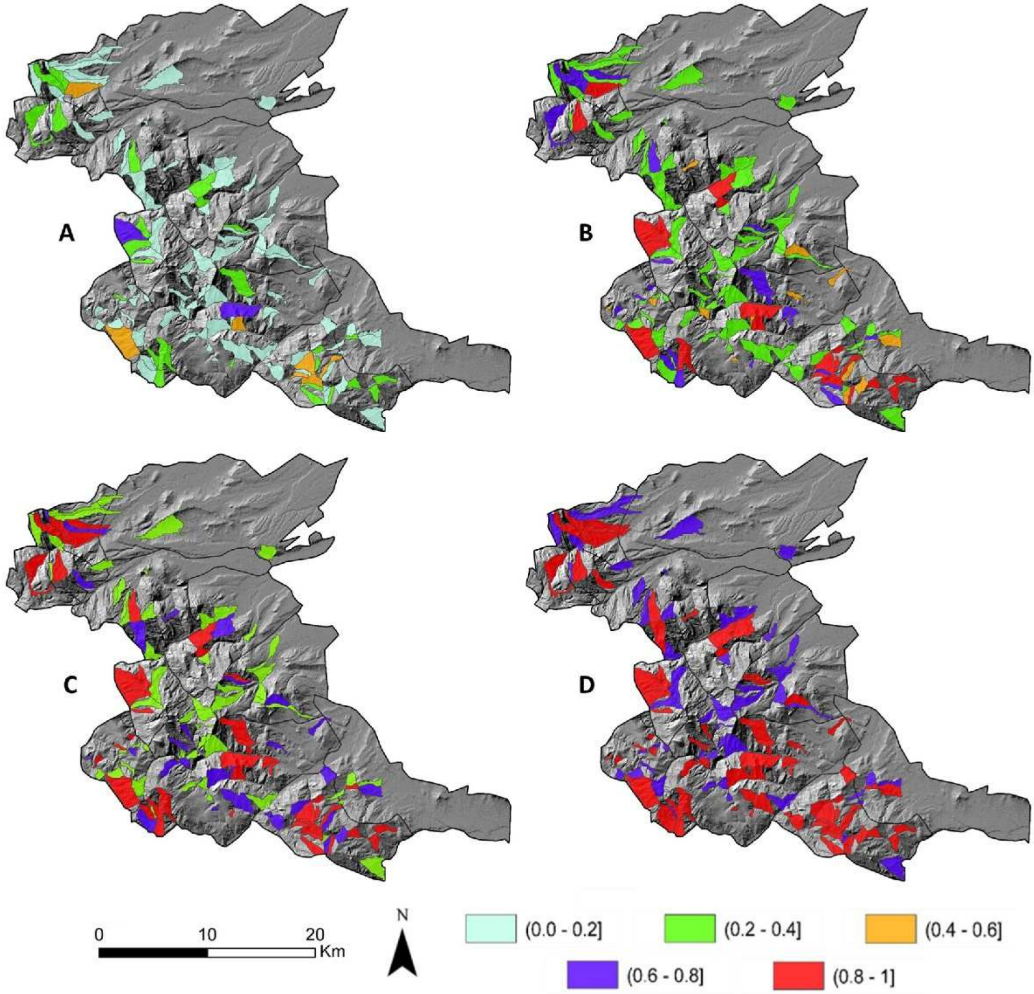


Fig. 51 - Exceedance probabilities of landslide occurrence for different periods (A - 1 year; B - 5 years; C - 10 years; D - 20 years). Square bracket indicates that class limit is included; round bracket indicates that class limit is not included.

As shown in Fig. 50 and Fig. 51, the slope units that counted more than 10 landslide events correspond to the slopes where residential buildings are located. As an example, Fig. 52 and Fig. 53 show a focus on the municipalities of Panni and Sant'Agata di Puglia, in which the slope units with the major number of landslide events are located.

The correspondence between the slope units with residential buildings and slope units with the major number of landslide events is probably due to the nature of the communications used to build the new multi-temporal inventory. As the matter of fact, landslide events were selected from communication collected by a regional administrative office in charge of planning structural mitigation interventions in the field of soil protection. Thus, the collected landslide events are those that caused damages and, consequently, the multi-temporal landslide inventory might not include the mass movements occurred within the territory that do not cause damages to assets.

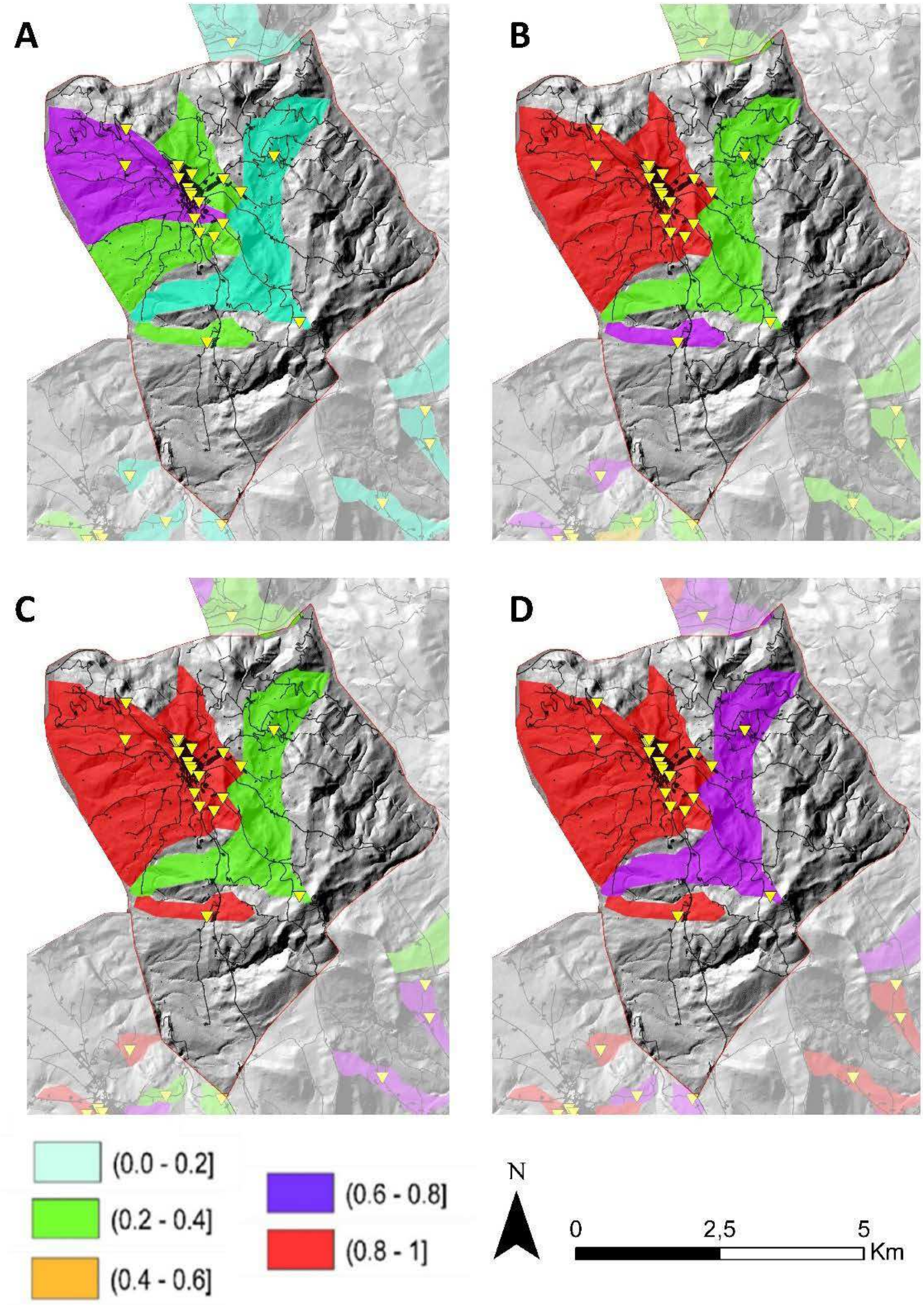


Fig. 52 - Focus on the municipality of Panni. Exceedance probabilities of landslide occurrence for different periods (A - *t=1* year; B - *t=5* years; C - *t=10* years; D - *t=20* years). Square bracket indicates that class limit is included; round bracket indicates that class limit is not included.

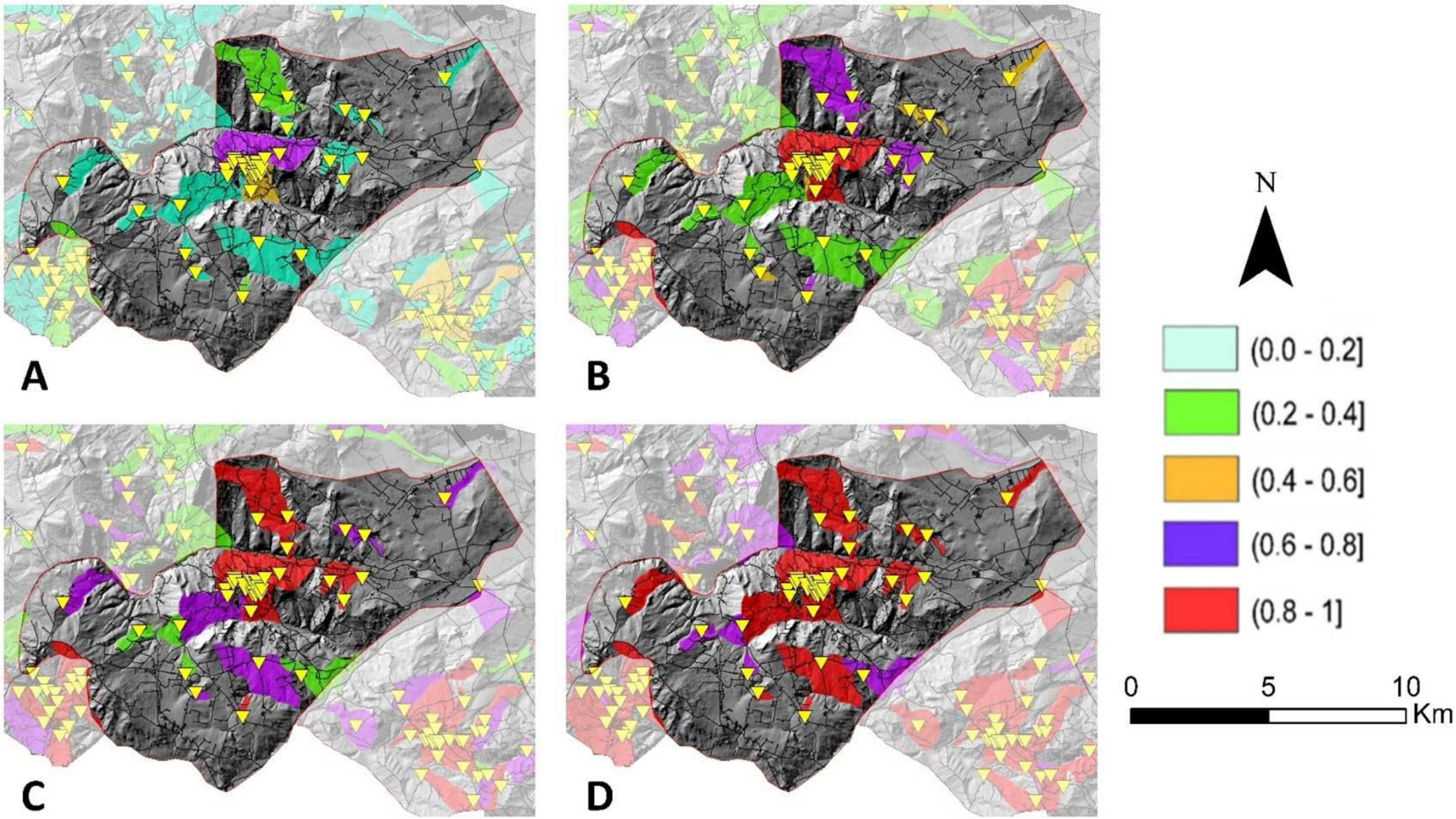


Fig. 53 - Focus on the municipality of Sant'Agata di Puglia. Exceedance probabilities of landslide occurrence for different periods (A - *t=1* year; B - *t=5* years; C - *t=10* years; D - *t=20* years). Square bracket indicates that class limit is included; round bracket indicates that class limit is not included.

6.3 Landslide risk assessment in monetary terms

In order to assess landslide hazard, which represent an intermediate result towards landslide risk assessment in monetary terms (Fig. 42), the landslide temporal map resulting from the application of the Poisson probability model for a period of one year (AEP) was combined with the susceptibility map.
The hazard map was constituted by cells of 20 m x 20 m with values ranging between 0 to 1. To facilitate the following landslide risk assessment in monetary terms, the resulting hazard map has been subdivided into several hazard classes. Each hazard class has a unique hazard value, which corresponds to the mean value of the reference interval (Table 28). As to the hazard value associated to the first class, that refers to the cells with value ranging between 0 to 0.01, it has been assumed equal to 0, because the first class was assumed at a negligible level of landslide hazard and risk (Fig. 54).

Table 28 - Ranges of the hazard classes and the corresponding hazard values.

Hazard Class	Range of the hazard class	Hazard value associated to the corresponding class
1	0 - 0.01	0
2	0.01 - 0.02	0.015
3	0.02 - 0.03	0.025
------	------	------
99	0.98 - 0.99	0.985
100	0.99 - 1.00	0.995

Hereafter, since the vulnerability was excluded from the current risk analysis and considered equal to 1, the economic risk assessment has been carried out as follow:

1. the economic values of each asset have been multiplied by the areal extent within each hazard class and its corresponding hazard value;
2. by summing all these combination within the unit area (either municipal area or slope unit), the economic risk associated to the probability of landslide occurrence during the next one year has been obtained.

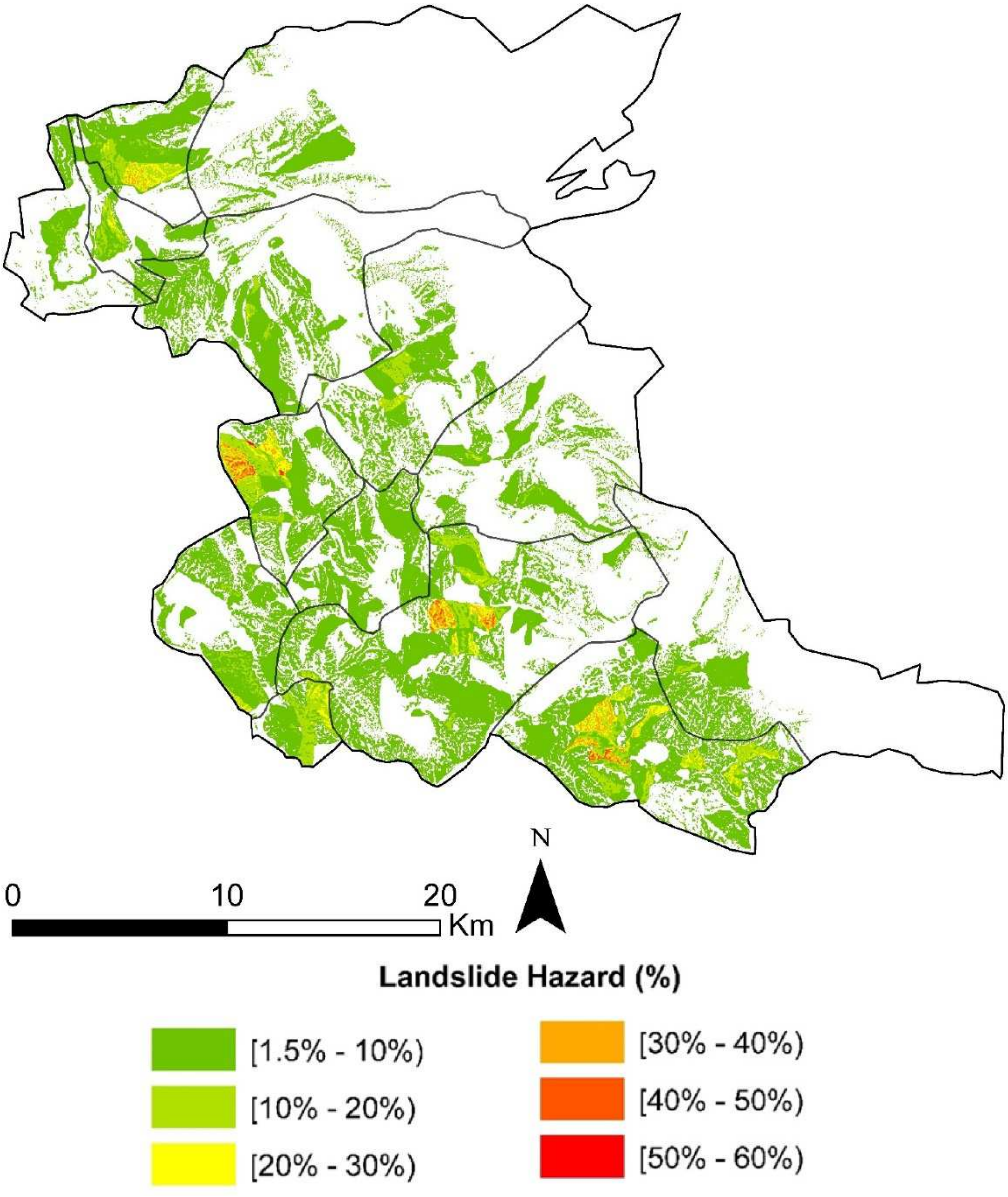


Fig. 54 - Joint probability of landslide spatial occurrence (susceptibility) and AEP (exceedance probability for a period of one year) within the study area.

Fig. 55 represents the results of landslide risk assessment in monetary terms estimated at municipal level, whereas Table 29 shows the result of the landslide risk assessment for the 14 municipalities, their areal extent in square kilometres and the landslide risk in monetary terms normalised by the corresponding municipal area.

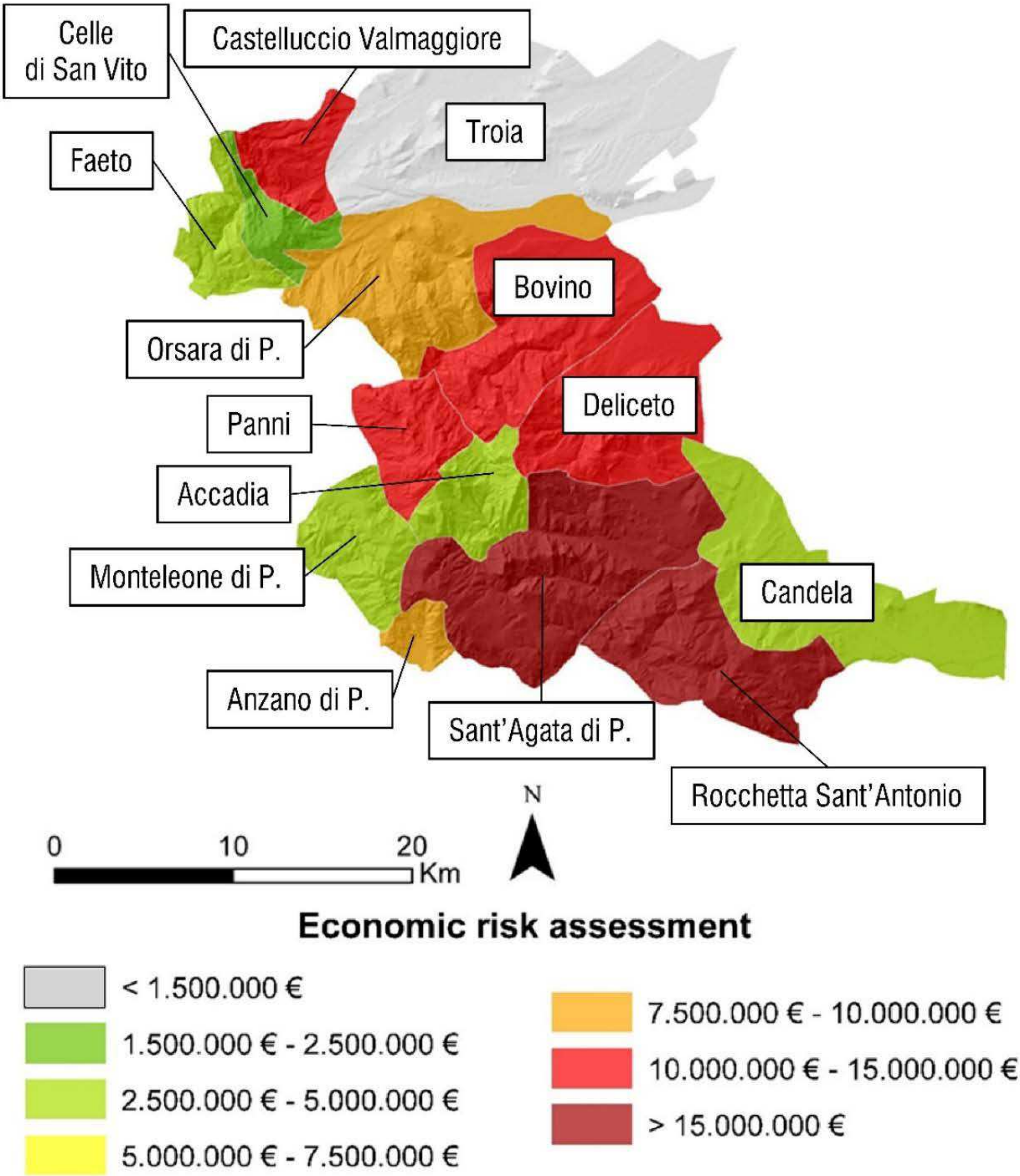


Fig. 55 - Ranking map of the 14 municipalities according to the estimated landslide economic risk.

Table 29 - Estimated landslide economic risk for the investigated municipalities, associated to the exceedance probability of experiencing one or more landslide in the next year, the estimated economic risk normalised by the corresponding municipal area. and the percentage of municipal area classified as hazardous (obtained from Fig. 54).

Municipality	Economic risk (€)	Municipal area (sq. Km)	Economic risk normalised by municipal area (€/ha)	% of municipal area classified as hazardous
Accadia	3,654,362.83 €	30.45	1,200.25 €	57%
Anzano di Puglia	8,697,134.79 €	10.88	7,992.37 €	77%
Bovino	12,218,878.41 €	84.21	1,450.92 €	24%
Candela	3,170,695.41 €	97.43	325.43 €	14%
Castelluccio Valmaggiore	14,919,567.59 €	26.59	5,611.36 €	62%
Celle di San Vito	1,616,804.50 €	18.36	880.66 €	46%
Deliceto	12,138,419.09 €	76.01	1,597.03 €	23%
Faeto	3,973,148.30 €	26.12	1,520.97 €	26%
Monteleone di Puglia	4,190,393.57 €	36.84	1,137.47 €	50%
Orsara	9,169,460.45 €	83.68	1,095.75 €	31%
Panni	14,117,571.98 €	32.61	4,328.78 €	63%
Rocchetta Sant'Antonio	21,846,918.86 €	72.46	3,015.18 €	60%
Sant'Agata di Puglia	20,047,555.50 €	116.15	1,726.00 €	47%
Troia	1,046,988.55 €	168.12	62.28 €	7%

As shown in Fig. 55 and Table 29, the estimated landslide risk in monetary terms results higher than the above-average value (9,343,421.42 €) for the municipalities Rocchetta Sant'Antonio (21,846,918.86 €) and Sant'Agata di Puglia (20,047,555.50 €), that are located in the southern part of the study area, followed by Castelluccio Valmaggiore (14,919,567.59 €), located in the northern part, and Panni (14,117,571.98 €), Bovino (12,218,878.41 €) and Deliceto (12,138,419.09 €), that are located in the central part. Comparing the estimated landslide risk and the extent of the municipal areas, they seem to be related with some exceptions. As the matter of fact, despite the high estimated landslide risk in monetary terms, Castelluccio Valmaggiore and Panni are two of the smallest municipalities of the study area. This is because around the two-third of the municipal areas are classified as hazardous areas. As to the municipalities of Troia (1,046,988.55 €) and Candela (3,170,695.41 €), they result as the least at-risk although they are two of the largest ones because around one-tenth of the municipal areas results as hazardous.

In order to reduce the influence of the municipal areal extent, another comparison among municipalities within the study area has been done by normalising the economic risk at municipal level by the corresponding municipal areal extent, as represented in Fig. 56.

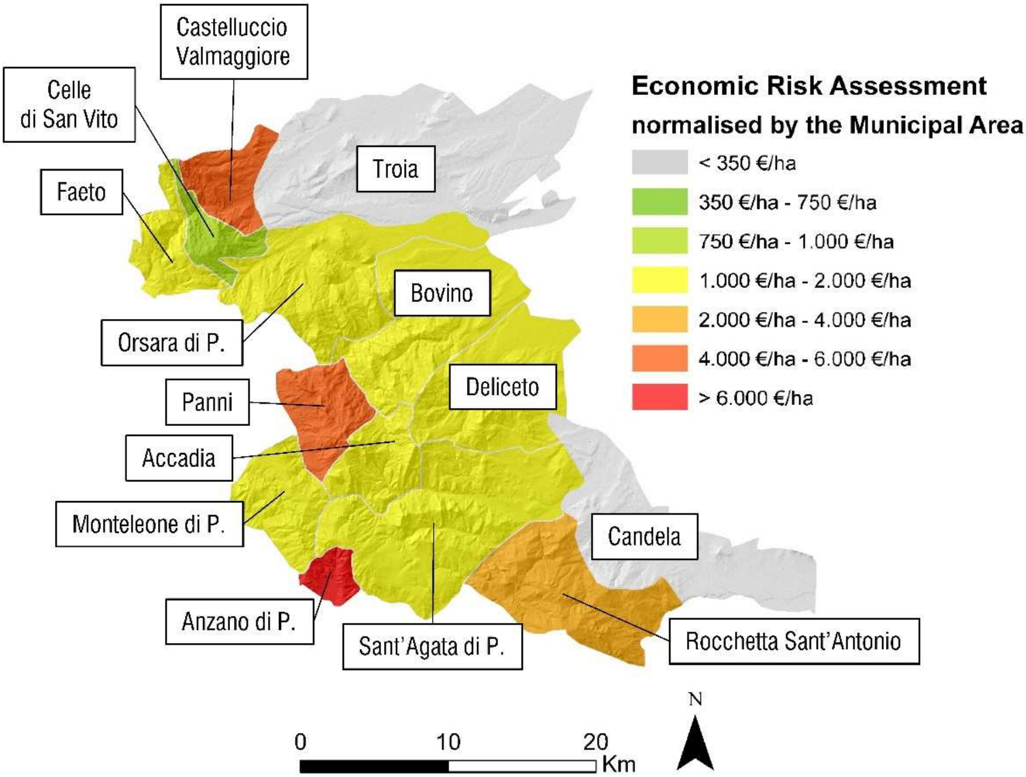


Fig. 56 - Ranking map of the 14 municipalities according to the estimated economic risk assessment normalised by the corresponding municipal area.

By normalising the landslide risk in monetary terms in respect of the municipal area, Anzano di Puglia (7,992.37 €/ha), Rocchetta Sant'Antonio (3,015.18 €/ha), Castelluccio Valmaggiore (5,611.36 €/ha) and Panni (4,328.78 €/ha) result as the municipalities with the higher risk level. In particular, Anzano di Puglia, that has a moderate value of estimated economic risk (8,697,134.79 €) and the smallest areal extent (10.88 sq.km), results as the municipality with the highest level of normalised landslide risk. Moreover, Troia (62.28 €/ha) and Candela (325.43 €/ha) are the municipalities at the lowers level of estimated economic risk. It can be noted that a good relation between the economic landslide risk normalised by municipal areal extent and the percentage of municipal area classified as hazardous exists. As the matter of fact, the municipalities with the highest percentage of hazardous area are Anzano di Puglia (77%), Panni (63%), Castelluccio Valmaggiore (62%) and Rocchetta Sant'Antonio (60%) are also the ones with the higher value of normalised risk. Concerning the municipalities with the lowest percentage of hazardous area, Troia (7%) and Candela (14%) are also the ones least-at-risk.

Focusing on two municipalities between the above-cited most-at-risk, that are Panni (Fig. 57) and Rocchetta Sant'Antonio (Fig. 58), the landslide risk assessment in monetary terms has been also carried out at slope unit level in order to define the location of the most at-risk slopes.

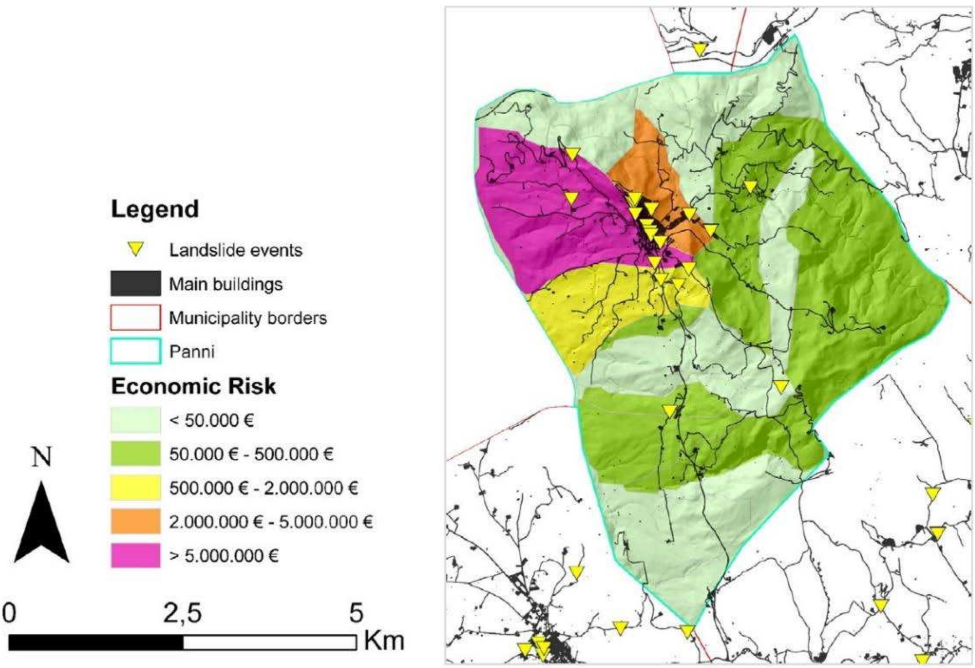


Fig. 57 - Landslide risk assessment in monetary terms at slope unit level for the municipality of Panni.

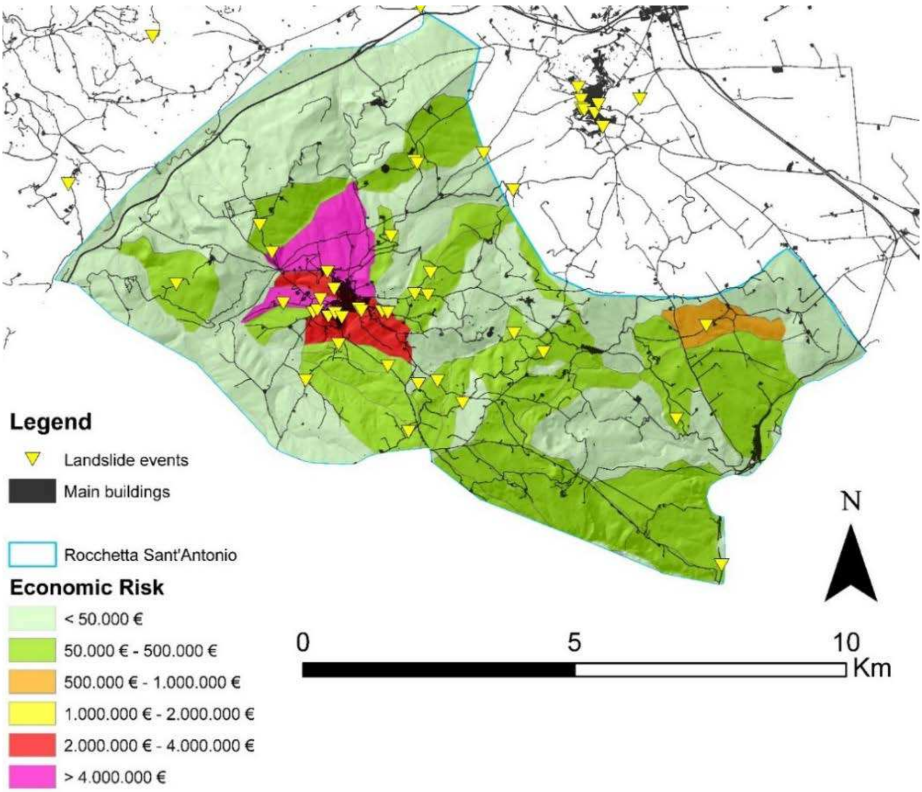


Fig. 58 - Landslide risk assessment in monetary terms at slope unit level for the municipality of Rocchetta Sant'Antonio.

In both cases, as shown for the slopes with the highest value of exceedance probabilities of landsliding (Fig. 52 and Fig. 53), most-at-risk slopes are those that involve residential buildings. As the matter of fact, the economic risk of residential buildings generally accounts for more than the half of the total economic landslide risk for each municipality within the study area.

A validation of the procedure to assess landslide risk in monetary terms might be carried out by comparing the estimated economic risk with the recorded economic losses related to past landslide events. However, because of the lack of these economic data, an attempt to validate the obtained results can be based on the comparison between the funds financed to mitigate landslide risk (obtained by the *ReNDiS* catalogue) and the estimated landslide economic risk. Table 30 shows the financed mitigation measures per each municipality and the yearly cost of mitigation measures normalised by the municipal areal extent.

Table 30 - Comparison between estimated landslide risk in monetary terms and financed mitigation measures for the municipalities within the study area.

Municipality	Estimated landslide risk	Areal extent	Economic risk normalised by municipal area	Financed mitigation measures	Yearly cost of mitigation measures normalized by areal extent
	€	sq. km	€/ha	€	€/(ha*y)
Accadia	3,654,362.83 €	30.45	1,200.25 €	1,876,456.90 €	29.35 €
Anzano di Puglia	8,697,134.79 €	10.88	7,992.37 €	2,750,800.00 €	120.38 €
Bovino	12,218,878.41 €	84.21	1,450.92 €	2,047,228.45 €	11.58 €
Candela	3,170,695.41 €	97.43	325.43 €	5,654,193.90 €	27.63 €
Castelluccio Valmaggiore	14,919,567.59 €	26.59	5,611.36 €	4,165,154.80 €	74.60 €
Celle di San Vito	1,616,804.50 €	18.36	880.66 €	6,267,976.73 €	162.58 €
Deliceto	12,138,419.09 €	76.01	1,597.03 €	7,466,456.90 €	46.78 €
Faeto	3,973,148.30 €	26.12	1,520.97 €	3,248,829.72 €	59.22 €
Monteleone di Puglia	4,190,393.57 €	36.84	1,137.47 €	1,032,913.80 €	13.35 €
Orsara	9,169,460.45 €	83.68	1,095.75 €	1,732,913.80 €	9.86 €
Panni	14,117,571.98 €	32.61	4,328.78 €	1,875,142.25 €	27.38 €
Rocchetta Sant'Antonio	21,846,918.86 €	72.46	3,015.18 €	3,597,705.61 €	23.64 €
Sant'Agata di Puglia	20,047,555.50 €	116.15	1,726.00 €	3,456,824.77 €	14.17 €
Troia	1,046,988.55 €	168.12	62.28 €	5,654,937.07 €	16.02 €

Comparing the cost of mitigation measures (Fig. 59) with the estimated economic risk, among the municipalities most financed, Deliceto (7,466,456.90 €) results with a corresponding high value of estimated economic landslide risk. Celle di San Vito (6,267,976.73 €), Troia (5,654,937.07 €) and Candela (5,654,193.90 €) are among the most financed municipalities although they result the less ones at-risk.

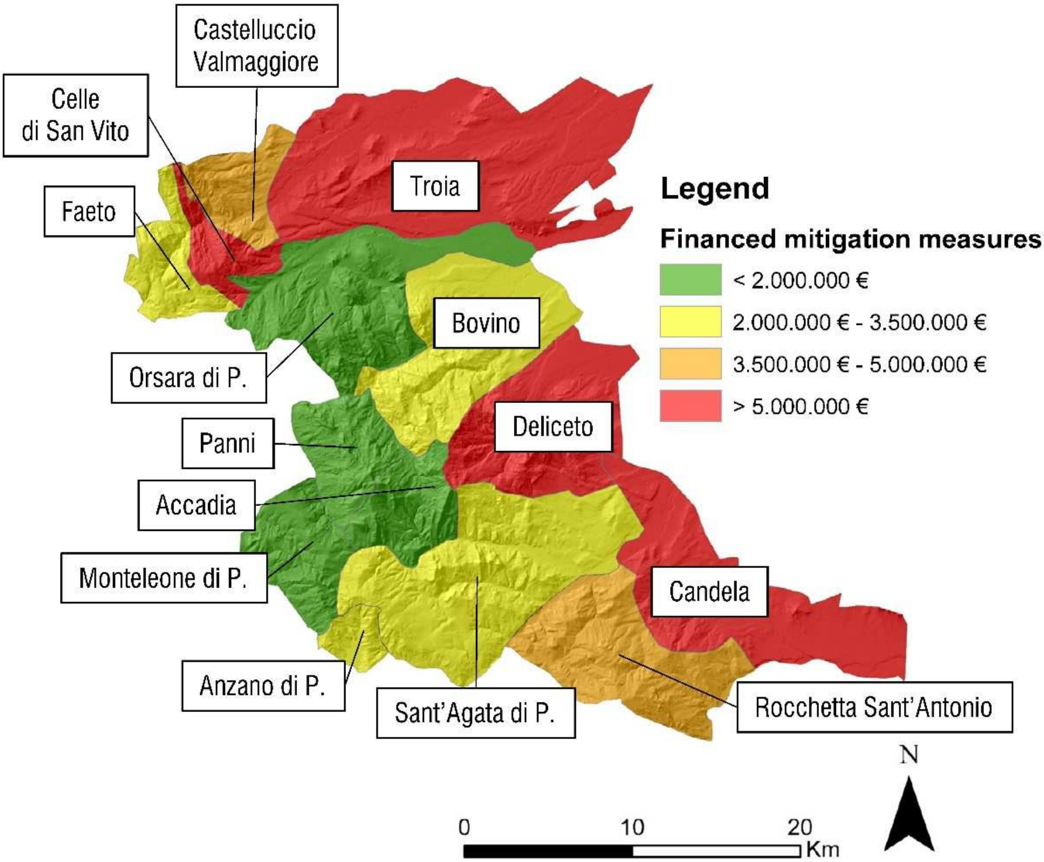


Fig. 59 - Financed landslide mitigation measures with the municipality of the study area.

To avoid the influence of the municipal areal extent, even in this case the funds of mitigation measures have been normalised by the municipal areal extent. Comparing the yearly cost of mitigation measures normalised by the municipal areal extent and the estimated landslide economic risk, it is possible to see that Castelluccio Valmaggiore (74.60 €/ha) and Anzano di Puglia (120.38 €/ha) are among the most yearly financed and they also result among the more at-risk. Instead, the most financed results Celle di San Vito (162.58 €/ha) even if it is among the least at economic risk (Fig. 60).

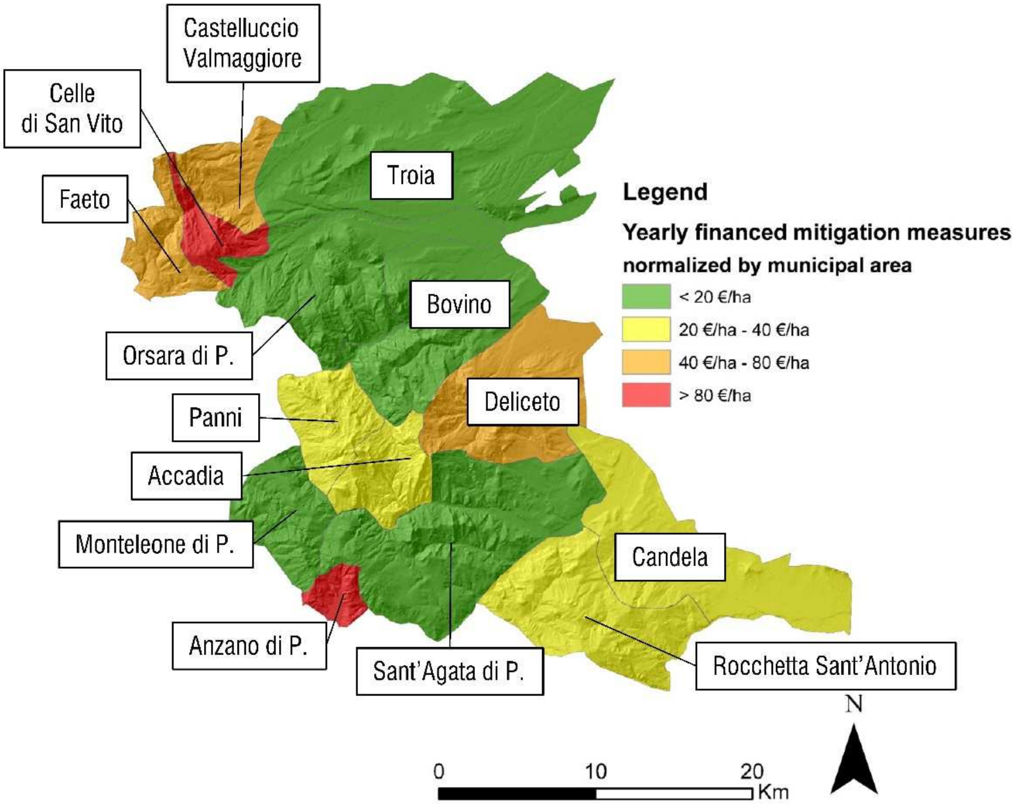


Fig. 60 - Yearly financed landslide mitigation measures normalised by areal extent.

7 CONCLUSIONS

The scope of the work has been reviewing and improving the current procedures concerning landslide hazard and risk analysis. In detail, this work has dealt with the implementation of temporal probability in landslide hazard analysis, aiming at estimating the risk in monetary terms at regional scale in a hazard-prone area located in southern Italy (Southern part of Daunia area, Apulia region). To date, as described in the Hydro-geomorphological Setting Plans (HSPs) currently adopted in the above-mentioned area, landslide hazard module considers just the spatial probability of landsliding (susceptibility), whereas landslide risk has been obtained by combining susceptibility and elements at risk. The results are synthesized in different hazard and risk maps subdivided in several hazard and risk classes.

A first critical aspect that emerges by examining the currently adopted HSPs concerning the Italian territory is that different procedures to assess landslide hazard and risk has been applied to classify it. According to the Italian legislation, Basin Authorities with local competencies have been unified in District Basin Authorities. For the municipalities located in the Daunia area, the current legislation assigns the coordination functions and tasks in the field of soil protection to the District Basin Authority of Southern Apennines. However, several hazard and risk classifications exist in its area of competence. They have been evaluated through different methods because several Basin Authorities were previously competent in many portions of the territory. Therefore, what emerges is the need to standardize hazard and risk classification methods within the area of competence of each District Basin Authority in order to avoid inequalities in hazard and risk classification, and consequently in the allocation of funds for mitigation measures. As already highlighted, another critical aspect in the procedure of HSPs regards the landslide hazard assessment. As the matter of fact, landslide hazard evaluation often concerns only the spatial probability of landsliding, excluding the assessment of temporal probability from risk analysis. This is essentially due to the lack of information concerning temporal occurrence of past landslide events in the available inventories. Concerning the Daunia area, the available inventories at national and regional scale report, indeed, scarce information about the date of occurrence of past landslide events. Thus, available data result incomplete towards the assessment of landslide temporal probability. However, assessing the temporal probability of land-sliding is important because it would show the frequency of hazardous phenomena, which is also a criterion of funding in Italian legislation.

Concerning the elements at risk, their exposure is not quantified as to the economic value. Currently, the elements at risk are just classified in a descriptive way, and spatially identified in comparison to their risk class.

In the light of the above, a novel landslide risk analysis, which takes into account temporal probability of landsliding, need to be based on a multi-temporal landslide inventory concerning spatial and temporal aspects of past landslide events, even of the smallest events.

Aiming at integrating temporal probability in landslide hazard evaluation at regional scale for the investigated study area, a landslide data collection has been carried out. As each municipality communicates the occurrence of mass movements that cause damages to regional administrative offices in charge of providing funds for facing the emergency phase and for mitigating landslide risk, information concerning spatial and temporal occurrence of landslide events were available. Therefore, for the selected study area, the analysis of paper documents stored in the archive of the Apulian administrative *Difesa del Suolo* office allowed collecting 493 landslide events occurred within the 14 investigated municipalities in the period 1998-2018 (around 23 landslides per year), compared to the 100 landslides with temporal information (from the beginning of the 20th Century) available in the official inventories.

Although they concern just the period 1998-2018, the main benefit of the new multi-temporal inventory regards its completeness about the recorded landslide events, even the smallest, with information about location, date of occurrence and the occurred damages. Moreover, a magnitude analysis based on the description of the occurred past landslide events has been done. As drawbacks, the reported landslide events concern events that cause damages to the only build environment. Moreover, descriptions are often not sufficiently detailed in order to describe the areal extent of landslides, as well as to identify the accurate location of occurred events and their typology.

The obtained landslide database has allowed to estimate the temporal probability of landslide applying a Poisson probability model. The result of the landslide temporal probability evaluation for the period of one year has been combined with the output of the spatial probability assessment (susceptibility index map). The obtained hazard map was, in turn, combined with the areal extent of the assets within each class of hazard and their economic value. As illustrated in the paragraph 3.5.2, because of the difficulties in assessing vulnerability, it was not assessed and assumed equal to 1.
The results of the risk assessment, which concern just direct and tangible losses, represent the landslide risk expressed in monetary terms associated to municipalities and slope units. Analysing the results of risk assessment, it is possible to see that the municipal areas with the higher risk values are those which involve residential areas.
As to the economic risk and funds for mitigation measures, even normalised by the municipal areal extent, it was possible to compare municipalities among them establishing a ranking of municipalities most-at risk. It seems that there is a better correspondence between the yearly cost of mitigation measures and the economic risk, both normalised by the municipal areal extent.
The future development of the work would regard the new landslide database, which has some weaknesses. In fact, the inventory does not include information about areal extent of landslides, as well as the limits about the location of mass movements have been clearly addressed in the paragraph 6.1. These limits are essentially due to the lack of precise information provided by the municipalities.
To overcome the limits of the current collected information and improve the quality of the new landslide database, some actions could be suggested. For example:

- it could be useful to involve local authorities in providing further data about the already inventoried events;
- because of the dynamic nature of the risk assessment and management of hazard-prone areas, it could be suitable to systematize future communications concerning landslide events through an entry data sheet concerning basic and essential information, thus standardising the quality of landslide information;
- the comparison among the data of the new landslide database and those collected in the available inventories would be useful to understand the state and

the distribution of the activity of landslides already mapped; also, it can help to identify new landslides, not even mapped.

Collecting landslide events by warning from municipalities and on-site investigations would consider just those events that cause damages. Consequently, the multi-temporal landslide inventory will not include mass movements without negative consequences on built environment. Thus, in order to consider the overall landslide movements, it is necessary to integrate different techniques (i.e. geo-morphological and remote sensing).

Other future development of the research should deal with:

- a thorough vulnerability assessment, focused on the main elements at risk (such as buildings and road infrastructures), towards a better understanding of landslide risk. In this sense, it would be useful integrating the magnitude of past landslide events based on the descriptions of the collected paper documents;
- the evaluation of indirect and cascading impacts, which is also connected to the vulnerability assessment;
- since most of the inventoried landslides are due to rainfall, the combination between spatial and temporal aspects of past landslide events and the amount of rainfall responsible for their triggering; this could allow the application of a more advanced methodological approach to assess landslide temporal probability, and/or to define rainfall thresholds useful in the early warning phase;
- in the field of risk management, the comparison of occurred landslide events and allocation of funds for mitigation interventions; this should allow cost-benefit analyses useful to understand if either mitigation measures have been useful to reduce the risk, or interventions resulted ineffective and the level of risk results still unacceptable.

Aware about the limitations and the assumptions of the procedure, as well as the restrictions of input data, the performed analysis can be considered a reliable landslide risk assessment, which aims at guiding choices of decision makers in charge of allocating funds (often limited) for mitigation measures. As the matter of fact, from the comparison between the estimated economic risk and funds for mitigation measures within the study area, it can be noted that it is not obvious that the municipalities most-at-risk have received more funds than the municipalities least-at-risk. Also, the proposed risk assessment can provide a mean to highlight the more exposed municipalities, pointing out areas that need further and detailed hazard and risk analyses.

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SKILLS

Languages
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Team working
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Problem solving: good
Communication: very good
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Data analysis
ArcGis: very good
Autocad: good
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Global Mapper: good
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Microsoft Office: very good
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EDUCATION

Polytechnic University of Bari
2016 - 2018
PhD in Risk and Environmental, Territorial and Building Development

Polytechnic University of Bari
2013 - 2016
MSc in Environmental Engineering
Thesis in Hydrogeology: "La salinizzazione degli acquiferi costieri e la teoria delle Transizioni Critiche. Analisi di scenari futuri per il Salento (Puglia, Italia)", Supervisors: Professor M. Dolores Fidelibus, Professor Valeria Monno, Professor David Alexander (UCL - IRDR), Dr. Gianluca Pescaroli (UCL - IRDR)

Polytechnic University of Bari
2008 - 2013
BSc in Environmental Engineering
Thesis in Applied Geology: "Le cavità artificiali di Gravina in Puglia (Ba): aspetti tecnici e storici", Supervisors: Professor M. Dolores Fidelibus, Professor Valeria Monno

PROFESSIONAL EXPERIENCES

Polytechnic University of Bari, Research fellow
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MAIN SCIENTIFIC PUBLICATIONS

Fedele V., Motta Zanin G., **Parisi A.**, Totaro V. (2019) - The complexity of risk in urban environment and the role of technological innovation. IEEE SMC2019, DOI: 10.1109/SMC.2019.8914640

Pellicani R., **Parisi A.**, Iemmolo G., Apollonio C. (2018) - Economic Risk Evaluation in Urban Flooding and Instability-Prone Areas: The Case Study of San Giovanni Rotondo (Southern Italy). Geosciences 8 (4), 112, DOI: 10.3390/geosciences8040112

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