Presidency of the Council of Ministers
Italian Civil Protection Department

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

National risk assessment

Overview of the potential major disasters in Italy: seismic, volcanic, tsunami, hydro-geological/hydraulic and extreme weather, droughts and forest fire risks

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Summary

Introduction

In Italy a new law of civil protection has been recently issued. This law, named “Code of Civil Protection” (Legislative Decree 1/2018), is in continuity with the previous regulatory framework. Nevertheless, it also introduces some innovations on civil protection competences and actions. For instance, the Art. 16 of the Code lists the risks of civil protection interest. In particular, the civil protection activities are mainly expected to deal with the following risks: seismic, volcanic, tsunami, hydro-geological/hydraulic, extreme weather, droughts and forest fires. According to the Code, in the present version of the Italian National Risk Assessment it has been decided to address all of these risks. Their analysis has reached different stages of maturity, depending on the risk. Therefore, for the risks already shown in the 2015 version of the National Risk Assessment (i.e., seismic, volcanic, hydrogeological/hydraulic and forest fires) an updated assessment is presented, whereas for the other risks the state-of-the-art and the development perspectives are shown.

THE FRAGILITY OF THE ITALIAN TERRITORY

The term “disaster”, in legal terminology, indicates a very serious public calamity, the effects of which may severely endanger people’s lives. A disaster, in fact, "is an event that affects a large number of individuals, producing effects on a generality of persons and, therefore, can only be called public".

In common language public disasters generally refer to “natural” disasters, i.e. volcanic eruptions, earthquakes, storms, landslides, floods, avalanches, ... even if, by opening a parenthesis, we are obliged to remember that natural phenomena, even extreme, become disasters only because of the presence of the human beings who, therefore, can be considered the determining factor in many disasters that have affected, over the years, the different countries of the world.

Among the countries subject to "natural" disasters, Italy is, unfortunately, at the top of the list because of the numerous and frequent phenomena that have affected and continue to hit its territory. From volcanic eruptions to earthquakes, landslides, flooding storm surges, Italy has been victim of a sequence of disasters that have caused decades of spending for the consequent destruction and casualties which, in turn, determined very high social and economic costs for the country. The survey "The geological and geo-environmental disruption in Italy" (It. Mem. Geological Survey, 1992), written by V. Catenacci, has determined that, for the 1946 to 1990 period, the Italian government has allocated an average of 4.5 million Euro per day for public calamities and registered a death toll of 7688 casualties.

Italy has been defined quite appropriately as either a "dancing ground" or a "geologically tumbled" country. Our country is in fact a geologically young and still evolving territory , which has not yet reached its equilibrium. The same landscape, so varied, from the rugged mountains of the Apennines to the steep Alps, to the gentle morphology of the hills, which characterize much of the Italian territory, as well as the steep and jagged coastlines and sandy beaches, all of this is the result of phenomena that constantly change the Earth's crust.

Landslides, floods, earthquakes, eruptions are just natural events of the recent geological structure of the Italian territory, but too often they turn into disasters due to human presence and activities. On the one side the latter disrupt the balance of nature through the degradation of pastures and mountain forests, the abandonment of mountains and hills, the excavation activities in the river bed areas to extract inert material for construction purposes, the occupation of the expanding areas around the rivers, the sealing of large areas of land. On the other side, they concentrate a large number of people in hazardous areas and in a vulnerable built environment, which increases the exposure of lives and goods to the occurrence of catastrophic events.

In Italy, the population has grown from 13 million in 1700, mostly concentrated in rural areas, to ca. 36 million at the end of XIX century, when the phenomenon of urbanization really began, up to the current 60 million people. Since 1860 to nowadays the population has almost doubled and has led increasingly to steal land to acquire farmland to forests, the river system has also seen the changing balance between surface water and groundwater, the population is concentrated in urban areas and the occupation of risk areas is a common trend. Inevitably, in this situation, the impact of natural disasters over the years has significantly increased, not only in Italy but in all industrialized countries. The fragility and vulnerability of the territory have interacted with the man-made environment, resulting in an imbalance that too often leads to tragic outcomes.

Earthquakes

Compared to other natural phenomena, an earthquake is a peculiar phenomenon, because it happens unexpectedly, without warning, almost instantly, with consequences that in terms of casualties, damage and affected population can prove to be quite dramatic.

Italy is a country with high seismicity. Our country, in the last 1000 years, has been affected by about 3000 earthquakes of medium and high intensity, greater than fifth or sixth degree of Mercalli scale, approximately 300 of which are equal to or greater than the eighth or ninth degree.

In the twentieth century, at least 7 earthquakes (not considering aftershocks) have had a magnitude equal to or greater than 6.5 (with effects between the tenth and eleventh degree Mercalli) and just in the last ten years 4 earthquakes attained or exceeded magnitude 6.0.

Considering the earthquakes up to the sixth degree of the Mercalli scale, which produce only minor damage, apart from Sardinia, the entire national territory has been affected at least once by a shock of this intensity. If we consider higher intensity events, these have never occurred in Piedmont, Lombardy and South Tyrol, part of the Tyrrhenian coast from Versilia to the River Volturno, the Adriatic coast South of Ancona (excluding Gargano), and Salento.

The highest seismic activity is concentrated in the central-southern part of the peninsula - along the Apennine ridge (Val di Magra, Mugello, the Tiber Valley, Val Nerina, Aquilano, Fucino, Liri Valley, Benevento, Irpinia) - in Calabria and Sicily, and in some northern areas, including Friuli, Veneto and part of western Liguria. The territory of central and southern Italy, in particular, was affected by some of the strongest and most destructive events that the historical memory has recorded. In the central Apennine, for example, the earthquakes of 1349 and 1703 caused extensive damage to the areas involved. The most recent ones are the L'Aquila earthquake that struck on April 6th, 2009, which reached magnitude Mw 6.3 and intensity IX-X grade of Mercalli scale and the 2016-17 seismic sequence of central Italy with two earthquakes of magnitude greater than 6.0 and effects corresponding to the XI degree in the Mercalli scale.

In the Southern Apennine, Irpinia has witnessed, over the centuries, some of the strongest earthquakes of Italian seismic history, until the most recent one of 23 November 1980, which left many deep scars still easily recognizable on the territory.

In Calabria and Sicily, the consequences of earthquakes like those of 1783, 1693 and December 28, 1908 - one of the strongest events (magnitude 7.1) ever recorded in Italy - are of historical significance, having deeply affected the society, economy and cultures of the areas involved.

Seismicity, as previously stated, is a feature of the land and therefore cannot be changed. However, it is possible to prevent the effects of an earthquake by acting on other components that determine the earthquake risks of a territory, in particular by reducing the vulnerability of buildings. In order to do this, since 1909, the State has intervened classifying the territory on the basis of the intensity and frequency of earthquakes of the past, and has provided specific regulations for the design of buildings in seismic areas. Today the entire Italian territory is classified into 4 zones, according to the different seismic hazard, providing anti-seismic planning/construction regulations to reduce the consequences of earthquakes on buildings. However the most challenging aspect is the reduction of the vulnerability of existing buildings, infrastructures, built heritage, for which a huge investments are needed, and, then, rational risk reduction strategies, based on well grounded risk assessments, is required to optimize future investments.

Tsunamis

The Mediterranean Sea is exposed to tsunami hazard due to high seismicity, steep sea floor slopes and several active volcanoes, both emerged and submerged. Being the coastline often densely inhabited and rich of infrastructures, the consequent risk is very high.

Over the past thousand years, tens of tsunamis have been documented along the Italian coasts. For the most recent among them (e.g., 1627, 1693, 1783, 1887, 1908), we know from historical sources the amount of destruction they caused. The most affected coastal areas were those of Southern Italy (Eastern Sicily, Calabria, Puglia). The most recent event (caused by a landslide from the flank of the Stromboli volcano during its last strong eruption) hit the Aeolian islands in 2002. Minor tsunamis were recorded also along the Ligurian and Adriatic coasts. The Italian coastline can also be reached by tsunamis generated far from our country, e.g., following a strong earthquake in the waters of the eastern Mediterranean Sea.

Because of the broad exposure of the Italian coastal territory to this risk, a National Alert System for tsunamis caused by earthquakes has been established – as a follow-up of the participation of Italy to the Intergovernmental Coordination Group of UNESCO for the establishment of a Tsunami Warning System in the NEAM region, the North East Atlantic, Mediterranean and connect seas. To support local administrations to include the tsunami risk in their civil protection plans, Italy has currently adopted a tsunami hazard model realized for the Mediterranean area within the TSUMAPS-NEAM project (http://www.tsumaps-neam.eu/) and, based on this, has established the alert zones to which the coastal municipalities can refer to implement their civil protection plans. The National Civil Protection Department is now working with their Competence Centres, namely INGV and ISPRA, to a national tsunami hazard model on which trace more detailed alert zones.

Volcanic activity

In Italy, volcanism owes its origin to a wide range of geological process, involving the entire Mediterranean area and linked with the Euro-Asiatic and African tectonic plates converging together.

The most evident results of this convergence are the earthquakes and volcanic activity in the Southern Tyrrhenian Sea and Sicily.

Italy, along with Iceland, has the greatest concentration of active volcanoes in Europe and is one of the first in the world by number of inhabitants exposed to volcanic risk.

Active or potentially active volcanoes affect southern Italy, with different levels of hazard. Etna and Stromboli erupt frequently and, being in open conduit condition, pose a limited hazard but with a short-term advice. The other volcanoes: Vesuvio, Vulcano and Campi Flegrei, have a very low eruptive frequency and have obstructed conduits. In this case, the hazard assessment is more complex because the expected intensity of future eruptions must be determined based on the eruptive history.

In Italy, there is an active monitoring and surveillance system, based on the detection of chemical and physical parameters, that allows to determine changes in the state of activity of volcanoes, and thus the probability of eruption. This surveillance of active volcanoes yields enough evidence to minimize dangerous effects of the eruptive activity.

During the twentieth century, the most significant eruptive episodes that interfered with human activities have been those of Vesuvio and Etna. Vesuvio eruption was very strong in April 1906; not particularly violent, conversely, that of March 1944, although causing 26 victims and the evacuation of 14,000 people. With regard to Etna, the activity that raises the most concern is that represented by flank eruptions, which over XX century have occurred, on average, every 3-4 years, targeting in particular the southern and the eastern side of the volcano, where the crops come up to about 1500 m above sea level, and villages are up to 900 m altitude. Moreover, in the most recent centuries, low-energy explosive eruptions and lava effusions came in succession, with a certain frequency, fueled both by the eruptive volcano's summit and from side vents. These eruptions have repeatedly affected the urban areas that are located on the slopes of the volcano, in particular with the accumulation of large amounts of ash.

Hydrogeological/hydraulic, extreme weather events

Flooding and landslides are the phenomena that most often affect Italian territory. The constitution and geological characteristics of the Peninsula and in particular of the Apennines produce hydro- geological instability.

With just 21% of the territory consisting of lowlands, compared to 40% and 39% of hills and mountains, often including the presence of clay reliefs, Italy holds one of the worst landslide records among other European countries and in the world, as it is among the most threatened countries by this phenomenon.

The young morphology as well as the steepness that characterize the territory can result in case of heavy rainfall in the rivers rushing, consequently determining severe erosion along the beds and thus dragging downstream a large amount of alluvial materials. These phenomena have been stressed , as stated above , by the depopulation of the mountains, neglect, abandonment, deforestation, quarrying which are all factors contributing to the loss of integrity of the mountain territory; and a mountain that is impoverished becomes more vulnerable and prone to collapse with serious repercussions on the downstream area. Landslides, in fact, are the result of pre-existing causes, usually natural, such as steepness, the geographic position of the layers, the lithology and determining causes, almost always intense and abundant rainfall and not adequate plant cover or accommodation of slopes (dry stone walls, the maximum cross-channel slope, ...) to protect the soil.

The changes to the route and section of the river courses (bridled, penstock, ...), made for human needs, led to a hardening of the river beds with side effects in case of flood. In fact, this deprived the area from a river outlet in case of exceptional flow rates, resulting from intense and concentrated rainfall over time.

Rain is the main cause for flooding, which is also aggravated by the deterioration of the area due to lack of maintenance or failure of outflow tract. Even along small waterways extended waterproofing parts of the territory and the presence of artifacts and various types of infrastructure (bridges, detected, buildings) can be observed that may occasionally become an obstacle to the flow of flood waters, giving rise to temporary reservoirs with subsequent possible overflow, which often causes the worst damage. In all these cases, water is not contained within natural or artificial banks, flooding and causing the breaking of dams/levees or other water projects, flooding and submerging large areas of territory producing incalculable damage.

Landslides and floods are also favored, as we said, by the clayey soils spread across about 20% of the Italian territory.

In order to update the landslide hazard map on the entire national territory, in 2017 ISPRA realized the new National Mosaic5 of the hazard zones provided by the River Basin District Authority. Similarly with the 2015 national mosaic ISPRA harmonized the PAI legends in 5 classes: Very high hazard H4, High H3, Medium H2, Moderate H1 and Attention zones AA. The total area of landslide hazard zones and attention zones in Italy is 59,981 km2 (19.9% of the national territory). If we take into account the most hazardous classes (high H3 and very high H4), the area amounts to 25,410 km2, equal to 8.4% of the Italian territory.

In order to the flood hazard, the mosaic has been realized according to the three hazard scenarios of Legislative Decree 49/2010: High probability scenario with return period of 20-50 years (frequent floods), Medium probability scenario with return period of 100-200 years and Low probability or extreme event scenario. The high flood hazard zones in Italy amount to 12,405 km2, the medium flood hazard zones to 25,398 km2 and the low hazard zones to 32,961 km2.

Most of the Italian territory is exposed to hydrogeological and hydraulic risks: there are 7,275 (out of about 8,000) Italian municipalities exposed to the risk of landslides and/ or floods, 16.6% of the national territory is classified as being more dangerous, 1,28 million inhabitants are exposed to landslide risk and more than 6 million are exposed to flood risk. Regions with the highest values of population at risk landslides and floods are Emilia-Romagna, Toscana, Campania, Lombardia, Veneto and Liguria.

What once could be a local news story, a landslide, flood, over the years, became, for the effects it produces, a matter of national interest. In XX century, in Italy, because of hydro geological emergencies there have been 12,000 dead, 350,000 homeless, tens of thousands of homes damaged as well as the disruption of bridges, hundreds of miles of roads and railways. Only in the last three decades, there have been more than 150 deaths and 60 affected provinces. Among the particularly catastrophic events, we must remember the historical floods of: Polesine (1951), Salerno (1954), Florence (1966), Genoa (1970), Piedmont (1994). Among the events characterized by landslide and a subsequent flood event, we remember the tragedies of Vajont (1963), Val di Stava (1985) and Valtellina (1987). Moreover, in the last ten years Giampilieri (Messina) 1th October 2009 and mudslides at least 31 deaths, 6 missing and 95 injured; Spezzino and Lunigiana (Toscana) 25-26th October 2011 floods at least 13 deaths; Genova 4th November 2011 Ferreggiano River flood at least 6 deaths; Grossetano (Toscana) 12th November 2012 at least 5 death; Sardegna 13th - 17-18th November 2013 , Flumendosa and Cedrino floods at least 17 deaths;

Rigopiano (Abruzzo) 18th January 2017, avalanche (earthquake plus heavy snowfall) at least 29 deaths; Livorno (Toscana), 9-10th September 2017 floods at least 8 deaths.

Droughts

Droughts are a complex, natural hazard that affects some part of Europe every year, especially Southern Europe. A water crisis is an imbalance between water needs and water availability. In the last twenty years, Italy faced an increasing number of droughts and water crises. Causes of water crises are not only natural, but also man-made: infrastructure backwardness, heavy losses from the network, high withdrawals, considerable waste, etc.

In the last twenty years, droughts and water crises hit not only Southern Italy (typically exposed to drought risks), but also the Central and Northern Regions, causing heavy damages to agriculture, manufacturing and civil uses. The 2003, 2006, 2007 and 2017 events affected Po basin, related to the longer river in the country, and also the more populated and industrialized one. The 2017 water crisis involved also some central Regions (Lazio, Umbria, Marche). At the beginning of 2018, another water crisis struck the Palermo area, in Sicily.

Several very important water crises, especially in 1988-90, 2003, 2006, 2007, 2012, 2017 drove Italy to adopt a more proactive approach instead of a reactive one. The proactive approach is based on identifying and arranging preventive measures and interventions before the advent of the critical situation. In this context, accurate and real-time monitoring of the hydrometerological variables and of the available water resources is extremely important. These data are also crucial for planning tools provided by Italian Law, in the context of the Water Framework Directive, for example, Water Protection Plans ("Piani di Tutela delle Acque") and Drought Management Plans in the context of Water Balance Plans ("Piani di Bilancio idrico").

Another important step for a new water governance was the institution, in July 2016, of the "Water Uses Observatories" ("Osservatori degli utilizzi idrici"), promoted by the Ministry of the Environment: they represent best practices and they also constitute a measure of the "Water Management Plans" ("Piani di Gestione delle Acque").

Climate change will exacerbate the existing problems, causing an increase of withdrawals for agriculture, energy production and drinking water: this is basically due to a combination of increasing temperatures and of decreasing and irregular rainfall.

Droughts and water crises assessments are based upon a complex mix of methodologies, referring mainly to continuous monitoring of strategic indicators, i.e., hydrometeorological variables (rainfall, temperature, etc.) and water availability indexes (stored surface reservoir volumes, aquifer water levels, river flows, reservoir outflows, snow reserves, etc.) Care has to be paid while choosing the appropriate indicators; in this context, integration of local and scientific knowledge to support drought monitoring is very useful to support drought management.

Forest fires

In the Mediterranean area, all the European countries are affected, in different way, by the problem of forest fires. In 2017, Italy was one of the five mostly affected European States together with Spain, Greece, Portugal and France. In 2018, according to the provisional data, forest fires have affected not only the Mediterranean countries but also Northern Europe countries, as Sweden and United Kingdom.

Generally, Italy is characterized by climate and vegetation which differ from north to south; these differences directly affect the distribution of forest fires along the whole territory.

In winter, forest fires are mostly located in the Alpine region (especially the North-Western Alps), while in summer they are mostly concentrated in the Mediterranean region (Southern Italy and major Islands). In Liguria (North-Western Italy) fires occur both in summer and winter at about the same frequency.

From 2000, there have been about 120,000 fires that burned about 730,000 hectares of woodland, a surface that doubles if we include the non-woodland, with an average of about 79,000 hectares per year. The threat of wildfires in Italy is not confined to wooded areas, as it extends to agricultural areas and urban-forest interface areas. The agricultural and rural areas, from the 1950s to now, have been gradually abandoned, both in regions with complex topography, where the mechanization of agriculture is unfavorable, and in the major islands and Southern Italy because of socio-economic changes.

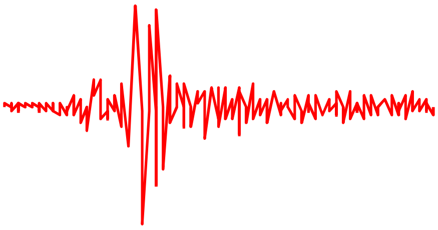
The national legislative framework about forest fires defines the responsibilities of different Administrations involved. The main actors are the Regions, which have the full responsibility of the prevision, prevention and firefighting activities (reconnaissance, surveillance, alarm and fire extinguishing, ground forces and regional aerial). The national Administrations support the regional firefighting activities through the coordination of the firefighting State air fleet.

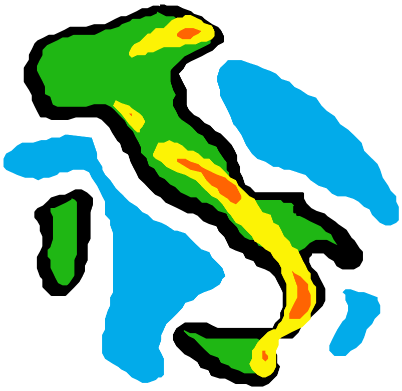
Conclusions

The images of the places destroyed by earthquakes, the spectacular lava flows threatening towns situated on the slopes of Etna, the aerial shots of cities and countryside flooded by the overflowing of rivers, are too often associated with events the consequences of which are unavoidable and must be accepted with fatalism and a sense of resignation. In fact, the severity of effects is the result of the interaction between a natural event, in terms of recurrence and predictability, and the artificial man-made environment. It is therefore misleading to call these events "natural disasters", trying to conceal the responsibility of man, who often built and occupied particularly fragile and vulnerable areas of the territory. Therefore, the risk of suffering serious harm, as a result of the natural occurrence of disaster events, can be reduced essentially by acting on the man-made environment, by establishing a new balance between man and nature. To achieve this result, however, we must realize the crucial importance of the awareness of citizens, the growth of a culture of prevention, and of course of the improvement of intervention capacity by the civil protection system, in its broadest sense of forecast and prevention of risks (risk assessment and risk reduction strategies, monitoring systems, identification and delimitation of areas at risk, ...) and of emergency management and overcoming.

Chapter 1

Seismic risk





National Civil Protection Department

INTRODUCTION

The seismic issue in Italy

Earthquakes are geological phenomena, associated to a rupture in the solid exterior part of the earth (lithosphere), triggering relative displacements along active faults, and are to a large extent unpredictable. It is not yet possible to predict, in a deterministic way, when and where exactly the next earthquake is going to happen, or how large its magnitude will be. However the areas where earthquakes have taken place in the past and where active seismic faults exist, continue to be the most likely to be hit by major earthquakes. In Italy those zones are essentially in the central-southern part of the peninsula - along the Apennine ridge (Val di Magra, Mugello, Tiber Valley, Val Nerina, Aquilano, Fucino, Liri Valley, Benevento, Irpinia) - in Calabria and Sicily, and in some northern areas, including Friuli, Veneto and part of western Liguria.

Considering that practically the entire national territory is exposed to seismic hazard, it is somewhat meaningless to make use of single earthquake scenarios, because the shift of few kilometres in the epicenter location would completely change the damage pattern. It is rather advisable, as the Italian Civil Protection Department (CPD) is actually in the process of doing, to base the National Emergency Plan on the Seismic Hazard Map, which provides the ground acceleration values expected for different return periods (see section 1.1).

An earthquake, for its severity and very large territorial impact, is without doubt the most disastrous event of natural origin. Figure 1.1 clearly shows that in one and half century between 1860 and 2010 in Italy the average mortality rate due to earthquakes has been about 30 times higher than the one due to landslides. This figure is even higher for other natural hazards.

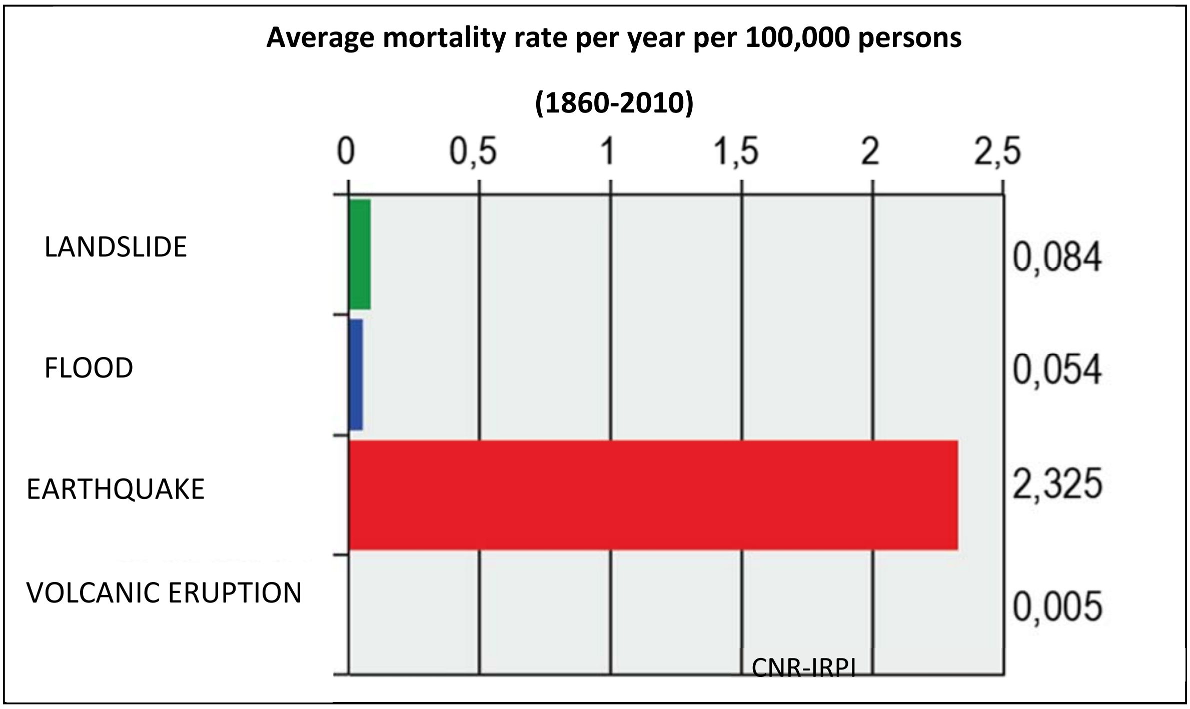


Fig. 1.1 – Comparison of the average mortality rate among different natural hazards in Italy

Italy is in fact one of the countries in Europe with the highest seismic activity. The frequency of events that have affected its territory and the intensity that some of them have historically reached, have brought a significant social and economic impact. Some numbers help to outline the extent of what we can define the seismic issue in Italy:

- Since 1000 A.D. nearly 30.000 events occurred, 220 of whom destructive, with a macroseismic intensity ≥ VIII degree of Mercalli Cancani Sieberg (MCS) scale.
- In the last 50 years, earthquakes caused monetary losses for about 180 billion Euro (including the 2016 central Italy seismic sequence).
- In the last two centuries, earthquakes caused about 160,000 victims (85,000 of which due to the 1908 earthquake in Reggio Calabria and Messina); moreover, they damaged and/or destroyed a great part of the historical and artistic heritage, whose value is not quantifiable.
- In Italy, the ratio between the damage caused by earthquakes and the energy associated to them, is much higher with respect to other seismic countries as California or Japan (e.g. the damage pattern of the 1997 Umbria-Marche earthquake is similar to that of the 1989 Loma Prieta - California, in spite of an energy about 30 times lower).
- The reason of the high damage caused in Italy even by small-medium magnitude earthquakes depends on the elevated vulnerability of Italian real estate: high number of historical, artistic, monumental and old buildings, degradation of many urban suburbs, illegal buildings particularly widespread in southern Italy, precisely where the hazard is higher.

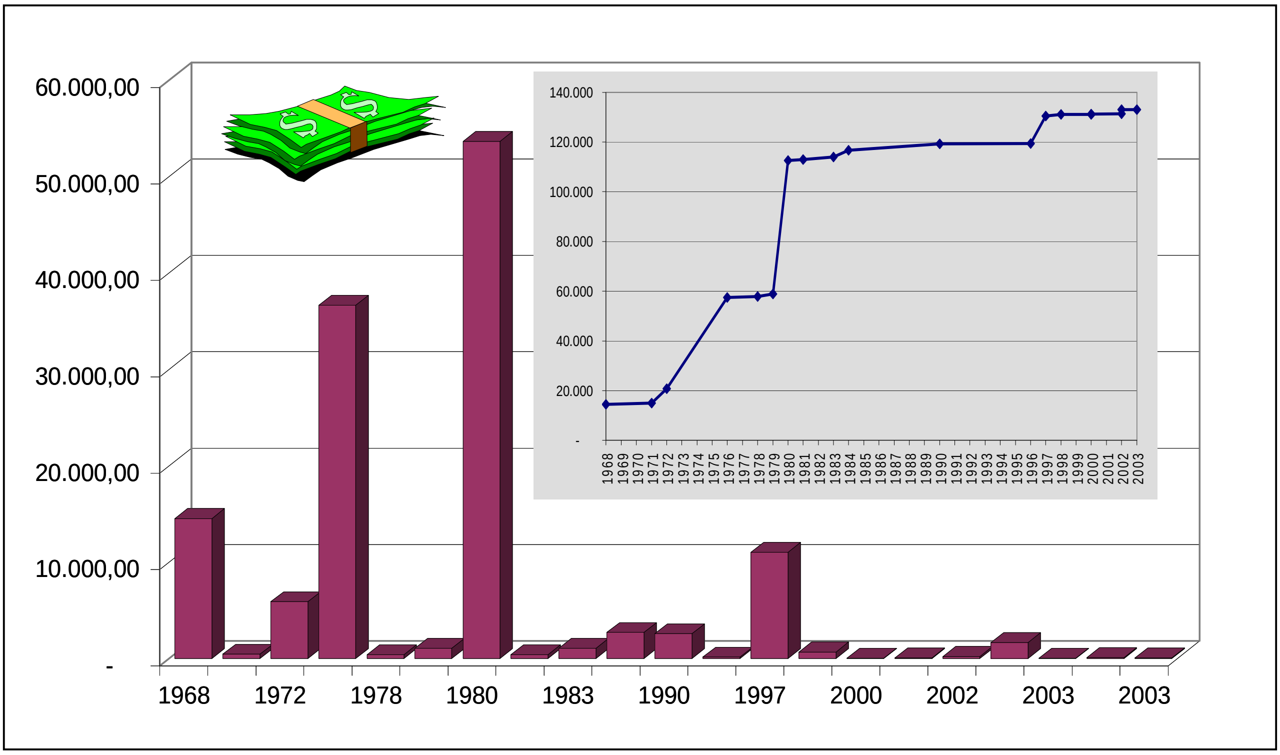


Fig. 1.2 – Cost of the Italian earthquakes in 35 years (million euro-2005), from 1968 to 2003

Figure 1.2 depicts the expenses (million euro updated to year 2005) incurred by the Italian Government for intervention, recovery and reconstruction after the most destructive earthquakes of the last decades of the last century, starting from 1968. The largest events, exceeding 10 billion euro, are: Belice 1968, Friuli 1976, Irpinia 1980, Umbria-Marche 1997. The last disastrous earthquakes of this century, i.e. the ones of April 2009 (L'Aquila), May 2012 (Emilia), August-October 2016 (Central Italy) are not included because a comprehensive final evaluation of the global economic losses can be only made after several years or decades. However, in a preliminary estimation carried out for the European Union, they totally quote about 45 billion euro.

It is remarkable that the global expenditure in 35 years exceeds 130 billion euro, and in 50 years is in the order of 180 billion euro, giving a value of almost 4 billion euro spent, in the average, each year by the Italian Government just for the cost of the direct damage caused by earthquakes.

Seismic risk assessment

According to ISO 31010, risks are the combination of the consequences of an event or hazard and the associated likelihood of its occurrence. Consequences are the negative effects of a disaster expressed in terms of human impacts, economic and environmental impacts, and political/social impacts. More specifically, as illustrated in Figure 1.3, seismic risk can be represented by the convolution of three elements

Seismic Risk = Seismic Hazard * Vulnerability * Exposure

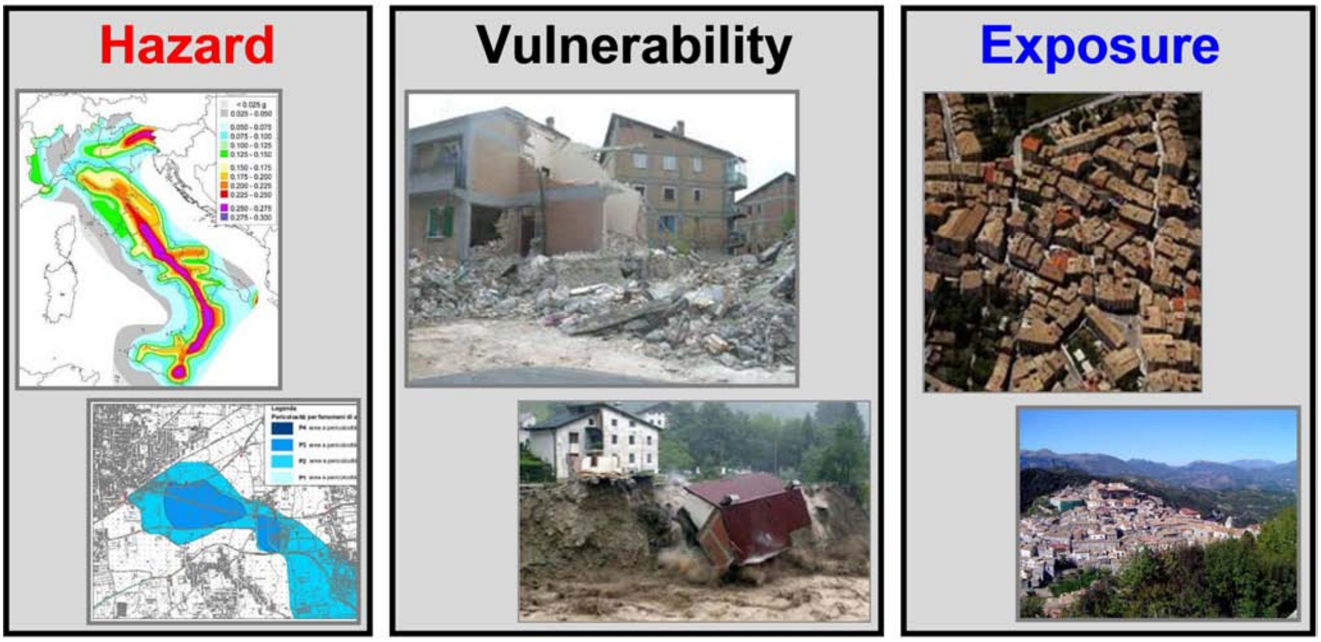


Fig. 1.3 – Main elements contributing to seismic risk

According to UNISDR, 2016, the following definitions apply:

Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.
Annotations: Hazards may be natural, anthropogenic or socionatural in origin. Natural hazards are predominantly associated with natural processes and phenomena. Anthropogenic hazards, or human-induced hazards, are induced entirely or predominantly by human activities and choices. This term does not include the occurrence or risk of armed conflicts and other situations of social instability or tension

which are subject to international humanitarian law and national legislation. Several hazards are socionatural, in that they are associated with a combination of natural and anthropogenic factors, including environmental degradation and climate change.

Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.
Annotation: Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.
Annotation: For positive factors which increase the ability of people to cope with hazards, see also the definitions of "Capacity" and "Coping capacity".

It is easy to understand that all three elements are essential in a seismic risk assessment: a strong earthquake in a desert or ocean bottom would cause no damage (high hazard, zero vulnerability); the collapse of an empty building would cause no casualties and little damage (high hazard, high vulnerability, low exposure). Seismic risk is increasing in the World and this is mainly due to an increase in exposure (Bilham 2009). Even the most recent earthquakes occurred in Italy, namely in 2009, 2012 and 2016-17, whose maximum magnitude were around 6 – 6.5, have emphasised, the critical influence of vulnerability and exposure in determining seismic risk.

Considering that it is not possible to avoid the occurrence of earthquakes (hazard) neither to eliminate the presence of man (exposure), the only way to mitigate seismic risk is to develop adequate risk reduction policies aimed at reducing physical and social vulnerabilities. In this respect, the first step to make is to improve the understanding of risk (1st priority of the Sendai Framework).

In order to improve the knowledge and the understanding of risks, the Italian Civil Protection Department has endorsed scientific institutions as centres of competence. As far as seismic risk is concerned, the main centres of competence are: INGV (National Institute of Geophysics and Volcanology), for hazard assessment, seismic monitoring and surveillance, as well as other activities aimed at understanding seismic phenomena; ReLUIS (Network of university laboratories for seismic engineering) and Eucentre (European Centre for Training and Research in Earthquake Engineering), for vulnerability, exposure and seismic risk assessment, as well as for other earthquake engineering issues; CNR-IGAG (Environmental and Geoengineering Institute of the National Research Council) for seismic microzonation,

RISK REDUCTION POLICIES

Risk reduction policies can be sorted into three different phases

PHASE 1 – PREVENTION

PHASE 2 – EVENT

PHASE 3 – POST-EVENT

In the present document the prevention activities carried out in phase 1 will be mainly dealt with in detail, while for the other two phases only technical activities aimed at improving the response to disasters are summarised.

PHASE 1 – PREVENTION

When: always, but less intensively when some event occurs

Objectives - Reduction of the seismic risk through:

1. Updating seismic knowledge and tools for risk reduction: monitoring, hazard, classification, and seismic building codes
2. Seismic risk assessment for a disaster risk reduction strategy
3. Microzoning and land use planning
4. Tax incentives and public funding for vulnerability reduction of the existing buildings, facilities and plants through strengthening and retrofit.
5. Improvement of preparedness through information to population and school education.
6. Technical training of experts.

Updating seismic knowledge and tools for risk reduction: Seismic <u>Monitoring</u>

A) *The National Seismic Network (RSN)*
The national monitoring network provides earthquake epicentre, hypocentre and magnitude in real time

The National Seismic Network (RSN – *Rete Sismica Nazionale*) is managed by INGV, the Italian Institute of Geophysics and Volcanology. In case of earthquake, INGV under a contract supplies in real time parameters of the epicentre to the CPD in order to organize emergency interventions. The network was established following the catastrophic earthquake of Irpinia in 1980. At the time, lack of immediate data caused hours of delay in detecting the epicentre of the quake and the consequential delay in rescue operations of the affected areas. The Special Commissioner for Civil Protection assigned to the former National Institute of Geophysics the task of creating a seismometric network with national coverage, with velocimetric stations linked to a unique centre for data collection and elaboration. From the first nucleus of the network, composed by seven stations linked to the National Institute of Geophysics premises, there are now, since the monitoring system has developed, almost 300 stations. Each station is linked to INGV, which elaborates signals in real time. A particular automatic procedure allows the detection of seismic events, the launch of codes for localization and magnitude determination and the creation of an archive of recorded events, available on INGV website.

Fig. 1.4 – Geographical distribution of the stations of the National Seismic Network.

B) *The Italian Strong Motion Network - RAN*
The Italian strong motion network measures ground acceleration generated by medium to high intensity earthquakes

The Italian strong motion network (RAN – *Rete Accelerometrica Nazionale*) is managed by the CPD, and records medium to high magnitude earthquakes. The network was acquired from the Italian electric company ENEL in 1997 and over the years has been improved and upgraded to digital instruments. As of today, it is composed by almost 600 seismic stations with 3-axial accelerometers, concentrated especially in high seismicity zones, which record and send quickly to the central server in Rome, through 3G connection, the measured ground acceleration. Such distribution of the shaking in epicentral zone is useful for emergency management. RAN data are used for in-depth studies in different sectors of seismic engineering and seismology. Activities developed in the accelerometric field and experiences acquired during the recent seismic sequences in Italy supply an important contribution for updating seismic regulations, for building and infrastructures design and for seismic characterization of soil. The central server carries out a first data processing, and produces a report of the event, including estimates of seismic intensity and signal response spectra, accessible either through a link on Department's website in the "Seismic Risk" section, or at http://RAN.protezionecivile.it . Based mostly on RAN data, INGV provides and updates the seismic sequence shakemaps (Michelini et al. 2008).

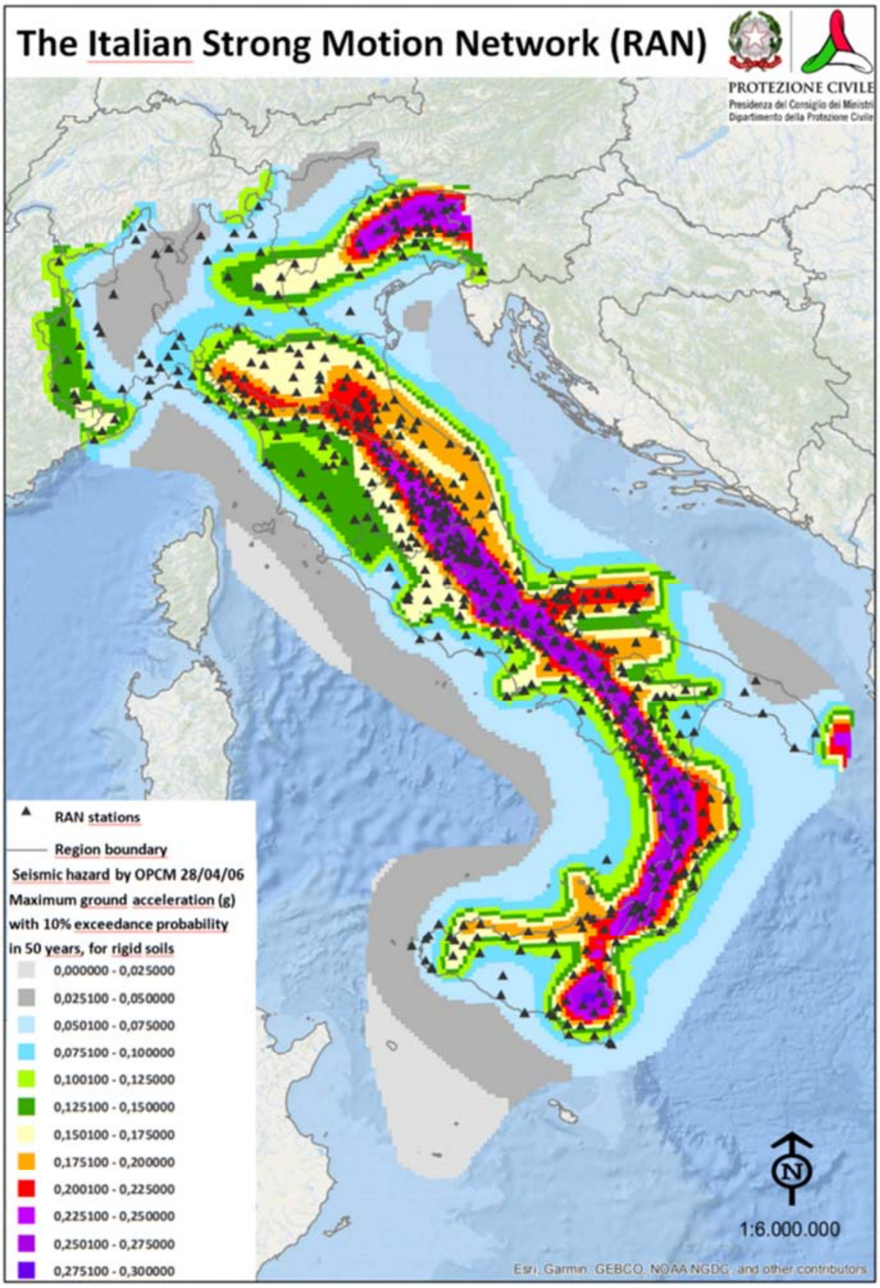


Fig. 1.5 – Geographical distribution of the stations of the Italian Strong Motion Network.

C) *The Seismic Observatory of Structures*
The national monitoring network measures the seismic response of public structures and infrastructures

Managed by the CPD, the Italian network of the Seismic Observatory of Structures (OSS – *Osservatorio Sismico delle Strutture*) allows to assess damage caused by an earthquake to the monitored buildings and others with similar features, providing useful information in a short time for the management of the emergency in the area affected. Moreover, OSS provides data to improve the understanding of the dynamic behaviour of structures during an earthquake, which are background for the updating of the design codes and technical standards for buildings in seismic areas. The network consists of a "fundamental sample", made up today by 124 public buildings (schools, hospitals, municipalities, etc.), as well as 7 bridges and 3 dams, equipped with a complete monitoring system based on 16- 32 acceleration measures, with sensors distributed all over the structure. A "supplementary sample" is under development: it currently includes 30 strategic public buildings for the management of the seismic emergency, equipped with a simplified monitoring system based on at least 7 acceleration measures, with sensors at top and ground level only.

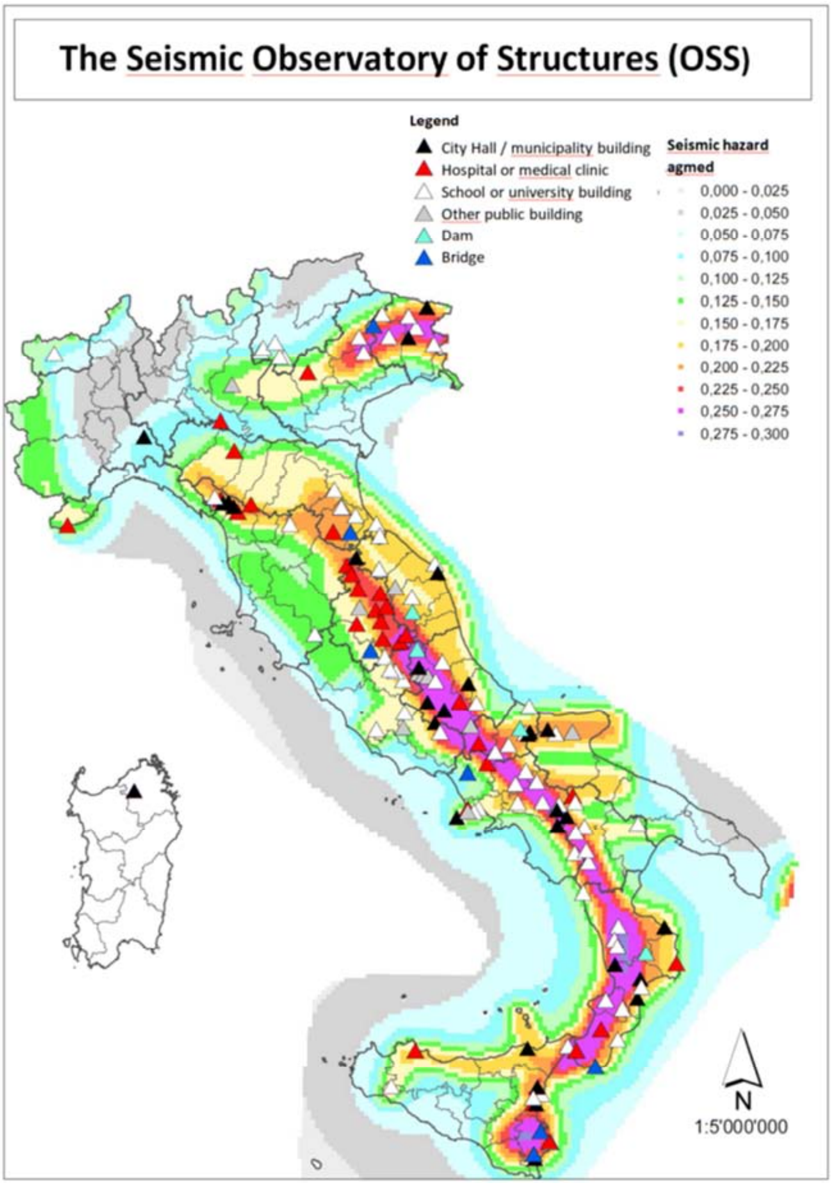


Fig. 1.6 – Geographical distribution of the structures monitored by the Seismic Observatory of Structures.

The monitoring system of each structure automatically records significant vibrations and sends quickly recordings through ADSL connection to the central server of the network in Rome, which is located in the headquarters of the Department. The central server carries out a first data processing, and produces a report of the event, including a damage parameter, accessible either through a link on Department's website http://www.protezionecivile.it in the "Seismic Risk" section, or at http://www.mot1.it/OSSdownload. OSS database of seismic recordings and structure documentation are available at http://www.mot1.it/ISS.

Updating seismic knowledge and tools for risk reduction: Hazard assessment

Similar to the analysis of other natural hazards, the classical approach to Seismic Hazard Assessment (SHA) consists of two parts:

1. Characterizing the sources of hazard (size and spatial location of earthquakes)
2. Characterizing the effect these sources would have on a particular location (earthquake ground motion).

The two fundamental types of analysis are probabilistic and deterministic. In the early years of earthquake engineering the use of Deterministic Seismic Hazard Analysis (DSHA) was prevalent.

A DSHA involves the development of a particular seismic scenario upon which a ground motion hazard evaluation is based. A simple example of a deterministic statement of hazard could be: the earthquake hazard at site *X* is a *PGA of 0.5 g* resulting from the occurrence of a *M=6.5* earthquake on fault *Y* at a distance of *10 km*.

In the past 30 to 40 years the use of probabilistic concepts has allowed uncertainties in the scale, location and rate of occurrence of earthquakes and in the variation of ground motion characteristics to be explicitly considered in the evaluation of seismic hazards. Probabilistic Seismic Hazard Assessment (PSHA) provides a framework in which these uncertainties can be identified, quantified and combined in a rational manner. An advantage of PSHA is that it results in an estimate of the likelihood of earthquake ground motion. This allows PSHA to be functionally incorporated into seismic design codes and seismic risk estimates, so that quantitative comparisons of different options in decision making can be carried out. The basic procedure of PSHA was first defined by Cornell (1968) and although numerous modifications have been made to the process, the basic elements of the calculations remain unchanged. The Cornell method is based on three specific assumptions:

1. earthquake recurrence times follow a Poisson process (events are independent and stationary in time);
2. event magnitude is exponentially distributed ($\log(N) = a - bM$);
3. seismicity is uniformly distributed inside each seismogenic zone.

It is common practice to represent the results of a PSHA model in terms of maps showing the value of a given ground motion parameter (e.g. Peak Ground Acceleration – PGA and Spectral Acceleration - SA) corresponding to an exceedance probability in a given period of time (typically 10% in 50 years corresponding to a mean earthquake return period of 475 years). Table 1.1 gives the correspondence between exceedance probability, exposure time, and return period-

Exceedance probability	Exposure time (years)	Return period (years)
10%	5	47
10%	10	95
10%	50	475
2%	50	2475

Table 1.1 - Exceedance probabilities and return periods

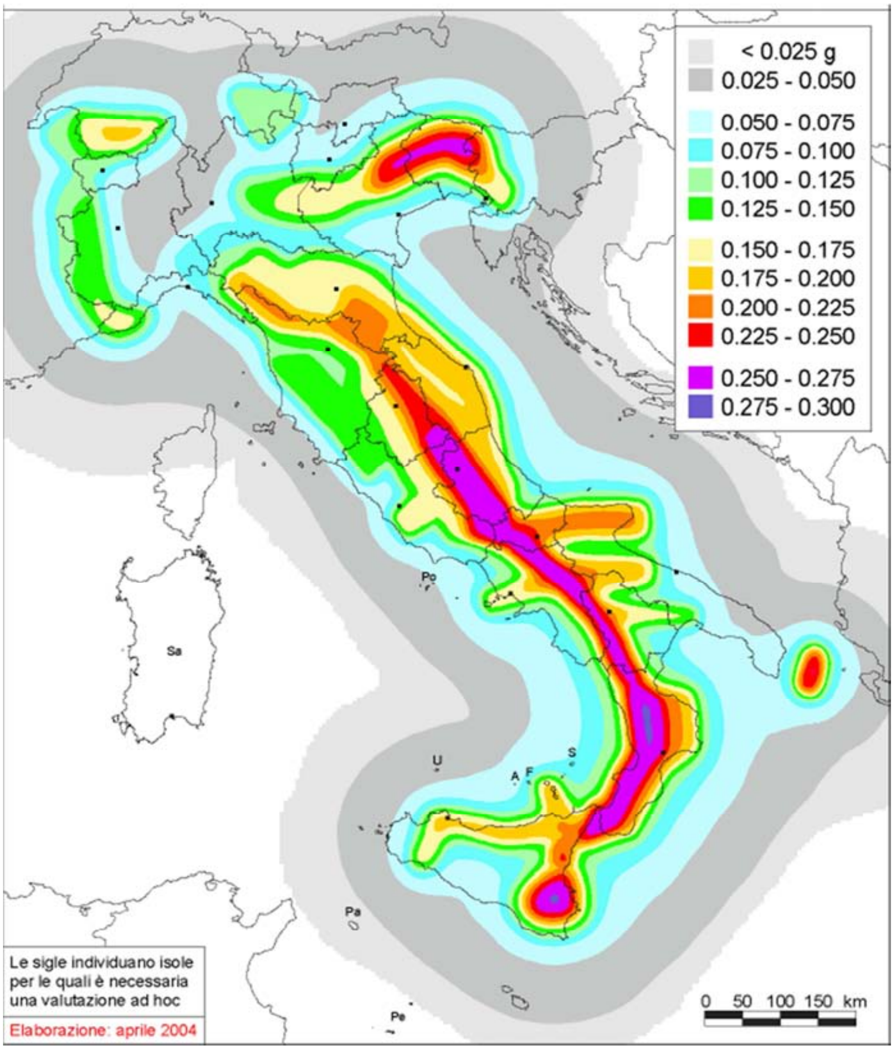


Fig. 1.7 - Hazard map of Italy realized by INGV in 2004: Peak Ground Acceleration (PGA) values (as a fraction of the gravity acceleration g) with a 10% probability of exceedance in 50 years (475 years return period).

A seismic hazard map shows the spatial variation in seismic hazard over a particular region or country. A hazard map is produced by carrying out hazard assessments in a large number of locations within the region under study, for example at the nodes of a grid defined to cover the entire area. Borders are then drawn through the resulting values at the nodes to obtain lines of equal PGA, sometimes referred to as iso-acceleration lines. The knowledge of seismicity and of the probability of occurrence of earthquakes in different parts of the Italian territory is continuously increasing in a constant updating process.

The most recently issued seismic hazard model in Italy, named MPS04, was realized in 2004 by the National Institute of Geophysics and Volcanology (INGV) (Stucchi et al. 2004, 2009), one of the centres of competence of CPD. It has been the basis for the new seismic classification of the Italian territory. It was also incorporated in the Italian Building Code in 2008, NTC08 (Decreto 2008), and in the most recently approved NTC18 (Decreto 2018). Finally, it has been assumed as the hazard component of many risk assessment, in particular of the most recent one, described in a paragraph below.

Figure 1.7 shows the PSHA map relevant to a return period of 475 years, which reports the peak ground acceleration in rigid soil condition with horizontal surface. Maps relevant to other return periods and other earthquake parameters can be found in http://esse1-gis.mi.ingv.it/.

In 2013, the SHARE EU project released a new seismic hazard model for Europe (http://www.share-eu.org/) (Woessner et al. 2015), also with the contribution of the authors of the Italian reference model MPS04. The main differences between the two approaches consist of the definition of the seismic sources (one single area source model in MPS04, the combination of area source, faults and smoothed seismicity models in SHARE) and in the ground motion prediction equations (GMPEs) adopted (SHARE uses a set of GMPEs recently developed on the basis of a large dataset of accelerometric recordings). Meletti et al. 2014 and Visini et al. 2016 investigated the results of the two models in terms of PGA maps, hazard curves and uniform hazard spectra (UHS) for selected localities. The cause of the largest differences seems to be the different adopted GMPEs. By comparing the uniform hazard spectra for some sites, in SHARE the expected accelerations are larger than in MPS04 for PGA and spectral ordinates up to 0.3 second, while they are lower for spectral periods greater than 0.3 second; the same behavior appears when comparing the GMPEs adopted in the two models. (Visini et al. 2016) by analyzing separately the PSHA results obtained by the 3 source models adopted in SHARE (i.e., area sources, fault sources with background, and a redefined smoothed seismicity model). Results show that, besides the strong impact of the GMPEs, the differences on the seismic hazard estimated among the 3 source models are relevant and, in particular, for some selected test sites, the fault-based model returns lowest estimates of hazard.

In 2013 the Italian Civil Protection Department promoted the establishment of a Seismic Hazard Center within INGV. In 2015 the Seismic Hazard Centre (Centro Pericolosità Sismica – CPS) of the National Institute of Geophysics and Volcanology (INGV) was commissioned to engage and coordinate the national scientific community with the aim of elaborating a new reference seismic hazard model, mainly designed to update the seismic code (Meletti et al. 2017). The Civil Protection Department (DPC) funded the project.

The main requirements of the new hazard model were discussed together with the national earthquake engineering community, to define the features of the seismic hazard model so that it can be adopted by the building code and used for risk assessment: the time-independent model has to cover the national territory, the reference soil is rock (Vs30 > 800m/s), the hazard will be expressed in terms of PGA, PGV, PGD, spectral acceleration, velocity, displacement, macroseismic intensity, the spectral ordinates to be assessed are between 0.05 and 4 seconds, and the return periods from 30 to 2500 years (probably extended to 10000 years).

The CPS outlined a roadmap to release within three years a significantly renewed PSHA model, with regard to both the updated input elements and the strategies to be followed. Since the beginning, CPS fixed some key constraints that had to be honoured when building a seismic hazard model for practical purposes. These points, which basically aim to guarantee a large participation and the scientific and non-scientific consensus, can be summarized as follows:

(i) use of international standards according to the state of the art in Probabilistic Seismic Hazard Assessment (PSHA) (e.g. SHAAC, 1997);
(ii) open and transparent procedures that guarantee totally reproducible outcomes;
(iii) use of outputs to be approved by the stakeholders;
(iv) involvement of the Italian scientific community as large as possible in proposing data, models and approaches;
(v) full and coherent exploration and representation of the epistemic uncertainty in the final seismic hazard model;
(vi) implementation of a robust testing phase, and of an elicitation session with national and international independent experts, in order to check the reliability of each component of the seismic hazard model.

Following a public call, about 150 researchers from universities and research institutions, besides INGV, have been involved in the project.

The activities were organized in 6 tasks: T1) project management, T2) input data, T3) seismicity models, T4) ground motion and intensity predictive equations (GMPEs and IPEs), T5) computation and rendering, T6) testing.

T1 planned the activities and managed the other 5 tasks to ensure achievements of the Project scopes.

T2 selected the most updated information about historical and instrumental seismicity, seismogenic faults, and deformation (both from seismicity and geodetic data) and compiled the necessary databases. The task released 15 deliverables, shared with all the participants.

T3 elaborated the seismicity models in terms of classic source areas, fault sources and gridded seismicity based on different approaches, with associated seismicity rates. Each earthquake rate model has to be reproducible, according a full description of its “making of”. Moreover, modellers have to explore the epistemic uncertainty related to their model; this step is crucial to estimate an overall epistemic uncertainty of the final model, which includes the uncertainty of each model and the uncertainty among models.

T4 selected the most recent models accounting for their tectonic suitability and forecasting performance. The forecasting performance of each GMPE has been evaluated through the comparison with accelerometric records available in the Italian (itaca.mi.ingv.it) and European (esm.mi.ingv.it) strong-motion databases. In this way, each GMPE has been ranked according to different specific metrics, so that the best performing GMPEs can be identified.

T5 identified the code OpenQuake (www.openquake.org) for calculation (Pagani et al. 2014). It is open source and large interaction could take place with the IT team in order to modify or integrate the code, as well as to ask for the development of new, dedicated functions.

T6 performed statistical procedures to test, with the available data, the whole seismic hazard models, and single components such as the seismicity models and the GMPEs. T6 also organised the elicitation session and finally weight the different models.

The new model has been implemented also according the suggestions of a participatory revision panel (5 Italian experts selected by DPC) that has been informed every 2 months about the activities of CPS. The release of the final model is scheduled for December 2018. A final scientific approval is expected by the National Commission for Major Risks (Commissione Nazionale per la previsione e prevenzione dei grandi rischi) in 2019. Then the new hazard model can be released for risk assessment and seismic code use.

Updating seismic knowledge and tools for risk reduction: monitoring, hazard, classification, and seismic building code – **Seismic classification**

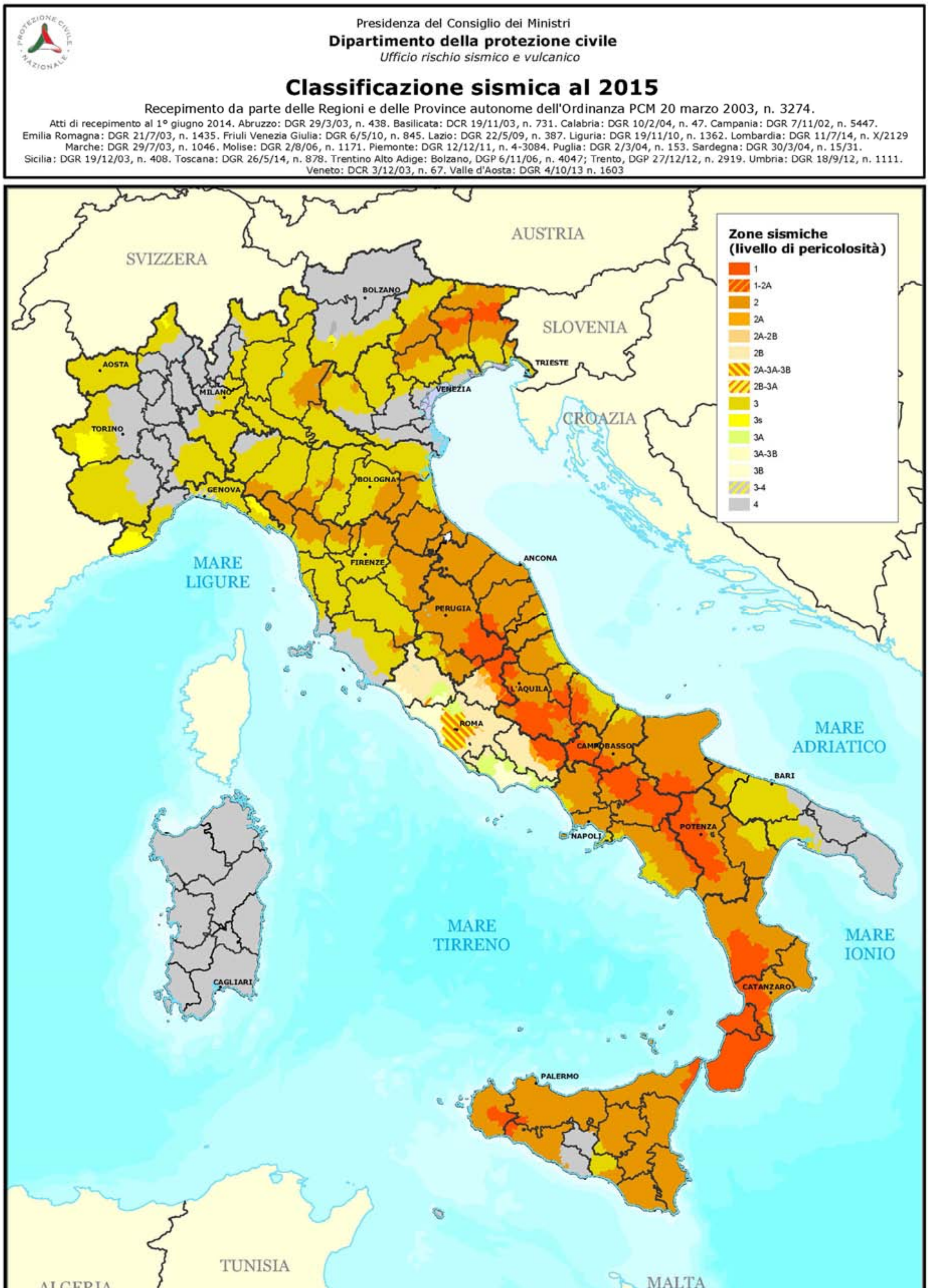
On the basis of the seismic hazard map MPS04 of Figure 1.7 and the criteria provided by the Ordinances of the President of the Council of Ministers n. 3274 of March 2003 and n. 3519 of April 2006 (OPCM 3519), an update of the seismic classification of the Italian territory has been realized as shown in Figure 1.8. The legal measures given in the above said ordinances contain the main principles according to which the Regions, appointed by the State to adopt the territorial seismic classification, have filled out a list of municipalities according to intervals of acceleration (ag), with a probability of exceeding the threshold equal to 10% in 50 years, to be assigned to the 4 seismic zones as illustrated in Table 1.2.

Seismic zone	Acceleration with a probability of exceeding the threshold equal to 10% in 50 years (ag)
1	ag > 0,25±0,025
2	0,15 < ag ≤ 0,25±0,025
3	0,05 < ag ≤ 0,15±0,025
4	ag ≤ 0,05±0,025

Table 1.2 - Distribution of the seismic zones according to the PGA on outcropping bedrock

Based on addresses and criteria established at national level, some Regions have classified their territory according to the four zones of table 1.2, while some other have introduced, in some cases, subzones to better adapt regional regulations to local seismicity features.

It has to be remarked that, according to the Italian building code issued in 2008 (Decree 2008), the seismic classification is no more effective for the design of new buildings and is useful only for planning management and building territorial control by relevant boards. In the new building code, indeed, the concept of "seismic zone" for the evaluation of the design seismic action is discarded and the seismic action, expressed through the elastic response spectrum, is defined consistently with MPS04, for each point of a mesh (10X10 km) covering the whole territory. The same approach has been kept in the recently enforced new Italian Building Code issued in 2018 (see following paragraph).



FB 2015

Fig.1.8 - Seismic classification map

Updating seismic knowledge and tools for risk reduction: monitoring, hazard, classification, and seismic building code – Seismic Building Code

A fundamental tool for seismic disaster risk prevention is also the Building Code, and in particular the part relevant to seismic design incorporated in the Italian Building Code. The basic objective of a seismic code is to ensure that constructions (buildings, bridges etc. affecting public and private safety) have the capacity to resist weak earthquakes with no damage, moderate earthquakes with minor structural damage, and strong earthquakes without collapse.

Most of the current seismic codes present the earthquake actions to be considered in design, in terms of an Elastic Response Spectrum (ERS) of absolute acceleration. In 2004 the last version of the European seismic code, named Eurocode 8 (EC8 - EN 1998-1, 2004), has been approved with the objective of achieving harmonization of earthquake safety throughout Europe. EC8 does not include any seismic hazard or classification map and each country has to adapt the code through a National Application Document (NAD) including maps providing the basic hazard information (i.e. values of PGA with a return period of 475 years).

As of 1 July 2009, the Italian Building code NTC08 (Decreto, 2008), approved on 1 January 2008, came into force, after 18 months of experimental application. The code was mainly inspired by Eurocode 8, but it contained significant changes and improvements, also introducing important new concepts and design criteria with respect to the previous regulations. First, the concept of "seismic zone" is discarded and, based on the MPS04 seismic hazard model, the seismic action (elastic response spectrum) is defined for each point of a mesh (10X10 km) covering all the territory. Second, the Italian guidelines follow the so called Performance Based Seismic Design (PBSD) requiring the definition of different levels of seismic actions and performance criteria to be met by structures under each level of loading. In particular NTC08 presents several new terms to describe seismic actions on structures. It introduces a reference period $\mathbf{V_R}$ for seismic actions, which is given by the product of the nominal life of a construction $\mathbf{V_N}$ and its coefficient of use $\mathbf{C_U}$, $\mathbf{V_R = V_N \times C_U}$. V_N is the number of years during which a structure, if subjected to regular maintenance, should be used for the purpose for which it was designed. It is suggested that: $V_N \leq 10$ years for temporary structures, $V_N \geq 50$ years for ordinary buildings and structures, and $V_N \geq 100$ years for large or strategic constructions. The coefficient of use is directly linked to the use class of the construction, from Class I (rare presence of people, construction for agriculture, $C_U = 0.7$) to Class II (normal presence of people, $C_U = 1.0$) up to Class IV (important public and strategic buildings, $C_U = 2.0$). Two damage limit states (SLO, SLD) and two ultimate limit states (SLU, SLV) are established in the code:

1. Operability limit state (SLO): after an earthquake, the entire construction, including its structural and non structural elements, is neither damaged nor subject to significant interruptions in functioning.

2. Damage limit state (SLD): after an earthquake, the entire construction undergoes a damage that does not compromise its solidity and resistance against vertical and horizontal actions. The structure is ready to be used even if the equipment might be subject to malfunctioning.

3. Limit state for the safeguard of life (SLV): after an earthquake, the construction is affected by failures and collapses of non structural components and equipment and damage to structural components that result in a significant reduction of solidity and resistance against horizontal actions. The construction retains part of the resistance against vertical actions and a safety margin against collapse from horizontal actions.

4. Collapse prevention limit state (SLC): after an earthquake, the construction is affected by serious failures and collapses of non structural components and very serious damage to structural components that result in a substantial loss of solidity and resistance against horizontal actions. The construction retains a safety margin against vertical actions and a small safety margin against collapse from horizontal actions.

According to the code, the probability of exceedance of the seismic action during the reference period varies with the limit state, as shown in Table 1.3 and Figure 1.9. The return period of the design earthquake can be evaluated assuming a statistical distribution of seismic events. If the Poisson model is used to predict the temporal uncertainty of an earthquake, the return period Tr is given by:

$$\boldsymbol{T_r} = \frac{1}{\lambda_{\boldsymbol{M}}} = -\frac{\boldsymbol{T_S}}{\ln(1-\boldsymbol{P})}$$

Where λ_M is the average rate of occurrence of the event, T_S is the time period of interest (the reference period V_R in this case) and P is the probability of occurrence of an event during a given time interval. As an example the return period for the SLV limit state for an ordinary building is given by: Tr =50/ln(1–0.1)= 475 years, with a nominal life of 50 years, a coefficient of use of 1.0 and a probability P of 10%.

Limit States		Probability of exceedance in 50 years (VR=50)	Return period (years)
Damage limit states	SLO	81%	30
	SLD	63%	50
Ultimate limit states	SLV	10%	475
	SLC	5%	975

Table 1.3 - Italian building code NTC08: probabilities of exceedance and return periods for an ordinary building (V_R=50 years)

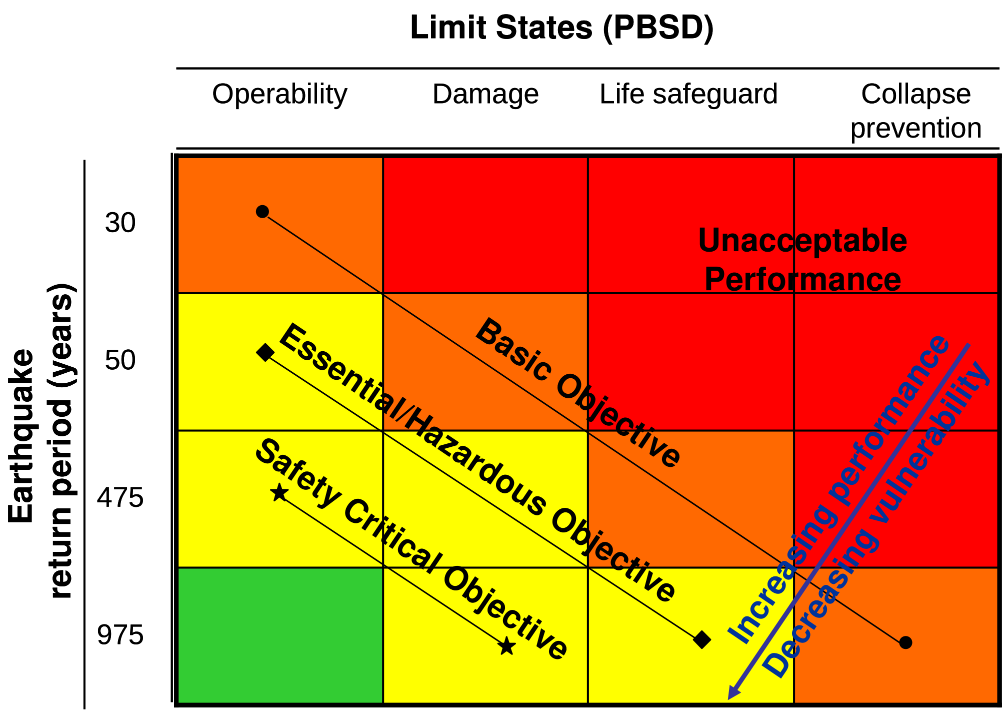


Fig. 1.9.- Performance levels as a function of different earthquake return periods and of the four limit states foreseen by the Italian building code in case of an ordinary building (V_R=50 years)

On January 17, 2018 the new Italian Building Code (NTC18) has been approved by the Minister of Infrastructures and Transport, in agreement with the Minister of Interiors and the Head of the Civil Protection Depratment. It was officially published on February 20, 2018, and then enforced 30 days after its publication. The main principles and design criteria have been kept practically unchanged with respect to NTC08, as well as its organization in 12 chapters, as listed below:

1. Object
2. Target safety and performance
3. Design actions
4. Civil and industrial constructions
5. Bridges
6. Geotechnical Design
7. Seismic design
8. Existing Constructions
9. Static final check
10. Drafting detailed structural design plans and reports
11. Materials and products for structural use
12. Technical references

Although all the chapters are needed for seismic design, the ones that provide specific criteria for seismic design are chapters 2, 3 and 7, and, for existing constructions, chapter 8. Some improvements and updates, also aimed at the alignment with other national and European standards on constructions, have been introduced in NTC18, but they do not need to be specifically addressed in the present document.

In order to investigate about the seismic structural reliability implied by design according to current standards, a national in-depth study, the RINTC – Rischio Implicito delle Strutture Progettate Secondo le NTC - project, which ran from 2015 to 2017, has been carried out, within a ReLUIS – EUCENTRE collaboration (Iervolino et al. 2018). A large group of researchers, experienced in specific structural typologies, designed a large number of buildings at differently hazardous sites. The considered structural configurations were: unreinforced masonry, cast-in-place reinforced concrete, precast reinforced concrete, steel, and base-isolated reinforced concrete. The same designed buildings were also modelled in three-dimensions for the purposes of nonlinear dynamic analysis, which served for seismic structural fragility assessment via state-of-the-art methodologies. The many findings of this investigation will help in improving new building codes in the future (Iervolino et al. 2018).

Seismic risk assessment for a disaster risk reduction strategy – General criteria and 2001 risk assessment

In Italy, the major issue of seismic risk does not concern the design and construction of new buildings, for which the compulsory compliance with the design and the construction process rules prescribed in the Building Code NTC18 guarantee an adequate safety level. It is rather the strengthening of existing high vulnerable buildings that has to be addressed in order to reduce significantly seismic risk. The vulnerability of existing buildings may be reduced with appropriate strengthening and retrofitting techniques but, due to the very large amount of funds required to secure the whole Italian real estate property (estimated in the order of some hundreds billion Euro), it is essential to establish a priority scale of intervention that may result only from a well-grounded seismic risk assessment. As discussed previously the main elements required for seismic risk assessment are hazard, vulnerability and exposure. The hazard assessment for Italy has been presented in a previous section. In the following sections, the main elements for vulnerability evaluation and loss estimation are discussed, focusing in their use for the risk assessment published in 2001 (Lucantoni et al. 2001).

Building inventory

The most accurate and complete data on building vulnerability available in Italy essentially comes from the population census (ISTAT). As an example shown in Table 1.4, using information relative to typology (masonry, R.C.) age of construction, number of storeys, the buildings have been sorted in 4 different typological classes (A, B, C1, C2) from the highest vulnerability (A) to the lowest (C2).

Age of construction (ISTAT census)		Percentages of typological classes			
		A	B	C1	C2
Masonry	< 1919	0,74	0,23	0,03	
	1919-1945	0.52	0,40	0,08	
	1946-1960	0,25	0,47	0,28	
	1961-1971	0,04	0,31	0,65	
	1972-1991	0,02	0,19	0,79	
R. C.		-	-	-	1

Table 1.4 – Example of building inventory based on the population census (ISTAT).

Vulnerability assessment

Constructing an earthquake loss model for a city, region or country involves compiling databases of earthquake activity, ground conditions, ground-motion prediction equations, building stock and infrastructure exposure, and vulnerability characteristics of the exposed inventory. The main aim of a loss model is to calculate the seismic hazard at all the sites of interest and to convolve this hazard with the vulnerability of the exposed building stock such that the damage distribution of the buildings can be predicted; damage ratios, which relate the cost of repair to the cost of demolition and replacement of the structures, can then be used to calculate the loss.

A significant component of a loss model is a methodology to assess the vulnerability of the built environment. The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity. The aim of a vulnerability assessment is to obtain the probability of a given level of damage to a given building type due to an earthquake scenario. Various methods for vulnerability assessment have been proposed in the past for use in loss estimation since the 80s in Italy (Braga et al. 1982), according to different methods, using different input data and providing different output data. In the 90s some proposals to classify the different methods were made (Corsanego & Petrini 1990, Dolce et al. 1994, Dolce 1996). According to a more recent classification proposal, the vulnerability assessment methods can be divided into two main categories: empirical or analytical, both of which are used in hybrid methods as shown in Figure 1.10 (reproduced from Calvi et al. 2006).

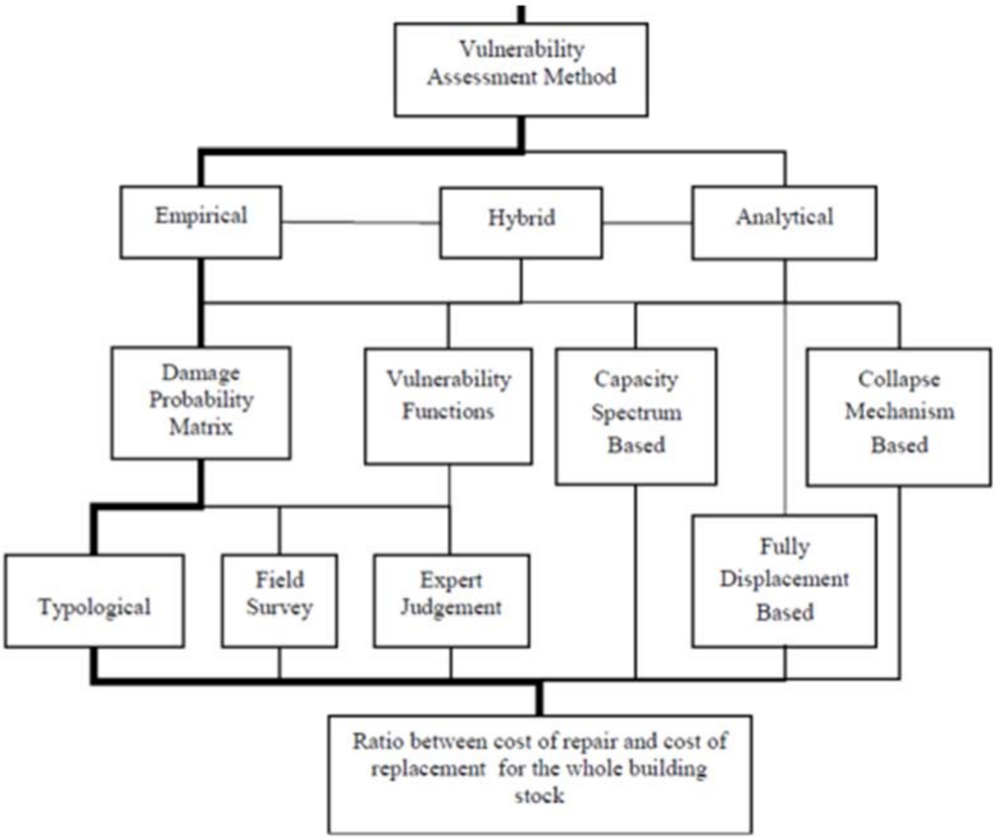


Fig. 1.10 - The components of the vulnerability assessment procedure (Calvi et al. 2006)

There are two ways of expressing the seismic vulnerability of a building or of a type/category of buildings: 1) damage probability matrices (DPM) (e.g. Braga et al. 1982, Di Pasquale et al. 2000, Dolce and Zuccaro 2004), which express the conditional probability of obtaining a damage level in a discretized scale (typically from 0=no damage to 5=collapse, according to the European Macroseismic Scale classification of damage, see Grünthal 1998), due to a ground motion of given (typically macroseismic) intensity for a given vulnerability class as shown in Figure 1.11;

	Vulnerability class - B					
Intensity	Damage Level					
	0	1	2	3	4	5
VI	0,36	0,408	0,185	0,042	0,005	0,0
VII	0,188	0,373	0,296	0,117	0,023	0,002
VIII	0,031	0,155	0,312	0,313	0,157	0,032
IX	0,002	0,022	0,114	0,293	0,376	0,193
X	0,0	0,001	0,017	0,111	0,372	0,498

Fig. 1.11 -Example of damage probability matrix for the building vulnerability class B (Di Pasquale et al. 2000)

2) fragility curves, which are continuous functions expressing, for each vulnerability class, the probability of exceeding a given damage level, depending on a ground motion parameter (e.g. PGA) as shown in Figure 1.12.

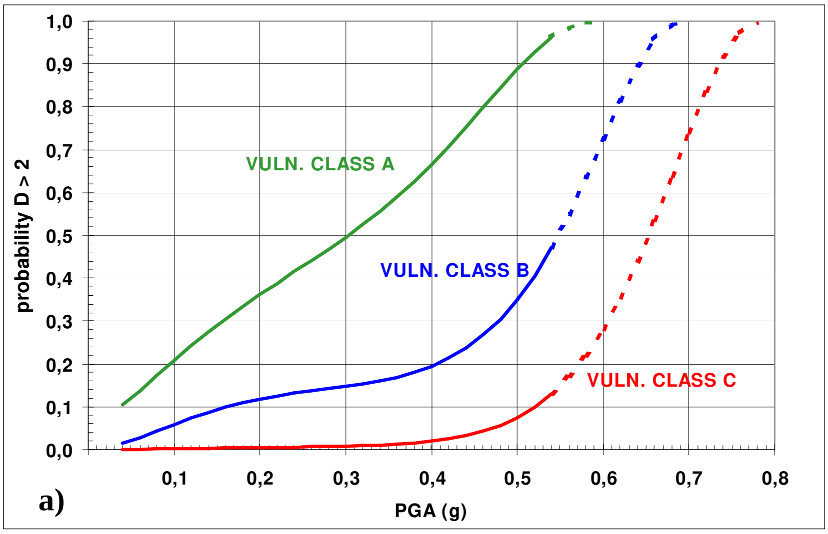


Fig. 1.12 - Example of fragility curves from Sabetta et al. (1998).

Fragility curves and damage probability matrices have traditionally been derived using observed damage data. The analytical/mechanical methods, on the contrary, make use of computational analyses applied to a mechanical model of a given building. Typically the capacity spectrum methodology, based on *pushover curves*, is used to obtain the performance point which is then correlated to a damage level through a scale calibrated to experimental data (Rossetto and Elnashai 2005; Borzi et al 2008a, 2008b). A drawback of the analytical methods is that a mechanical model can more or less adequately represent the behaviour of a reinforced concrete building and very poorly that of a masonry building. To this end, the hybrid methods, combining post-earthquake damage statistics with simulated analytical damage statistics, can be particularly advantageous, in particular when there is a lack of damage data at certain intensity levels for the geographical area under consideration.

Seismic risk maps (2001)

As illustrated in Crowley et al. 2009, since the mid 90s in Italy, a significant effort has been made towards the development of seismic risk maps at national level. The first seismic risk maps for Italy were prepared in 1996 by a Working Group set up specifically for this task by the Department of Civil Protection. As presented in Lucantoni et al. (2001), the aforementioned seismic risk maps were updated based on recent seismic hazard studies and improved damage probability matrices (Di Pasquale et al. 2000) and fragility curves (Sabetta et al. 1998). Seismic hazard data in terms of both PGA and macroseismic intensity (on the Mercalli-Cancani-Sieberg, MCS, scale) were used in the production of the seismic risk maps. The vulnerability of the residential building stock was modelled (as previously described in Table 1.4) using 4 vulnerability classes (A, B, C1 and C2) calibrated with the data coming from the about 80000 buildings inspected following the 1980 Irpinia and 1984 Lazio-Abruzzo earthquakes. The results obtained in terms of percentage of the damaged surface (“loss risk”) and of the expected people involved in building collapses (“life risk”), are shown in Figure 12.

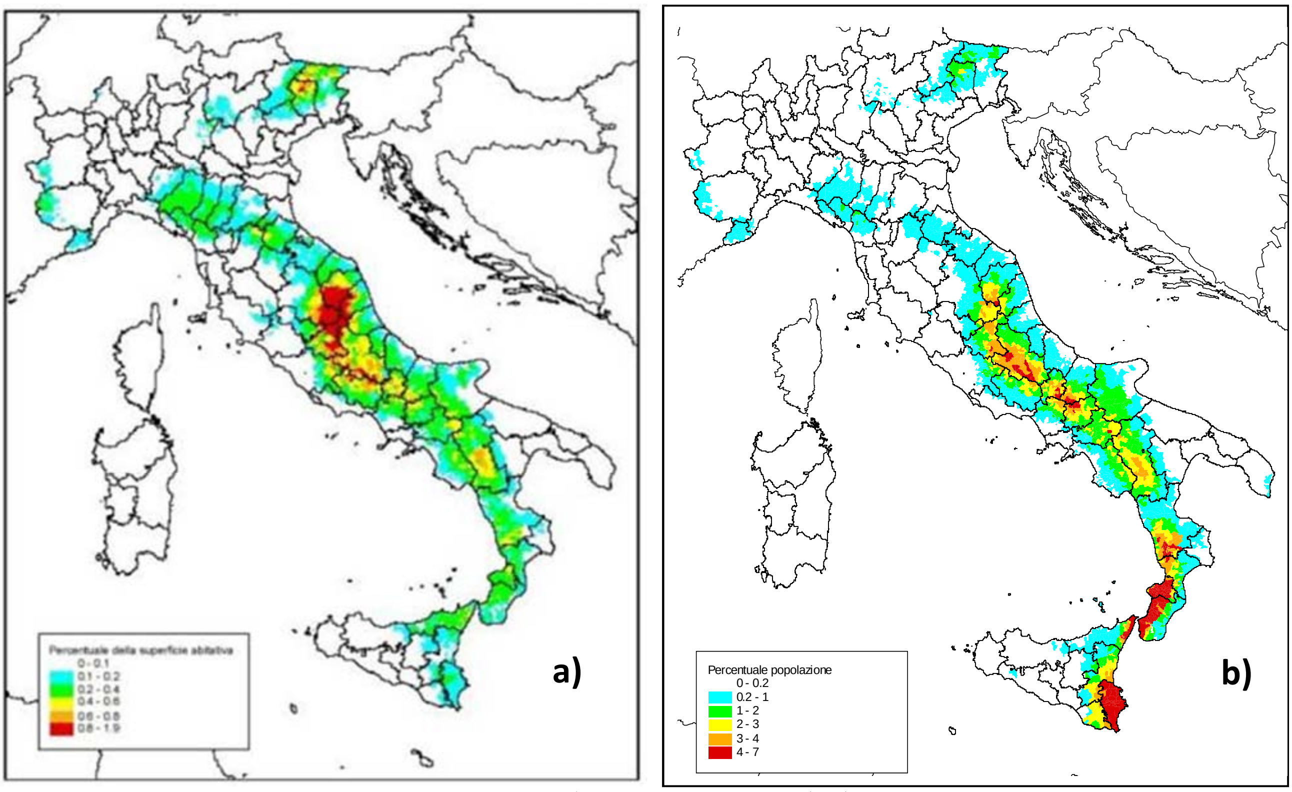


Fig. 1.13 – Seismic risk maps of the Italian territory (Lucantoni et al. 2001): a) percentage of the damaged surface of the residential real estate expected per year in each municipality; b) percentage of the expected people involved, in 100 years in each municipality, in building collapses.

Seismic risk assessment for a disaster risk reduction strategy –2018 risk assessment

Since the production of the above described risk assessment and map in 2001, considerable advancements have been made in the evaluation of seismic hazard, making the MPS04 hazard model available, and in the vulnerability assessment methods. In the meanwhile damage data from recent earthquakes were collected and organized in the unified damage database DaDO (Dolce et al. 2017), which includes detailed data relevant to the eight most important Italian earthquakes, in the 1976-2012 period. Moreover, the development of the centres of competence, particularly of ReLUIS, a university consortium encompassing all the Italian universities which are active in earthquake engineering research, offered the opportunity to involve a large scientific community operating in the seismic vulnerability and risk field to make a new harmonised seismic risk assessment.

Attention is focused on the national dwelling building stock again. This is justified, on the one hand because it represents the most important part of the buildings stock, and therefore of the relevant direct economic losses and, quite often, of casualties, on the other hand because its exposure/vulnerability characteristics are well described by the Italian national population and building census of 2001.

An important requirement of a risk assessment is not only its robust scientific base, but also its consensus in a wide scientific audience, as also required by the new civil protection code (D.Lgs. N.1 /2018). Therefore, it the entire scientific engineering community dealing with seismic risk has been involved in this project. Several research groups were activated at the beginning of 2018. Four of them have produced vulnerability/exposure models for masonry buildings, while two of them for reinforced concrete buildings, based on different approaches. Namely:

- PLINIUS Centre, University of Naples Federico II – masonry buildings - empirical approach
- UNIPD – University of Padova – masonry buildings - mechanical approach
- UNIPV – University of Pavia - masonry buildings - empirical approach
- UNIGE – University of Genova - masonry buildings - heuristic approach
- EUCENTRE -European Centre for training and research in earthquake engineering – reinforced concrete buildings - mechanical approach
- UNIPV-UNINA - University of Naples Federico II and University of Pavia - reinforced concrete buildings - empirical approach

The various approaches differ not only for the fragility curves they obtain, but also for the way these fragility curves are associated to the various categories of buildings drawn from the building census.

In order to have immediate result comparability among the various approach, along the entire process of risk evaluation, a specific risk computation platform on which the different models could be run was considered as necessary. At this end, EUCENTRE was committed by the Civil Protection Department to implement the IRMA platform, that allows different vulnerability/exposure model to be processed, their relevant results to be easily compared and combined.

The availability of DaDO not only allowed research groups to implement new empirical vulnerability models, but also to calibrate the different, even mechanical, models on real damage data and to make sanity checks on them.

With the same aim, a unified metrics for damage levels has been adopted by all the methods, based on the damage levels definitions provided in the European Macroseismic Scale (Grünthal et al. 1998), from negligible/slight damage (D1) to destruction (D5).

Since conventional damage levels cannot allow decision makers to fully appreciate the impact of earthquakes, more suitable quantities expressing the impact are computed through transformation relationships from damage levels to consequences such as: expected direct economic losses (repair/reconstruction costs), expected number of unusable buildings/dwellings (long and short term), dead, injured and homeless.

To avoid inconsistencies due to the use of different hazard models assumed in the risk calculation, the same hazard model is assumed with all vulnerability models, namely the official Italian hazard model MPS04 (Stucchi et al. 2004, 2015).

Further important common choices for all the approaches were made, relevant to the type of soil and the minimum value of soil acceleration for which damage can be expected in any type of dwelling building. As for the type of soil, it has been assumed that the acceleration values provided by the MPS04 hazard model are directly assumed, thus implying that a A-type soil is assumed everywhere, in order to avoid arbitrary choices or large uncertainties in the selection of soil characteristics in specific sites. As for the minimum value of soil acceleration producing damage, a 0.03g value was assumed, based on expert opinion of the working group.

A strong collaboration among the different research groups was established. Several fruitful meetings were organized in order to compare the different vulnerability/exposure models and to discuss intermediate results.

As well known, all the steps of the risk assessment process are affected by large uncertainties coming from different sources. However only the epistemic uncertainty due to the consideration of different vulnerability/exposure models has been considered and reported in the results, by simply showing minimum and maximum values, besides the average values of the quantities of interest. However the results of this risk assessment appear to be quite realistic and compliant with some loss data available, as discussed in the paragraph describing the results. In any case they are meant to be the baseline to test and measure costs and benefits of different hypothetical actions for disaster risk reduction and then to set up of a national seismic risk mitigation strategy.

The IRMA platform

The IRMA (Italian Risk MAps) platform integrates tools to perform damage scenarios and risk maps for the Italian territory. It has been developed by EUCENTRE for the Italian Department of Civil Protection. IRMA is addressed to the scientific community to produce risk maps and damage scenarios for the Italian territory.

In IRMA the assessment of damage produced by an earthquake or for risk assessment is performed by using OpenQuake (OQ), a calculation engine developed by Global Earthquake Model (GEM) (http://www.globalquakemodel.org). The components of OQ have been completely integrated into the platform. The scripts that create the input files and interpret the outputs, have all been automated. All operations are managed through dialogue boxes. In IRMA the user can create and then load different exposure/vulnerability databases and different sets of fragility curves. The hazard for the calculation of the risk maps is, instead, preloaded and is based on the MPS04 hazard model, developed by INGV and adopted at national level first with Civil Protection Ordinance (OPCM 3519/2006).

The IRMA platform is extremely flexible and allows different exposure databases derived from the ISTAT 2001 census to be combined with different sets of fragility curves to produce risk maps. These latter are relevant to conditional damage assessments (where the condition is the occurrence of an earthquake with a selected return period) or unconditional damage assessments (where the condition is removed by considering the probability of a ground shaking severity in a selected time observation window). It is also possible to produce damage scenarios using shakemaps as seismic input. This possibility has been added to allow the users to validate their vulnerability and fragility model by comparing numerically calculated damage scenario with the observed damage data contained in the DaDO platform (Observed Damage Database) that contains all the buildings damage data caused by earthquakes occurred in Italy in the last 40 years. The results of all the activities processed using the IRMA platform can be displayed on maps, in tables and downloaded as shapefiles or in csv format.

Summarising, the IRMA platform was designed in order to:

- Collect, process, and show information on seismic fragility defined with the different methodologies developed by the various research groups;
- Provide a unique calculation tool to process data of fragility, exposure, damage, and seismic risk;
- Show, share, compare and combine the elaborations processed by the different research groups,

The platform has been designed and developed to have the following features:

- The calculation engine is OpenQuake v3.2.0 (Pagani et al. 2014);
- The platform is extremely flexible so that it can:
  - process different exposure/vulnerability models, based on the same exposure database provided by the national population and building census carried out in 2001 (ISTAT-2001) and any set of fragility curves provided by the user;
  - carry out conditional and unconditional risk analyses, considering different metrics (damage levels, direct economic losses, casualties, homeless, unusable buildings and dwellings)
  - calculate damage and loss scenarios with the same damage and loss metrics.
- The user can:
  - create the exposure/vulnerability database starting from the ISTAT 2001 census database;
  - create a set of fragility curves;
  - combine different exposure/vulnerability databases with different sets of fragility curves as well as produce conditional (for selected return periods) or unconditional (for selected observation time windows) damage maps;
  - calculate conditional or unconditional risk maps considering human losses, economic losses, and impact in terms of unusable buildings in the short and long time span;
  - calculate damage scenarios using shakemaps;
  - aggregate the damage maps, the risk maps, and scenario maps previously calculated. Maps can be made for the whole building stock or for a portion of the building stock. This can be done by selecting masonry or RC buildings, by selecting regions (i.e. Lombardi, Tuscany, ect.), and by filtering municipalities as a function of demography. Therefore, aggregation can be made for materials, regions, and municipality with different demography;
  - view the results in maps and tables;
  - download the map in shapefiles and tables in csv format.

<u>Exposure/vulnerability models - PLINIUS Centre – University of Naples Federico II -Masonry buildings</u>

The model proposed by the PLINIVS Study Centre is intended to describe the seismic masonry buildings behaviour with a procedure derived by a critical observational approach on the basis of the post-earthquake data. The damage data exploited to build the procedure is the PLINIVS database, in which data connected to several Italian seismic events are collected. The information in the database is about structural and typological features of the damaged buildings, the level of damage of the buildings and the hazard input (in intensity) for each municipality. The most important seismic events, for which most data are collected, are L’Aquila2009 and Irpinia1980, and on the basis of this data the model is derived. Furthermore, fragility curves are described in terms of PGA so the input hazard used is derived from the INGV shakemap for the seismic event of L’Aquila, and using the Margottini (Margottini et al. 1992) conversion on the intensity data of Irpinia1980.

The first step adopted in the method is the conversion of the level of damage reported in the detection forms Irpinia (Braga et al. 1982) and AeDES (Baggio et al. 2007) aedesinto the five level of damage of the EMS-98 are used as a reference for the model. This conversion is summarized in Table 1.5.

IRPINIA FORM

	vertical structure								
irpinia form	0	1	2	3	4	5	6	7	8
conversion	0	0	1	2	3	3	4	4	5

	horizontal structure								
irpinia form	0	1	2	3	4	5	6	7	8
conversion	0	0	1	2	2	3	4	4	5

AeDES FORM

	HIGH			**MEDIUM**			**LOW**			**NO DAMAGE**
	> 2/3	**1/3 - 2/3**	**<1/3**	**> 2/3**	**1/3 - 2/3**	**<1/3**	**> 2/3**	**1/3 - 2/3**	**<1/3**	
vertical structure	5	5	4	3	3	3	3	2	2	0
horizontal structure	5	4	4	3	3	3	2	2	1	0

Table 1.5 – Conversion of the damage in the forms in the damage of the EMS-98

The second step of the procedure is the definition of the vulnerability classes. In this work the SAVE method (Zuccaro 2002) is adopted, a procedure that define a correlation between the occurrence of a level of damage of and its typological characteristics of the damaged buildings. In this work only three classes of vulnerability are defined, and the limit values of SPD (Synthetic Parameter of Damage – see Zuccaro 2002, SAVE task 1) used to define the class are, according to the damage values: A Class from 2,10 to 5; B class from 1,6 to 2,1 and C class from 0 to 1,6.

As third step, the vulnerability curves are derived with a regression method. A distribution of the observed data is associated to each PGA value for each vulnerability class. A reliability of the distribution of the buildings on the level of damage is also taken into account. To this purpose only the dataset of the L'Aquila 2009 is exploited. In particular, keeping in mind that the dominium of the function is the acceleration, the reliability of the building distribution on the level of damage is evaluated as a ratio between all buildings detected having the input PGA considered and all buildings in the municipalities affected by the PGA considered according to ISTAT2001. The same reliabilities for each PGA values are extended to the Irpinia1980 data. Furthermore, knowing that low PGA values do not produce any damage, a strong assumption is done imposing that there are no damages for PGA $\leq$ 0,03 g. The reliability associated to each PGA value is used as a weight for the regression of the logarithmic function that describes the fragility curve. Table 1.6 reports the parameters of the lognormal fragility curves of the predefined vulnerability classes.

	μ_1 [g]	β_1 [-]	μ_2 [g]	β_2 [-]	μ_3 [g]	β_3 [-]	μ_4 [g]	β_4 [-]	μ_5 [g]	β_5 [-]
A	0,07	1,10	0,15	1,10	0,27	1,00	0,54	1,00	1,07	1,00
B	0,15	0,90	0,28	0,90	0,46	0,90	0,77	0,90	1,22	0,90
C1	0,29	0,80	0,62	0,80	0,79	0,80	1,29	0,80	2,27	0,80

Table 1.6 – Medians [μ] and logarithmic standard deviations [β] of the lognormal fragility curves for vulnerability classes.

At the end, the building distribution on the classes is evaluated using the BINC procedure (Cacace et al. 2018). The BINC procedure has been modified to be applied to the IRMA platform and the only three parameters (number of floors, age and materials – in this case masonry only) have been considered. All the possible combinations of these three parameters have been considered and for each of them the corresponding estimate of the distribution of vulnerabilities has been obtained.

Exposure/vulnerability models - UNIPD – University of Padova – Masonry buildings

The seismic vulnerability model for the large-scale seismic risk assessment, developed by the University of Padova, is based on the mechanical fragility estimate of the residential masonry building stock grouped in ten macro-categories, defined by five construction ages (pre-919, 1919-45, 1946-60, 1961-80, post-1980) and two classes of height (low-rise "L" and mid/high-rise "MH", i.e. up to or more than 2 storeys). This information is available for the entire building stock in the national census. To this aim, a database of over 500 masonry buildings, collecting the main building information (geometric features, material properties and typological/constructive features), was created. The detected parameters showed a certain correlation not only with the construction age, but also with the geographical position: indeed, for the same macro-category, it was possible to observe significant differences among various regions and, in the same region, among various locations. Therefore, the buildings were appropriately sampled to guarantee both the typological and geographical representativeness of the building stock; i.e., sampling involved several Italian regions and municipalities. The building information was retrieved directly from the related projects and, in the case of missing information, reference was made to design manuals, codes, and specific literature was created[1].

The mechanical fragility was calculated for each building of the database by using Vulnus Vb 4.0, a software developed at the University of Padova (Bernardini et al. 2009, Munari 2009) which assesses the in-plane failure and the main out-of-plane mechanisms. Then, on the basis of the Fuzzy theory and the judgments on the quality of the information provided, Vulnus returns a set of 3 fragility curves, defined in terms of PGA, for each building: one curve (White) represents the most probable fragility, while the other two define the maximum probable range of fragility (Upper and Lower Bounds). The damage level (DS) associated with these fragility curves is DS2-3, according to the EMS-98 scale (Grünthal 1998), as they provide the probability of triggering kinematics or shear failures based on linear analyses. The mechanical fragility of the macro-categories was obtained following these phases: calculation of the average fragility, for each municipality, of buildings of the same construction period and number of storeys; calculation of the average fragility curves of those obtained in the various municipalities, still subdivided by period and number of storeys; weighted average of the previous fragilities, where the weights correspond to the statistical distribution of the buildings per number of storeys, within each construction period. In this way, the same weight is assigned to the different geographical areas (in the absence of further information) and the typological representativeness of the built stock is restored.

In order to define fragility for all damage levels of the EMS-98 scale (from DS1 to DS5), the model of Lagomarsino and Cattari (2014) (which is derived from the macroseismic vulnerability model of

[1] *References for the database creation*: Donghi D. (1905), *Manuale dell'architetto*, Utet. Moretti B. (1946), *Ville. 68 Esempi di ville e case di campagna*, Hoepli. Moretti B. (1947), *Case d'abitazione in Italia*, Hoepli. Ceccarini I. (1952), *Composizione della casa*, Hoepli. Corrado V. et al. (2014), *TABULA: Buildind Typology Brochure – Italy*.

Lagomarsino and Giovinazzi 2006) was taken as reference, and the correlation law between macroseismic intensity and PGA of Margottini et al. (1992) was assumed. This model was calibrated on the mechanical fragility results, thus obtaining a mechanical-heuristic vulnerability model. The calibration was performed by evaluating, for each mechanical fragility curve obtained (White, Upper- and Lower-Bounds, for each macro-category), the best linear combination between the fragility curves (associated with a damage level DS2-3) of the various classes of the macroseismic model; for this purpose, the genetic algorithm NSGA-II was implemented to minimize both the absolute error between the curves, according to the criterion of the least squares, and the relative error between them, calculated as the difference between the positive and negative areas subtended between the two curves. Therefore, for each macro-category, three sets of fragility curves (from DS1 to DS5) were obtained, associated with the White, Upper- and Lower-Bounds probabilities. A single fragility set was finally derived by assuming the mean fragility of the White set and the maximum dispersion, for each DS, given by the fragility range between the Upper- and Lower-curves. The results obtained are summarized in the 4-class vulnerability model of Table 1.7. The fragility for each macro-category can be obtained through the linear combination coefficients of the vulnerability classes listed in Table 1.8.

Vulnerability	**DS1**		**DS2**		**DS3**		**DS4**		**DS5**	
class	μ [g]	β [-]	μ [g]	β [-]	μ [g]	β [-]	μ [g]	β [-]	μ [g]	β [-]
A	0.07	0.74	0.13	0.77	0.21	0.78	0.34	0.77	0.62	0.81
B	0.11	0.74	0.19	0.75	0.31	0.75	0.50	0.76	0.91	0.79
C1	0.17	0.68	0.30	0.71	0.48	0.74	0.79	0.79	1.44	0.70
C2	0.31	0.79	0.55	0.74	0.88	0.74	1.42	0.68	2.47	0.61

Table 1.7 – Medians (μ) and standard deviations (β) of the lognormal fragility curves for vulnerability classes

Vulnerability	**Pre-1919**		**1919-45**		**1946-60**		**1961-80**		**Post-1980**	
class	**MH**	**L**	**MH**	**L**	**MH**	**L**	**MH**	**L**	**MH**	**L**
A	100%	29%	65%							
B		71%	35%	100%	41%	11%				
C1					59%	89%	100%	65%	42%	
C2								35%	58%	100%

Table 1.8 – Composition of the masonry building stock in terms of percentages of vulnerability classes

Exposure/vulnerability models - UNIPV – University of Pavia – Masonry buildings

The vulnerability model proposed by the University of Pavia for large-scale seismic risk assessment of residential masonry buildings is empirically derived and takes advantage of post-earthquake damage data from Italian events. The source of damage data consists of the web-based platform Da.D.O. (Dolce et al. 2017), including damage databases of nine earthquakes occurred in Italy since 1976. In this work, only the 1980 Irpinia and 2009 L'Aquila post-earthquake data were employed, given the availability of shake maps for seismic input characterisation. All the Irpinia municipalities were completely surveyed (Braga et al. 1982), whereas, in case of L'Aquila seismic event, only municipalities with completeness threshold of 90% were considered to be completely inspected. To account for the negative evidence of damage, this complete dataset was integrated by buildings located in non-inspected and partially inspected (completeness lower than 10%) municipalities.

Key ingredients of the proposed vulnerability model are the description of the seismic vulnerability, in terms of fragility curves for vulnerability classes, and the composition of the vulnerability model, obtained by subdividing the masonry building stock into the predefined vulnerability classes.

Fragility curves were defined in terms of PGA, estimated from shake map at the municipal level, for five damage levels of the EMS-98 scale (Grünthal et al. 1998), identified based on the maximum damage observed on selected building components (e.g., Rosti et al. 2018). The rules proposed by Dolce et al. (2017) and Rota et al. (2008) were adopted for converting the damage description of the survey forms into the EMS-98 discrete damage levels. Typological fragility curves were derived for eight masonry building typologies, identified on the basis of the texture and quality of the masonry fabric, in-plane flexibility of diaphragms and presence (or absence) of ties. The lognormal distribution was fitted to observational damage data via the maximum likelihood estimate approach, assuming a unique value of dispersion for all damage states of each building typology, to ensure the ordinal nature of damage (e.g. Lallemant et al. 2015). The random component, expressing the probability distribution of the response variable given the ground motion intensity, was described by the multinomial distribution (e.g. Charvet et al. 2014). The identified building typologies were then merged into three vulnerability classes of decreasing vulnerability (i.e. A, B and C1), through a hierarchical agglomerative clustering (e.g. Day and Edelsbrunner 1984), based on the similarity of the observed seismic fragility. Table 1.9 reports the parameters of the lognormal fragility curves of the predefined vulnerability classes, further refined based on the class of height (i.e. L-low-rise: 1-2 storeys and MH-mid-/high-rise: >2 storeys).

Vulnerability class	**Class of height**	**θ_{DS1} [g]**	**θ_{DS2} [g]**	**θ_{DS3} [g]**	**θ_{DS4} [g]**	**θ_{DS5} [g]**	**β [-]**
A	**L**	0.12	0.19	0.26	0.35	0.58	0.75
	MH	0.11	0.18	0.23	0.31	0.58	0.82
B	**L**	0.23	0.51	0.66	0.99	1.73	1.03
	MH	0.17	0.33	0.43	0.62	1.21	1.00
C1	**L**	0.48	1.35	1.93	2.74	4.71	1.22
	MH	0.42	1.07	1.44	2.12	3.82	1.20

Table 1.9 – Medians and logarithmic standard deviations of the lognormal fragility curves for vulnerability classes.

The vulnerability model was composed by defining the percentages of the masonry building stock belonging to the predefined vulnerability classes. Post-earthquake damage data were classified into macro-categories, according to the building attributes of the national census (i.e. construction material, class of height and construction age). For each macro-category, the fragility curve of each damage state was expressed as a linear combination of the fragility curves of the vulnerability classes. The fractions of each macro-category belonging to the predefined vulnerability classes (Table 1.10) were derived through an optimisation problem, by minimising the sum of the squared errors with the empirically-derived fragility curves of a given macro-category.

Vulnerability class	**<1919**	**1919-45**	**1946-61**	**1962-71**	**1972-81**	**>1981**
A-L	86%	45%	9%	5%	0%	0%
B-L	0%	44%	59%	4%	0%	0%
C1-L	14%	11%	32%	91%	100%	100%
A-MH	97%	22%	0%	0%	0%	0%
B-MH	0%	78%	75%	18%	0%	0%

C1-MH	3%	0%	25%	82%	100%	100%

Table 1.10 – Composition of the masonry building stock in terms of percentages of masonry macro-categories belonging to the different vulnerability classes.

Exposure/vulnerability models - UNIGE – University of Genova – Masonry buildings

The ReLUIS Research Unit of the University of Genoa (coordinator: Sergio Lagomarsino; coworkers: Serena Cattari, Daria Ottonelli and Sabrina Vignolo) has derived fragility curves for the masonry residential buildings in Italy from the macroseismic vulnerability model (originally proposed by Lagomarsino and Giovinazzi 2006 and further developed within this research). The method may be classified as heuristic, in the sense that: a) it is based on the expert judgment that is implicit in the European Macroseismic Scale (EMS 98), with some assumptions on the fuzzy definition of the binomial damage distribution; b) it is calibrated on the actual damage observed in Italy, available in DaDO. This approach guarantees a fairly well fitting with observed damage but, at the same time, ensures physically correct results for both low and high values of the seismic intensity (for which observed data are incomplete or lacking), and a coherent distribution between the different damage levels.

The IRMA platform (Italian Risk Maps) is based on the vulnerability classes (from A to D) and the five damage levels defined by the EMS 98 (D_k, from D1 to D5). Fragility curves are associated to each damage level for each vulnerability class. Therefore, the vulnerability class is representative of a seismic behaviour (represented by the fragility curves), notwithstanding the building typology; indeed, buildings of different types may behave similarly (belong to the same vulnerability class) while buildings of the same type may behave differently. The information on the Italian building stock is taken from ISTAT 2001, in terms of material (masonry and r.c.), age and number of storeys. For masonry buildings, subtypes are defined in terms of age and height, associating to each one the percentage of buildings in the different EMS 98 vulnerability classes.

The original macroseismic vulnerability model, described in details in Bernardini et al. (2010), represents the seismic behaviour of each vulnerability class by an analytical correlation between the macroseismic intensity (*I*) and the mean damage level (μ_D) in terms of two parameters: the vulnerability index (*V*) and the ductility index (*Q*) (the latter equal to 2.3, when directly derived from EMS 98). The mean damage level is obtained from the damage levels observed in buildings of a specific class, hit by a given macroseismic intensity. The calibration of the model by the observed damage data in Da.D.O. has highlighted that Q is well correlated with *V*, thus providing a model defined by only one parameter:

$$\mu_D = 2.5\left[1 + tanh\left(\frac{I + 3{,}45V - 11.7}{0.9 + 2.8V}\right)\right]$$

Vulnerability Class	A	B	C	D
V	0.99	0.80	0.61	0.42

The derivation of fragility curves, to be implemented in IRMA, requires: a) the identification of the mean damage level μ_{Dk}, which a probability of 50% is associated to the attainment of damage level k (assuming a binomial distribution: $\mu_{Dk} = 0.9k - 0.2$); b) a correlation law between *I* and *PGA*, directly obtained from the INGV shake map of L'Aquila earthquake (2009):

$$PGA = f_1\, f_2^{I-5}$$

with f_1=0.05 [g] and f_2=1.66, resulting very similar to Margottini et al. (1992) (f_1=0.043 [g] and f_2=1.66).

The lognormal fragility curve parameters (median value and dispersion) are then given analytically by:

$$PGA_{Dk} = f_1 f_2^{[6.7-3.25V+(0.9+2.8V)atanh(0.36k-1.08)]}$$

$$\beta_{Dk} = \sqrt{\beta_1^2(V, f_2, k) + \beta_2^2(k)}$$

where the dispersion is given by two contributions:

- $\beta_1 = (a_k f_2 + b_k)\,V + (c_k f_2 + d_k)$ is implicit in the EMS 98 macroseismic model and has been obtained by fitting the analytical curves through the following coefficients:

	D1	D2	D3 - D4	D5
a_k	0.625	0.75	0.719	0.75
b_k	-0.5075	-0.675	-0.523	-0.535
c_k	0.281	0.219	0.25	0.3125
d_k	0.0131	-0.1031	-0.245	-0.309

- $\beta_2 = 0.36 - 0.06\,k$ is related to the variability obtained by fitting damage data observed after different earthquakes (in particular Irpinia 1980 and L'Aquila 2009), and might be eliminated if a regional vulnerability should be introduced in the future.
-

The parameters of the fragility curves for the EMS 98 vulnerability classes are given in Table 1.11.

Vulnerability	D1		D2		D3		D4		D5	
class	PGA [g]	β [-]	PGA [g]	β [-]	PGA [g]	β [-]	PGA [g]	β [-]	PGA [g]	β [-]
A	0.064	1.00	0.161	0.81	0.309	0.79	0.594	0.78	1.491	0.85
B	0.104	0.92	0.232	0.72	0.409	0.69	0.722	0.68	1.605	0.74
C1	0.180	0.83	0.350	0.63	0.560	0.57	0.898	0.56	1.744	0.61
D	0.275	0.76	0.481	0.55	0.716	0.49	1.064	0.47	1.860	0.51

Table 1.11 – median (PGA) and dispersion (β) of the lognormal fragility curves for vulnerability classes

The vulnerability index *V* was obtained for the masonry buildings subtypes, which may be defined by ISTAT data by considering age and storey class (Low 1-2; Medium 3-5; High >5). Therefore, the percentage of buildings in each class was identified (Table 1.12), in order to reproduce the observed vulnerability.

Vulnerability	Pre-1919			1919-45			1946-61			1962-81			Post 1981		
class	L	M	H	L	M	H	L	M	H	L	M	H	L	M	H
A	80%	60%	100%	25%		60%									
B	20%	40%		75%	90%	40%	50%	70%	85%		20%	45%			
C1					10%		50%	30%	15%	70%	80%	55%		40%	70%
D										30%			100%	60%	30%

Table 1.12 – Composition of the masonry building stock in terms of percentages of vulnerability classes.

Exposure/vulnerability models - EUCENTRE – European Centre for training and research in earthquake engineering – Reinforced concrete buildings

EUCENTRE utilizes the analytical methodology SP-BELA (Simplified Pushover-Based Earthquake Loss Assessment) to set up the vulnerability model of reinforced concrete (RC) buildings used in IRMA. SP-BELA assigns the vulnerability classes "C2" or "D" to RC buildings. This class assignment depends on both the construction period and the seismic classification year of the municipalities to which buildings belong. However, regardless of the seismic classification year of the municipality, all RC buildings built before 1982 are however considered as not seismically designed, since the previous building codes are considered to be not effective in terms of seismic performance.

Simplified Pushover-Based Earthquake Loss Assessment (SP-BELA) is an analytical procedure that allows to estimate the structural vulnerability of buildings through the definition of fragility curves. This methodology can be applied to different structural typologies, i.e.: masonry buildings (Borzi et al. 2008a), RC frame buildings (Borzi et al. 2008b and c), and precast buildings (Bolognini et al. 2008). According to the procedure, fragility curves are obtained by comparing the displacement capacity of representative building classes with the displacement demand for the considered damage levels.

The fragility curves for RC buildings through SP-BELA are defined in several steps. The first step of the procedure defines a sample of buildings through Monte Carlo generation starting from a building prototype that is representative of the selected building typology. The buildings sample is generated by varying predefined structural parameters (i.e., building geometry, loads, material characteristics, deformation capacity) according to probabilistic distribution relationships. Once the representative sample of a given type of structure is defined, SP-BELA carries out a simulated design for each building within. The simulated design reduces the number of random variables describing the sample, since some structural characteristics (i.e., dimension and reinforcement of structural elements) are not random variables, but are rather designed according to the code in force in the period of construction.

Subsequently, each building is subjected to a non-linear static analysis whose final product is a pushover curve from which the properties of an equivalent (in terms of vibration period, displacement, and dissipation capacity) single-degree-of-freedom (SDOF) system are defined. The equivalent damping factor is defined as a function of ductility.

The seismic demand is defined through a spectral displacement. A displacement spectral shape is anchored to each value of peak ground acceleration PGA for which the point of the fragility curve derives. To account for the variability of seismic demand, in SP-BELA the seismic demand is calculated by considering the 50th percentile spectral shapes that the Italian Seismic Code (in the following, NTC08) defines for all the 8101 municipality in Italy for the nine return periods. In addition of that, both the corner period T_c and the parameter F_o vary according to predefined probabilistic distribution laws. Specifically:

- the corner period T_c is assumed to have a uniform distribution between $0.7*T_c$ and $1.3*T_c$ which account for the variability of spectral shape related to soil condition;

- F_0 follows a log-normal distribution law for which the mean μ and the standard deviation σ are 2.5 and 1.1, respectively.

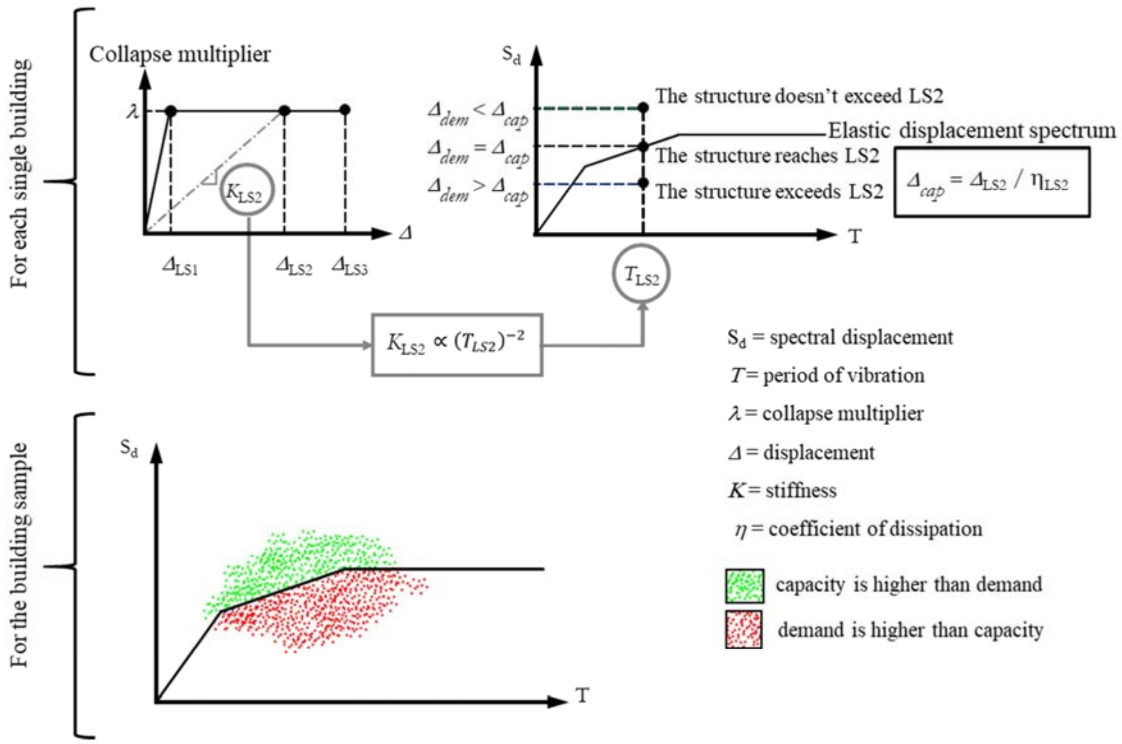


Fig. 1.14 - Procedure to calculate the probability of exceedance of limit condition.

The procedure to calculate the probability of exceedance of each limit is depicted in Figure 1.14. For each building of the sample, the pushover curve is calculated. Parameters defined through the curves are: the equivalent period of vibration T_{eq}, the displacement capacity Δ_{cap}, and a coefficient η which increases the displacement capacity (i.e., reduce the displacement demand) accounting for energy dissipation. For each limit state, a point on the plane of the spectrum can be plotted. If the point is above the spectral curve, the capacity Δ_{cap} is higher than the demand Δ_{dem} and hence the corresponding building satisfies the limit condition. When the point is below the spectrum, demand is higher than capacity and the building does not satisfy the limit condition, thus evolving in the higher damage condition. Repeating the procedure for all the buildings of the sample, the number of points below the spectral curve divided by the population dimension gives the probability of exceedance.

Exposure/vulnerability models - UNINA-UNIPV – University of Naples Federico II & University of Pavia – Reinforced concrete buildings

Empirical fragility curves for the Italian residential Reinforced Concrete (RC) building stock were derived on the basis of the data published by the Italian Department of Civil Protection in the online platform DaDO (Dolce et al. 2017), collecting single-building post-earthquake damage data from past Italian earthquakes.

The DaDO platform collects post-earthquake damage databases of nine seismic events occurred in Italy, from Friuli 1976 to Emilia 2012. Different criteria were adopted to select the events used for fragility analysis, namely: the availability of data on RC buildings; the type and detail of information on damage (i.e., presence or not of information on damage non-structural components such as infill walls); the presence of data characterized by "complete" surveys in damaged Municipalities. The Peak Ground Acceleration (PGA) was the selected ground motion Intensity Measure, estimated at the building locations by the INGV ShakeMaps (Michelini et al. 2008); hence, a further criterion used to select the events was the availability of ShakeMaps consistently derived with the INGV procedure. As a result, only data from two events were retained, namely Irpinia 1980 and L'Aquila 2009 earthquakes. Furthermore, in order to predict with higher accuracy the expected damage for very low PGA values, it was decided to include in the damage database of the L'Aquila 2009 event buildings from completely non-surveyed (or surveyed for a very minor part of the building stock) Municipalities. Buildings located in these Municipalities, in the areas least affected by the ground shaking, were surveyed only under explicit request of the owner. Non-surveyed (likely because non-damaged) buildings were, of course, not present in the original version of the database, but disregarding them may lead to bias in the fragility evaluation. For this reason, these buildings, whose amount and characteristics were evaluated form census data, were assumed as negative evidence of damage and hence added to the database as non-damaged buildings. Damage States were defined consistently with the European Macroseismic Scale EMS-98 (Grünthal 1998). A global damage level was assigned to each building, in accordance with the damage conversion rules proposed by DaDO platform and by Rota et al. (2008), for structural components, and by Del Gaudio et al. (2017), for non-structural components, respectively, considering the maximum level of damage between the two types of components.

The ground motion range was subdivided into equally-spaced bins of 0.05g width. Empirical damage data were approximated by fitting a lognormal cumulative distribution through the Maximum Likelihood Estimation (MLE) method. To ensure the ordinal nature of damage, a constant dispersion value for all damage states of a given building typology was assumed. The random component was described by the multinomial distribution (Charvet el al. 2014). In order to derive empirical fragility curves, building typologies were defined first, based on the selection of main building parameters influencing seismic fragility. Typological fragility curves were derived for RC buildings by defining building typologies based on two parameters, namely the number of stories (from 1 to 5, including the vast majority of the buildings in the selected database) and the type of design (for gravity loads only, for seismic loads pre-1981 – deemed as "obsolete", and for seismic loads post-1981). Data on damage to buildings designed for gravity loads only were mostly included in the Irpinia 1980 dataset, whereas buildings with effective seismic design were only present in the L'Aquila 2009 dataset. A clear hierarchy was observed within these typologies, with increasing damage for buildings designed for gravity loads only, for seismic loads pre-1981 or for seismic loads post-1981, respectively. Fragility curves were derived for each one of these 15 typologies (i.e. considering the 3 seismic design levels and the 5 height classes). However, the proposed fragility curves had to be rederived to fit the specific buildings categories resulting from the ISTAT census data. "Class" fragility curves were then defined for two vulnerability classes, C2 and D, of decreasing vulnerability, and depending on the class of height. More specifically, buildings designed for gravity loads only or for seismic loads pre-1981 were grouped in class C2, whereas buildings designed for seismic loads post-1981 were assigned to class D. Moreover, these classes were further specialized to three ranges of height, i.e. low-rise: 1-2 stories, mid-rise: 3-4 stories, and high-rise: >4 stories (Table 1). To this end, these 6 (=3×2) sets of fragility curves were derived as a weighted average of the abovementioned 15 (=5×3) sets of typological fragility curves, using as weights the probabilities of occurrence of each typology within the corresponding class, evaluated based on ISTAT census data at national scale, consistent with the aim of national-scale applications.

Vulnerability class	Class of height	θ_{DS1} [g]	θ_{DS2} [g]	θ_{DS3} [g]	θ_{DS4} [g]	θ_{DS5} [g]	β [-]
C2	L	0.213	0.518	0.857	1.388	1.646	0.790
	M	0.126	0.250	0.397	0.806	0.931	0.693
	H	0.081	0.119	0.164	0.328	0.498	0.509
D	L	0.422	1.163	1.822	3.024	4.458	0.951
	M	0.253	0.774	1.417	2.682	7.386	0.995
	M	0.183	0.351	0.598	1.129	1.196	0.531

Table 1.13 – Parameters (i.e. medians and logarithmic standard deviation) of the lognormal fragility curves for vulnerability classes

Risk assessment results in terms of damage levels

The most interesting results are those relevant to the *unconditional risk assessment*, as it accounts for all the losses that can occur in a given time windows due to the earthquakes occurring in this time window with their probability. In particular, two time windows have been chosen, namely one year, which means to provide the annual frequency of the considered damage levels or loss types, and fifty years.

The results shown here are relevant to different types of losses, for which different metrics have been assumed. However, all of them are derived from the estimates of the buildings and dwellings affected by the five damage levels that each research group has made, by considering the relationship between damage levels and losses of different types, as seen in a previous paragraph.

The results of the elaborations of each of the research groups, four for masonry buildings and two for reinforced concrete (RC) buildings, have been further processed to obtain the average estimated values. In particular, the average values, as well as maximum and minimum, obtained by the four groups studying masonry buildings have been computed. Similarly, average, maximum and minimum values have been computed for RC buildings. In order to get the estimated average, maximum and minimum values relevant to the entire national building stock, the values relevant to masonry and RC buildings have been finally summed up. This procedure has been followed for the unconditional seismic risk expressed in term of both damage levels and consequences of different kinds.

In table 1.14 and table 1.15 there are shown the estimated average, maximum and minimum values of the expected number of dwellings affected by the considered five damage levels

Damage Level	D1	D2	D3	D4	D5
	EXPECTED NUMBER OF DAMAGED DWELLINGS IN 1 YEAR / 1000				
Average	**143,1**	**38,7**	**17,8**	**6,1**	**2,1**
Maximum	203,1	65,1	31,4	8,1	3,3
Minimum	84,4	15,6	7,9	2,6	0,4

Table 1.14 - Average, maximum and minimum values of the expected number of dwellings affected by the considered five damage levels in one year – thousands of dwellings.

Damage Level	D1	D2	D3	D4	D5
	EXPECTED NUMBER OF DAMAGED DWELLINGS IN 50 YEARS / 1000				
Average	**4199,7**	**1436,0**	**783,0**	**290,9**	**103,6**
Maximum	5738,4	2198,7	1348,0	382,2	161,9
Minimum	3154,4	631,2	372,2	130,6	19,5

Table 1.15 - Average, maximum and minimum values of the expected number of dwellings affected by the considered five damage levels in fifty year – thousands of dwellings.

Looking at the average values, it can be noticed that a very large number of damaged dwellings is expected per year, and, proportionately in fifty years. In particular this number reduces of one order of magnitude passing from D1 to D3 and from D3 to D5. It has to be noticed that 2100 dwellings in collapsed buildings per year or, equivalently, more than hundred thousands in 50 years are expected.

Looking at the maximum and minimum expected values, it can be noticed that large variations, in the order of 50%, are obtained just because of the differences among vulnerability models. As said above, even larger uncertainties would be obtained if randomness and other epistemic uncertainties related to hazard, including soil amplification and coseismic effects, exposure and vulnerability are taken into account. This confirm the difficulty in making estimates of the effects of future earthquakes.

The results can be also represented in maps that show the geographical distribution of the damage. In order to provide a different view of the risk of damage, the maps in figs 1.15, 1.16 and 1.17, provide the average expected ratios in one year of the number of dwellings affected by damage levels 1, 3 and 5, respectively, over the total number of dwellings in the municipalities.

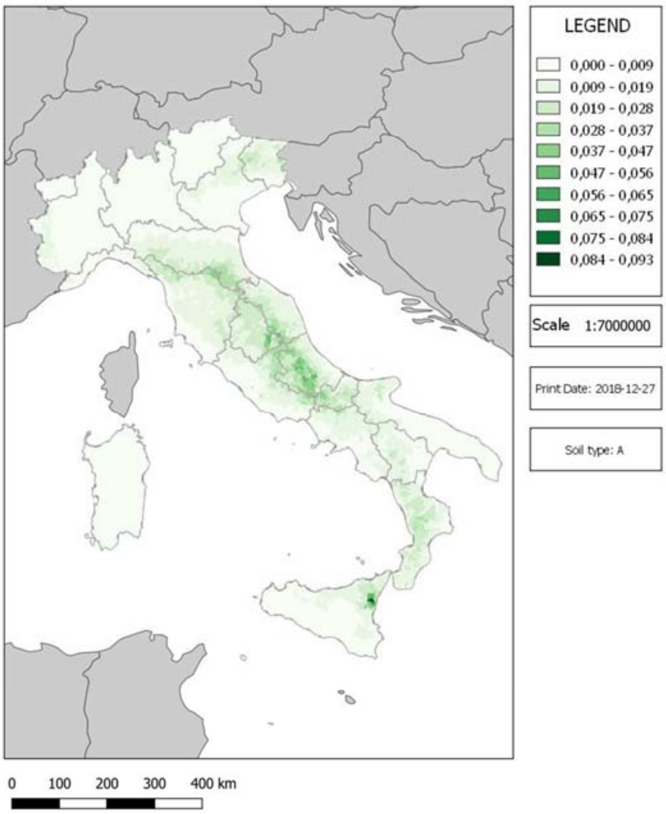


Fig. 1.15 – Map of the average expected ratios in one year of the number of dwellings affected by Damage Level 1 over the total number of dwellings in the municipalities.

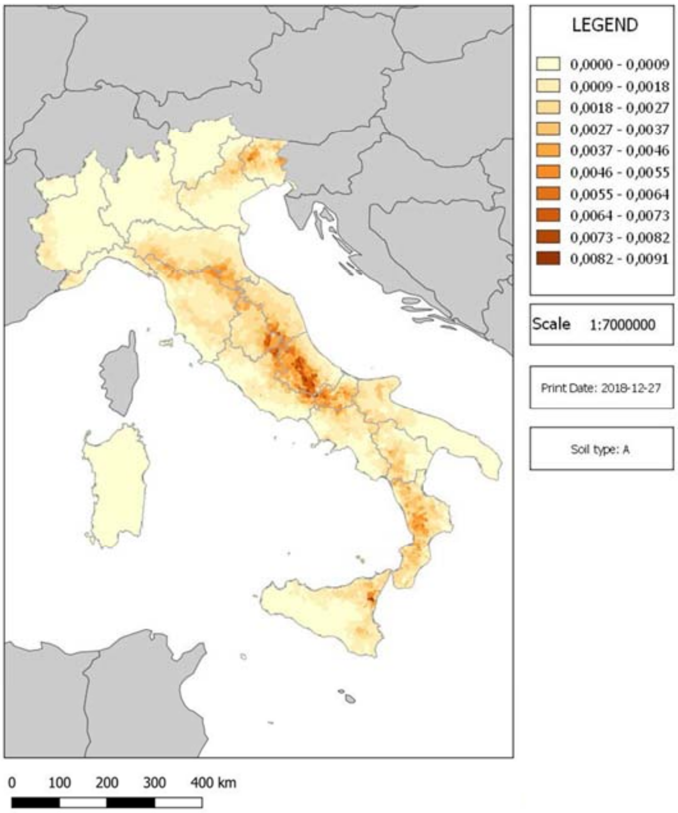


Fig. 1.16 – Map of the average expected ratios in one year of the number of dwellings affected by Damage Level 3 over the total number of dwellings in the municipalities.

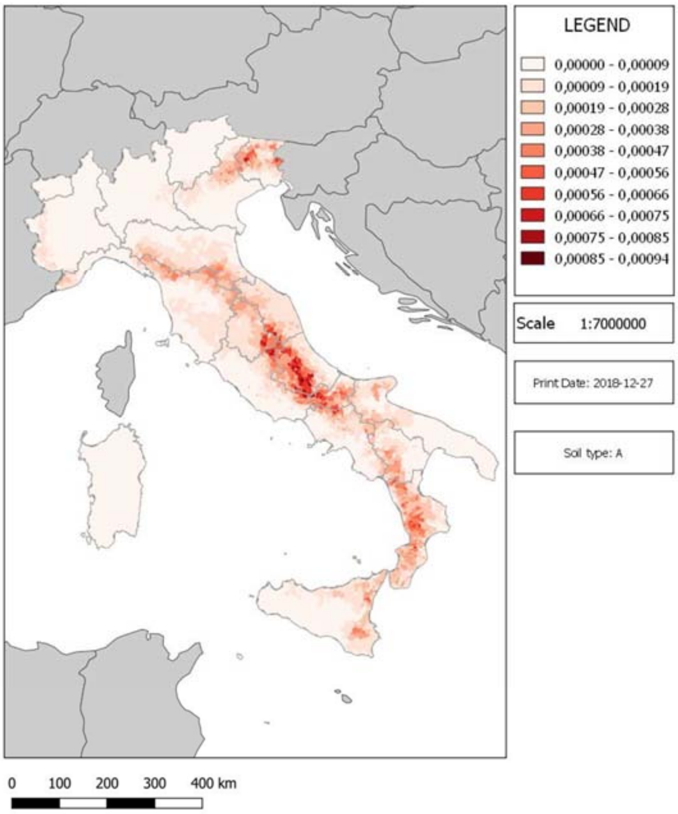


Fig. 1.17 – Map of the average expected ratios in one year of the number of dwellings affected by Damage Level 5 over the total number of dwellings in the municipalities.

Since the maps of figs. 1.15 to 1.17 do not provide absolute number but rather ratios, they underline the specific risk of buildings in a certain municipality. That is why hazard governs these results, while exposure only affects the ratio geographical distribution only through the presence of more or less vulnerable building types.

Risk assessment results in terms of consequences

In order to provide more useful risk quantities that describe the impact of earthquakes potentially occurring in the national territory in the future, the attention has been focused on the consequences for the population and for the building stock. More in detail, the following impact quantities have been considered, in the assumed time window:

- No. of dead
- No. of injured
- No. of homeless
- Direct economic losses (i.e. cost of repair or reconstruction of damaged/collapsed buildings) in euro
- No. of unusable buildings and unusable dwellings in the short term
- No. of unusable buildings/ dwellings in the long term
- No. of collapsed buildings/dwellings

The evaluation of the above quantities is based on the values of the expected numbers of buildings affected by the different damage levels, shown in the previous paragraph. The translation of the building/dwelling damage levels into the above said impact quantities is carried out by assuming the relationships described below. They are the same for all the elaborations of the research groups that have carried out the analyses considered in the present risk assessment, thus avoiding any further different in the translation from damage to consequences.

There are several proposals for assessing expected casualties after earthquakes. The original idea from Coburn and Spence (1992) was further developed and updated by various authors based on local context and considering observed data after significant earthquakes world wide (Spence et al. 2011). An example for Italy may be found in Zuccaro and Cacace (2011). In any case, the high uncertainty in these estimates is emphasised in all the works, due to the several factors that can affect the real impact (presence of occupants in the different day hours and year seasons, damage and (partial or total) collapse mechanisms of the buildings, effectiveness of rescue operations, etc..

The probability of injury or death of the building occupants is generally evaluated as a function of the damage level of the building. It is assumed that the ratio of injured and dead with respect to occupants provided by the population census is significant only for damage levels D4 and D5 (the most severe ones).

Although the expected number of dead and injured may vary depending on structure type of the building (i.e. distinguishing between Masonry or Reinforced Concrete buildings), the evaluations in IRMA are carried out by assigning a percentage of expected dead and injured for D4 and for D5 independently from the building material. The equation to calculate the expected number of deaths N_d or injured N_i are

$$N_d = \sum_{j=1}^{n} \left[\left(O_{Mj,D4} \cdot p_{d,D4} + O_{Mj,D5} \cdot p_{d,D5} \right) + \left(O_{RCj,D4} \cdot p_{d,D4} + O_{RCj,D5} \cdot p_{d,D5} \right) \right]$$

$$N_i = \sum_{j=1}^{n} \left[\left(O_{Mj,D4} \cdot p_{i,D4} + O_{Mj,D5} \cdot p_{i,D5} \right) + \left(O_{RCj,D4} \cdot p_{i,D4} + O_{RCj,D5} \cdot p_{i,D5} \right) \right]$$

with

n = number of storey or class of storey
$O_{Mj,D4/D5}$, $O_{RCj,D4/D5}$ = number of occupants in building type (M or RC) with number of story equal to j or with a number of storey in the storey class j which experienced a damage level D4 or D5
$p_{d,D4}$, $p_{d,D5}$ = percentage of dead with respect to the occupants for damage levels D4 and D5
$p_{i,D4}$, $p_{i,D5}$ = percentage of injured with respect to the occupants for damage levels D4 and D5

The values adopted for the percentages of dead and injured are reported in Table 1.16.

Expected Casualties	D4	D5
Dead p_d (%)	1	10
Injured p_i (%)	5	30

Table 1.16 – Casualties percentages for computation of human losses

Following standard procedures to compute direct economic losses, the total direct economic losses are evaluated based on loss parameters that are related to damage repair and considering the building inventory data.

The equation used in IRMA to calculate the direct economic losses is:

$$L = CU \left(\sum_{j=1}^{n} \sum_{k=1}^{5} A_{M,j}\, p_{M,k} c_k + \sum_{j=1}^{n} \sum_{k=1}^{5} A_{RC,j}\, p_{RC,k} c_k \right)$$

with

n = number of storey or class of storey
CU = Reference unit cost (Euro/m^2) of a building, including technical expenses and VAT (unitary cost of construction of a building)
$A_{M/RC,j}$ = built area of a building type (Masonry or Reinforced Concrete) with number of stories equal to j or with a number of storey in the storey class j
$P_{M/RC,k}$ = damage probability of a building type (Masonry or Reinforced Concrete) to experience structural damage state k
c_k = percentage cost of repair or replacement (with respect to CU) for each structural damage state k

The expected losses are significantly influenced by the damage distribution, as well as by the value of CU and by the percentages assumed for c_k, varying the damage level. Several studies investigated on such relevant factors (e.g., Dolce et al. 2006; Dolce and Goretti 2015).

The cost parameters adopted in the previous equation to compute expected losses in IRMA are calibrated on the actual repair costs that were monitored in the reconstruction process following recent Italian earthquakes (Di Ludovico et al. 2017a, b), see Table 1.17.

CU Including Technical Expenses and VAT	Percentage cost of repair or replacement c_j	D1	D2	D3	D4	D5
1350 Euro/m^2	% (min)	2	10	30	60	100

Table 1.17 – Cost parameters used for computation of direct economic losses

In addition to casualties and economic losses, the earthquake impact is measured in terms of unusable and collapsed buildings (or dwellings) and of number of homeless. These quantities are quite important to estimate also a type of indirect costs, i.e. those relevant to the temporary shelter and dwelling solutions, as well as, generally speaking, an important factor affecting the social impact of earthquakes.

Unusable buildings (or dwellings) are the unsafe ones. Analogously to the approach followed for direct economic losses, also the number of unsafe buildings is evaluated on the basis of the damage distribution and building inventory.

In particular, usable buildings, among the damaged ones, are those affected by very slight damage, while unusable buildings are distinguished in two sub-categories, namely unusable buildings in the short term UnB_{st} (due to light or moderate damage) and unusable buildings in the long term UnB_{lt} (due to more severe damage).

The equations to estimate usable buildings Us (“agibili” in italian), UnB_{st} (“inagibili breve periodo" in italian) and UnB_{lt} (“inagibili lungo periodo" in Italian) are:

$$Us = \sum_{i=1}^{5}(N_{Mi}u_{usk}) + \sum_{i=1}^{5}(N_{RCi}u_{usk})$$

$$UnB_{st} = \sum_{i=1}^{5}(N_{Mi}u_{stk}) + \sum_{i=1}^{5}(N_{RCi}u_{stk})$$

$$UnB_{lt} = \sum_{i=1}^{5}(N_{Mi}u_{ltk}) + \sum_{i=1}^{5}(N_{RCi}u_{ltk})$$

with

$N_{M/RCi}$ = number of masonry/RC buildings that experience structural damage level k
u_{usk}= percentage of usable buildings for each structural damage level k
u_{stk} (u_{ltk})= percentage of unsafe buildings in the short (long) term for each structural damage level k.

The percentages of usable and unsafe buildings (or dwellings) assumed in IRMA as a function of the damage level are reported in Table 1.18. Although different percentages could be adopted for RC and masonry buildings, for the sake of simplicity no distinction has been made in the present assessment.

% Unsafe buildings	D1	D2	D3	D4	D5
u_{us}	100	60	0	0	0
u_{st}	0	40	40	0	0
u_{lt}	0	0	60	100	0

Table 1.18 - Default percentages of usable and unsafe buildings (or dwellings)

Similar equations are used to estimate the number of unusable dwellings, simply substituting the number of dwellings instead of the number of buildings.

The expected number of collapsed buildings (or dwellings) in IRMA is evaluated by considering 100% of buildings (or dwellings) in damage state D5. Finally, the number of homeless is estimated by counting the number of inhabitants in the unusable (short and long term) buildings and subtracting the estimated number of deaths.

By applying the above equations to the results in terms of damage levels obtained by all the 6 risk models, the results of the unconditional risks in terms of consequences are evaluated and then combined, by evaluating again the average, maximum and minimum values. The main results at national level are summarised in tables 1.19 and 1.20.

	Costs (1y) Billion euro	*Unusable dwellings (1y) in the short term*	*Unusable dwellings (1y) in the long term*
Average	**2,13**	**20938**	**15635**
Maximum	3,27	31847	22024
Minimum	1,27	9962	7404

Table 1.19 - Average, maximum and minimum values of the expected direct economic losses in 1 year and of of the expected number of unusable dwellings in the short and in the long term in 1 year.

	Dead (1y)	*Injured (1y)*	*Homeless (1y)*
Average	**505**	**1744**	**78602**
Maximum	763	2588	131952
Minimum	123	469	40381

Table 1.20 - Average, maximum and minimum values of the expected number of dead, injured and homeless people in 1 year.

The average direct cost per year results to be in the order of 2 billion euro, while maximum and minimum values differ by approximately ±50% with respect to average, thus confirming the high uncertainty in this estimation. Assuming a reconstruction cost of 1350€/sqm, the asset replacement cost results to be in the order of 3400 billion euro and the expected annual loss is therefore in the order of 0.063% of the asset replacement cost. These figures account for the direct (repair/reconstruction) costs of the dwelling building stock only and appears quite consistent with the total costs of earthquakes in the last 50 years, shown in the introductory paragraph of the present chapter. These latter, indeed, consider all the costs of past earthquakes, including direct costs of repair/reconstruction of industrial/commercial buildings, public buildings, infrastructures, cultural heritage, as well as the emergency management costs (e.g. shelters, temporary houses, etc.). Including all the other costs typically implies doubling the direct costs calculated for dwelling buildings only (Dolce et al. 2015), thus leading to an expected total costs in the order of 4-4.5 billion euro per year. This is somewhat greater than the real average costs in the last 50 years, which, on the other hand, have been characterised by a seismicity that has neither attained nor overcome magnitude 7.

The consequences on the population in table 1.20 provide a high number of fatalities, in the order of 500 per year. Although this appears inconsistent and largely overestimated with respect to the figures of the last 50 yrs (about 5100), they appear underestimated if compared with the figures relevant to the 1860-2010 time window, when more the 200000 dead occurred in 150 yrs shown at the beginning of the present chapter. On the other hand, besides the above considerations on the last 50yrs seismicity, the number of casualties due to an earthquake is the most difficult consequence quantity to estimate as it implies the greatest uncertainty. It depends, indeed, on the population exposure where (epicentre distance from large cities) and when (time of the day, day and season) an earthquake occurs.

The unusability of dwellings due to damage and the consequent homeless are also important to evaluate the economic impact due to the not negligible costs for temporary housing arrangement of people as well as the social impact of earthquakes. The figures reported in table 1.19 and 1.20, with an average expected number in the order of 36000 unusable dwellings per year and almost 80000 homeless, summing the short and long term, are impressive, resulting in important economic (in the order of 1/4÷1/2 of the direct costs for dwelling repair/reconstruction) and social impacts.

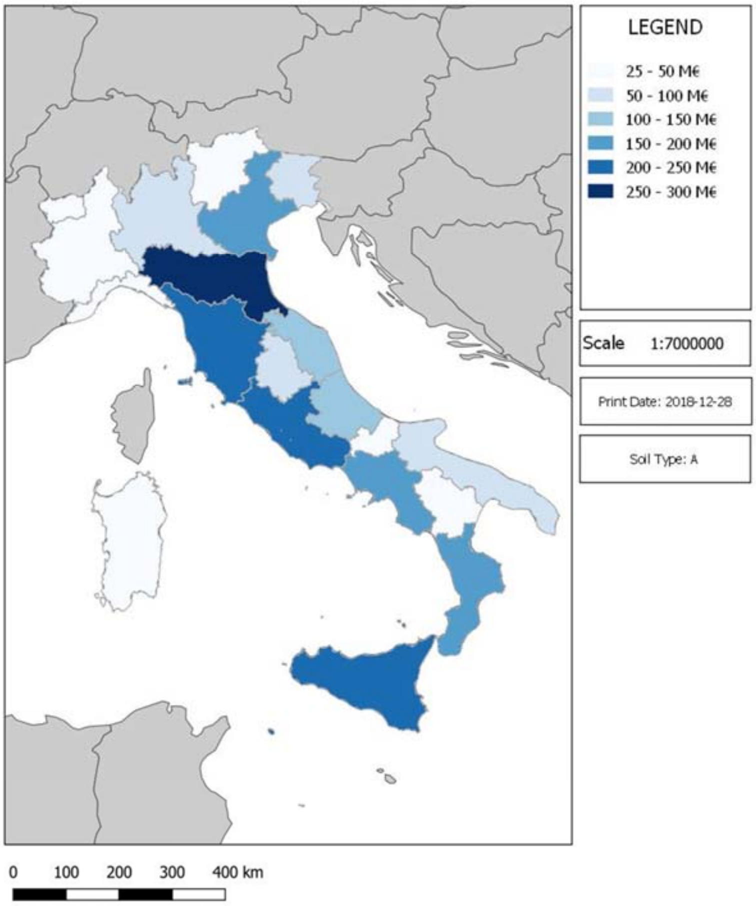


Fig. 1.18 – Map of the average expected direct economic losses in one year per region.

The geographical distribution of the economic losses per region is shown in the map of fig. 1.18. It is to be remarked that the total expected direct losses in a region strongly depends on the building exposure, besides hazard and building vulnerability. A comparison with figs. X1, x2 and x3 clearly emphasize this aspect. In these latter, in fact, the risk (of damage) is referred to a single generic dwelling in a municipality, and is therefore a sort of "individual risk", while in fig. 1.18 the risk is referred to the total number of damaged dwellings in each region.

Finally, it is interesting to compare the above results with the risk assessment carried out at global (world) level by the Global Earthquake Model (GEM) Foundation (Silva et al. 2018), in particular considering the country profile of Italy (https://downloads.openquake.org/countryprofiles/ITA.pdf). As for the direct economic losses of residential buildings, the value obtained by GEM is 1.67 billion dollar, in good agreement with the 2.13 billion euro in table 1.19 taking into account the lower value attributed by GEM to the residential building asset. In fact, considering that the expected annual loss calculated by GEM is 0.067% of the asset replacement cost, it appears in excellent agreement with 0.063% found in the present assessment. It has to be remarked that the assessment made by GEM has used different hazard and vulnerability models, in order to be consistent with other countries in Europe and all over the world.

Microzoning and land use planning

In order to implement an effective urban planning and optimize the territory use in relation to the basic hazard, the local amplification and the co-seismic effects, a key point is to realize an adequate seismic microzoning. Seismic microzoning (SM) can be defined as “the assessment of local seismic hazards by identifying the zones of a given geographic area which have a homogeneous seismic behaviour. In practice, SM identifies and characterises stable zones, zones prone to local amplification of seismic motion, and zones prone to instability”. The issues addressed by SM studies have had a strong scientific development in the past few years, although their importance had already emerged in the past.

Fig. 1.19 - Guidelines for the implementation of seismic microzoning in Italy

To this end, a significant step forward in Italy, is represented by the approval of the “Guidelines and Criteria for Seismic Micro-Zoning” by the Italian DPC and the Conference of Italian Regions and Autonomous Provinces (Gruppo di lavoro MS 2008). These guidelines (Figure 1.19) represent the core of the seismic risk analysis applicable to land, urban and emergency planning, as well as to technical design standards. The results of the guidelines represent a major advance in terms of scientific and operational methods and instruments proposed for prevention, as well as of technical administrative cooperation with the potential players of land management policies focused on seismic risk mitigation. Over 100 specialists and experts contributed to this document, making available their specific skills and know-how, embracing the interdisciplinary approach and establishing a dialogue with the directly concerned Administrations.

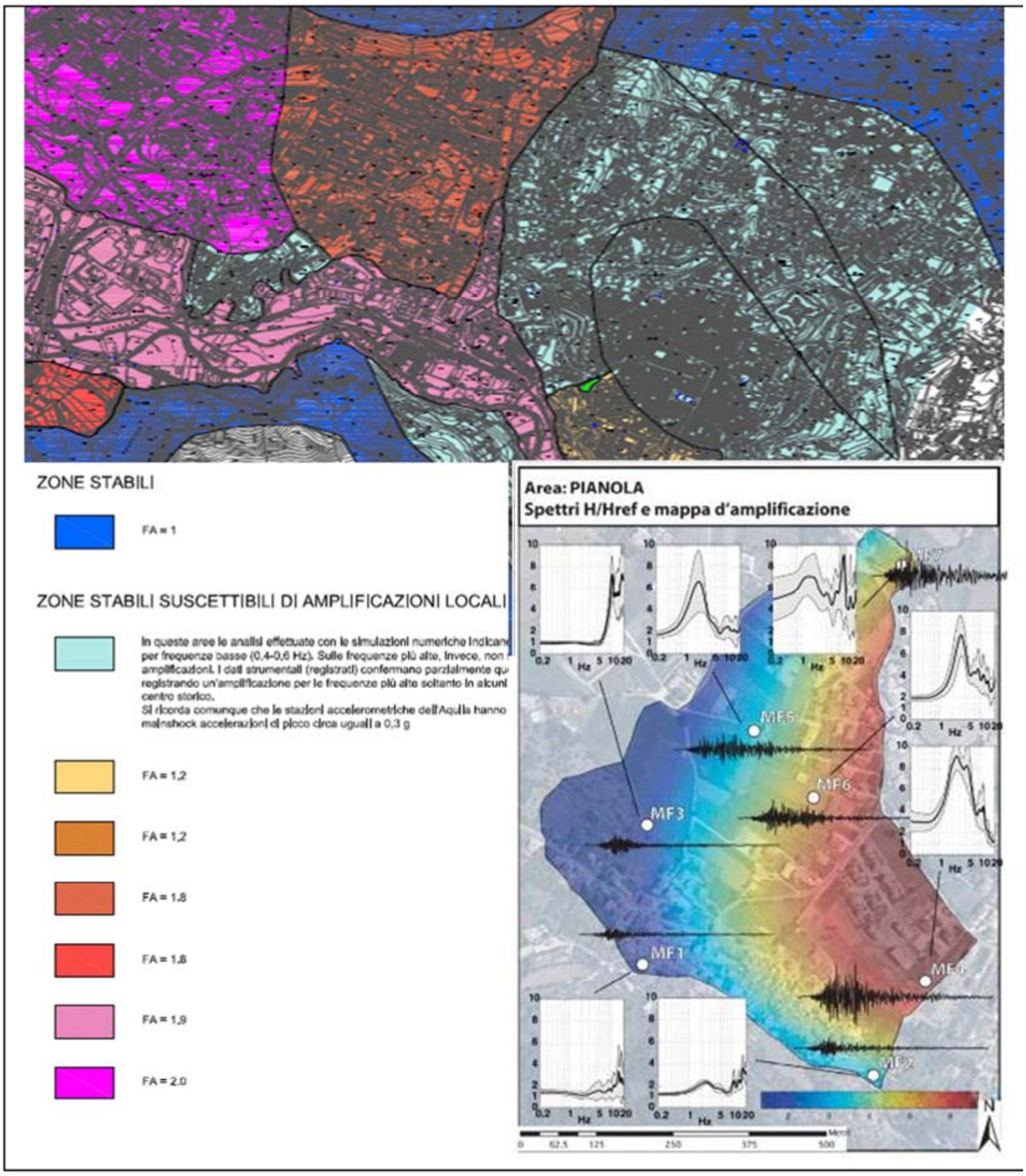


Fig. 1.20 - Example of a microzoning map for the center of L'Aquila

According to ICMS08, the SM studies are divided into three levels of in-depth analysis:

• Level 1 of SM consists of a collection of pre-existing data (inventories) or results from specific rapid survey campaigns (in particular environmental seismic noise measurements), elaborated in order to divide the territory in qualitatively homogeneous zones with respect to the phenomenologies described above (amplifications and permanent instabilities).

• Level 2 (when geological and morphological conditions allow the application of simplified methods) and level 3 of SM allow to associate values of amplification factors (AF) (levels 2 and 3) and response spectra (limited to level 3) to the stable zones subject to amplification defined in level 1.

Level 1 and 2 can only be applied to land planning, level 3 to land planning and to support the design of interventions on buildings.

A first example of the application of the guidelines has been made in Abruzzo region after the l'Aquila earthquake of April 6th, 2009 (Figure 1.20). A microzonation study has been realized for towns with macroseismic intensity ≥ VII. The operations involved about 150 researchers from 8 Italian Universities, 7 research centers, and 3 Regions. The Italian DPC has carried out the coordination of the team.

In the meanwhile, Law 77/2009, concerning the reconstruction of the areas affected by the 2009 earthquake, allocated almost one billion euro in seven years for seismic prevention on the whole Italian territory (Dolce 2012). This allowed CPD to set up a National Plan for Seismic Prevention. The plan has been implemented by investing not only in the seismic upgrading of buildings and infrastructures, but also in the seismic microzonation (SM) of municipalities. For the first time, through a multi-year organic program, the entire national territory is being involved in studies for the seismic characterization of areas and interventions to make public and private buildings safer. This investment allows about half of Italian municipalities, i.e. the most seismically dangerous ones (ag ≥ 0,125g), to be endowed with SM - at least level 1 studies.

In 2012 CPD introduced the analysis of the Emergency Limit Condition (ELC). This analysis constitutes a first tool focused on the integration of territorial interventions of seismic risk mitigation at the municipal scale, and deals with activities for the verification of systems for emergency management.

Among the diverse limit conditions of urban settlements, the ELC corresponds to the condition by which, in the wake of a seismic event, the entirety of an urban settlement suffers physical and functional damage sufficient to produce an interruption in almost all urban functions, including residential systems. The urban settlement conserves the use of the majority of its strategic functions during an emergency together with its connections and accessibility from the surrounding territory.

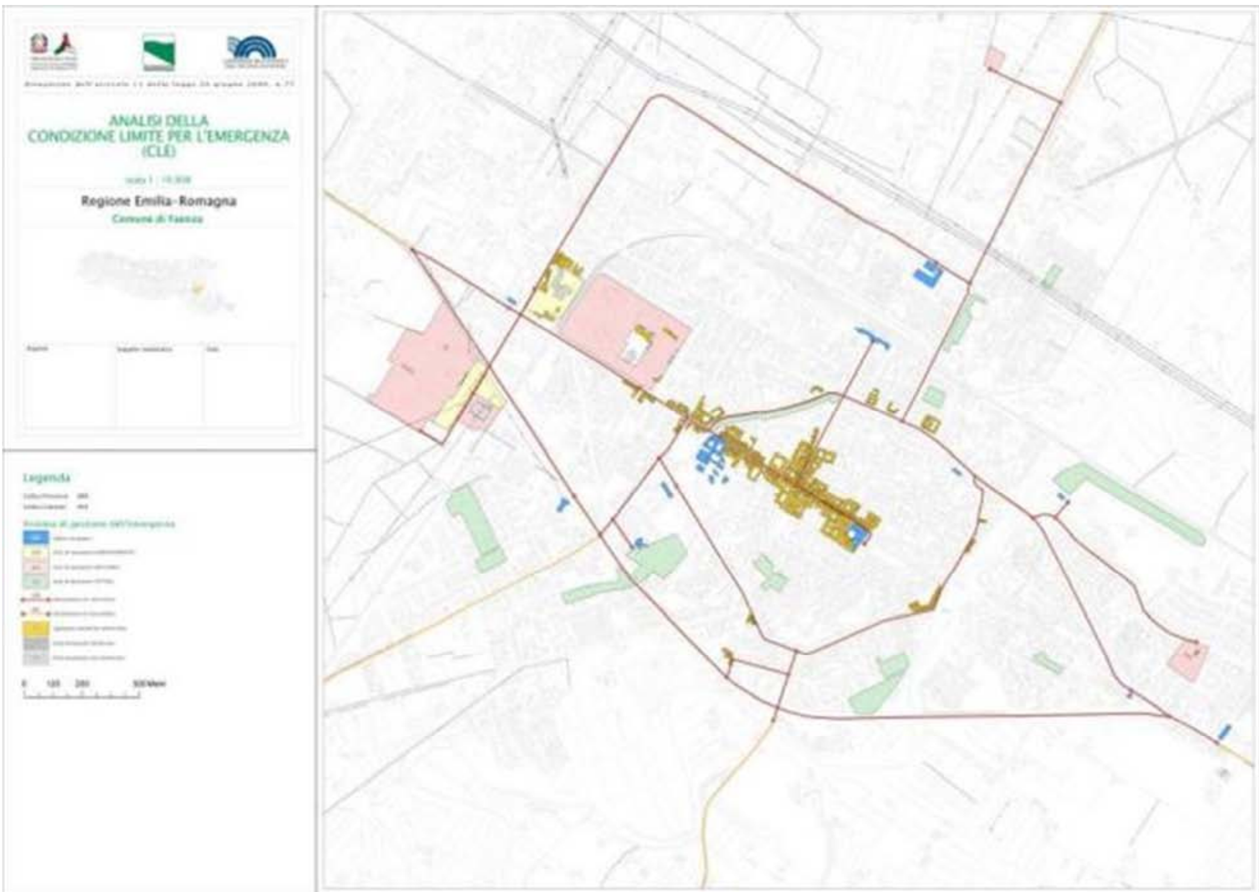


Fig. 1.21. – Example of Emergency Limit Condition (ELC) map

The analysis of the ELC must always be conducted in concomitance with SM (Seismic Microzonation) studies. For ELC, as well as for MS studies, it is necessary to fulfil specific standards of surveying and archiving (Analysis of the Emergency Limit Condition. ELC. Graphic and Data Archiving Standards).
The ELC analysis for a specific settlement requires the compulsory identification of the following items:

• emergency situation management structures;
• system of interconnections between the structures and the network of territorial access. ELC analysis represents a new operative tool focused on increasing the safety of inhabited areas. This tool is compared with other experiences matured to date across the country. Internet resources: http://www.protezionecivile.gov.it/jcms/it/commissione_opcm_3907.wp
http://www.protezionecivile.gov.it/jcms/it/cle.wp

With regard to the state of implementation of the activities funded by Law 77/2009 (around 100 million euros), to date (November 2018) a total of 3410 SM studies are planned (see Figure 1.22), representing about 80% of the municipalities eligible for funding (3896 municipalities with ag≥0.125g), of which 1904 delivered (55%), and 3039 analysis of CLE, of which 1317 delivered (43%).

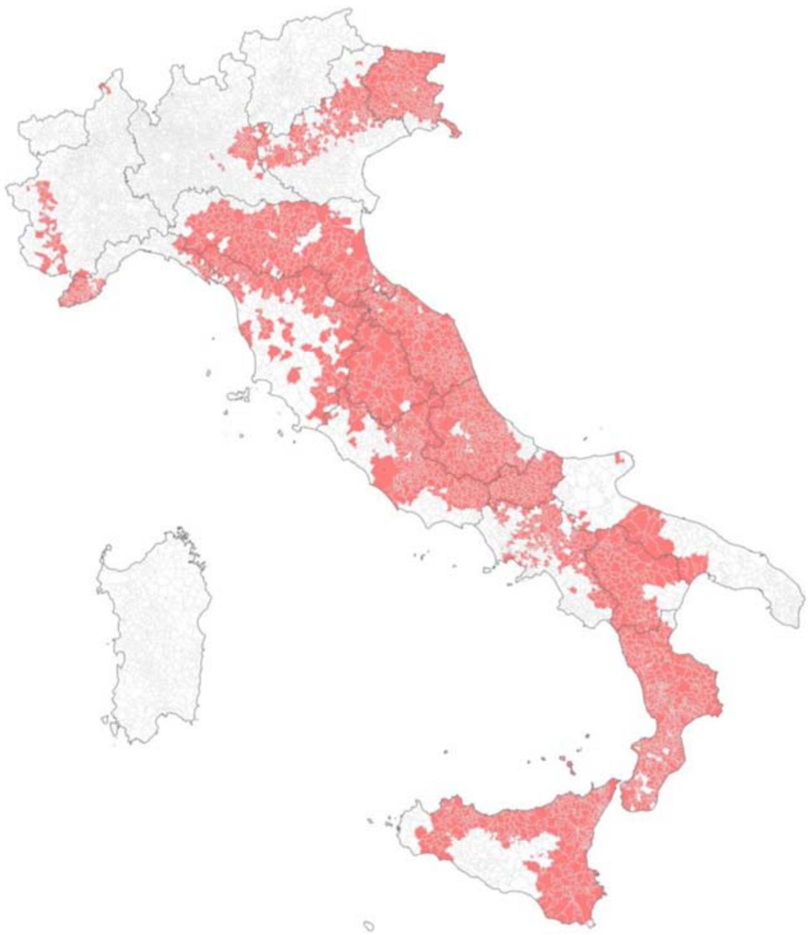


Fig. 1.22 – Municipalities where MS studies are completed or programmed (November 2018)

The entire activity has seen the full participation of the Regions, which have legislated to incorporate the Seismic Microzonation and the analysis of the Emergency Limit Condition in land planning. There was also a broad involvement of the Professional Bodies, primarily the Geologists, who recognized in the initiative an initial moment of cultural growth and participation in a process of improvement of the understanding conditions aimed at mitigating seismic risk at the local level.

The high level of quality, standardization and homogeneity at the national level have been guaranteed by the general adoption of the "Guidelines for seismic microzonation" (ICMS 2008), ase well as of the standards for the SM studies and for the analysis of ELC, prepared by the Technical Commission - Article 5, OPCM 13 November 2010 , No. 3907, whose membership includes representatives of the Regions and Autonomous Provinces), of the municipality association and of the professional chambers.

An extensive and necessarily fast application of level 3 SM was carried out according to the ICMS 2008, soon after the 2016-17 seismic sequence of Central Italy, to support the reconstruction of the affected areas, having in mind the Building Back Better principle. The 2016-17 sequence occurred when the level 1 SM studies were completed or in progress in many affected municipalities. Further information on the level 3 SM are provided in the Post-event phase chapter.

Tax incentives and public funding for the vulnerability reduction of existing buildings, facilities and plants

As already mentioned, considering that it is not possible to modify hazard, the most direct way to mitigate seismic risk is to move forward with the reduction of vulnerability of existing buildings and facilities through interventions aimed at improving the resistance of structures to earthquakes. This can be mainly achieved by directly funding the interventions or through tax incentives for private owners.

The first example in Italy of a tax incentive aimed at seismic risk mitigation dates back to 1997, when the financial law n.449 introduced, for the private landlords, the possibility of having a 50% reduction of taxes (VAT), for strengthening and reclamation building works in 3394 Italian municipalities classified, at that time, as “high seismic risk” zones.

Regarding public funding, in the past years (starting in 1986) small investments in seismic prevention have been made, mainly financing public strategic buildings like hospitals and schools. Up to 2003 about 300 million euro, of which 66 for private buildings, have been spent in prevention (excluding of course the expensive post-earthquake reconstruction operations which would clearly improve the seismic resistance of buildings, according to the modern Building Back Better principle). After the San Giuliano earthquake in 2003, about 750 millions euro have been allocated, mainly for intervention on schools and public strategic buildings.

After the L’Aquila earthquake in 2009, Decree n. 39 of 28/4/09, which became law n. 77 of 24/6/09 (Art. 11), allocated a budget of 965 M€ in the years 2010-2016 for activities of seismic risk reduction in Italy.

This amount is just a small fraction of what is actually needed, nevertheless a wide-spectrum national plan for seismic risk mitigation has been implemented. The primary objective of the plan, whose strategy and supervision is in charge of the Italian Civil Protection Department, is to reduce human losses, so that the action is especially addressed to high hazard and high risk areas. It is implemented not only through the seismic upgrading of structures, to produce the immediate reduction of the seismic risk of the retrofitted constructions, but also through the evaluation of the local seismic hazard and the seismic resilience of urban systems, according to a more integrated and prospective strategy for seismic risk mitigation (Dolce 2012).

The following lines of action have been implemented:

- Seismic micro-zoning studies, already dealt with in the previous paragraph;
- Vulnerability reduction of strategic public buildings and bridges/viaducts and of private buildings;
- Urgent intervention.

Funds were distributed among different Italian regions on the basis of a seismic risk index (Figure 1.23) drawn from the probability of building collapse in the various regions, as derived from the seismic risk assessment maps available in 2010 produced by CPD and by the competence centres. Only the municipalities with a maximum ground acceleration, as deduced from the Italian hazard map MPS04 with return period of 475 years, higher than 0.125 g were allowed to access the contribution (Dolce 2012).

To summarise, the philosophy of the national prevention program is essentially based on:

- Pointing towards the reduction of the risk of human losses, rather than economic losses;
- Dealing with a wide spectrum of problems, then stimulating the attention of private owners and administrators towards the different problems of seismic risk (vulnerability of buildings, importance of local amplification and coseismic effects and use of microzonation studies to improve urban and emergency planning, correct implementation of civil protection plans considering the vulnerability of the strategic elements and of the interconnection routes);
- Asking for co-funding by local public administration and by private owners, in order to at least duplicate the actual effects of the allocated fund of the State.

The different actions are implemented through programs of the Regions and the Autonomous Provinces. The regional programs are defined according to the regional priorities, considering the requests of municipalities.

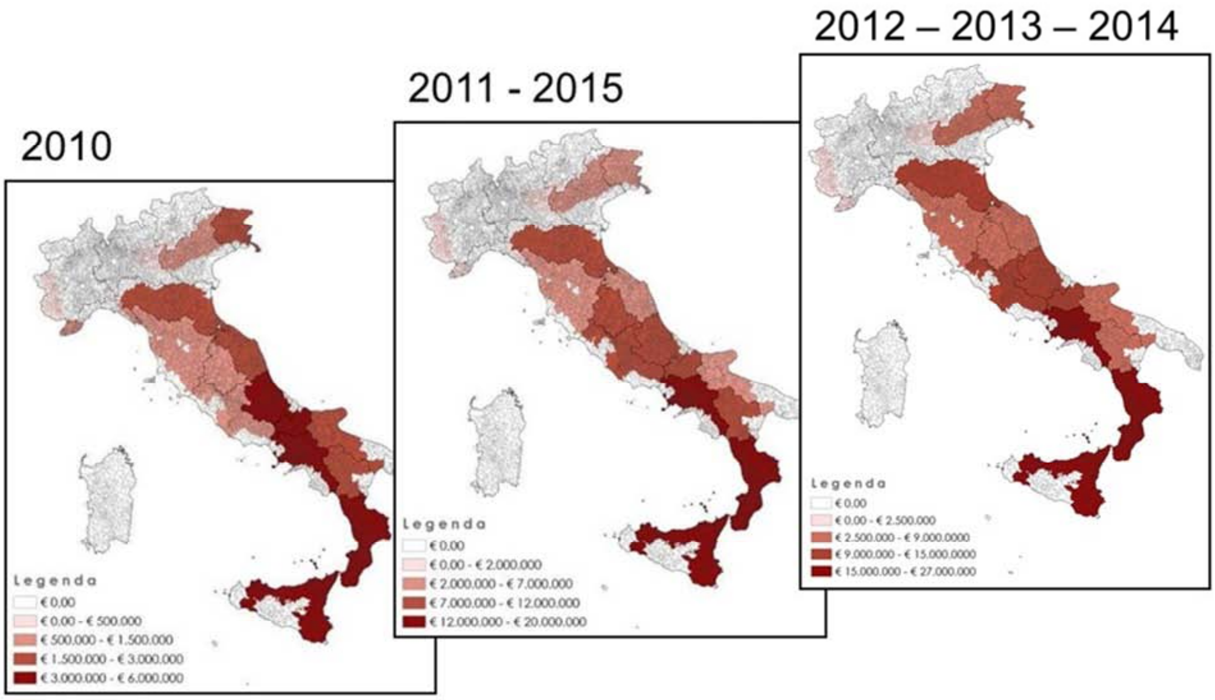


Fig. 1.23 – Allocation to the Italian regions of the funds foreseen by law n. 77 of 24/6/09, according to risk.

As far as public buildings and bridges are concerned, the contribution of the State is evaluated as a quota of a conventional total cost for intervention, depending on both the type of intervention (local strengthening, global retrofit, reconstruction) and the safety deficit, i.e. the result of the safety verification.
As far as private buildings are concerned, the same types of intervention are allowed. However, the State contribution is lower and must be considered as an incentive rather than a total refund of the expenses, being aimed at partially refunding the costs of the intervention on the structural parts only.

The selection of the private buildings to be retrofitted with the State contribution is quite critical, both because of the huge number of private buildings needing seismic retrofit and because the general lack of any seismic vulnerability or risk assessment, useful to decide individual priorities. A first criterion is related to the number of municipality on which this action can be applied. This decision is relied upon Regions, which can adopt different criterion - e.g. priority given to municipalities with the highest seismic hazard in the Region. A second criterion is related to the rules to give a priority classification of individual buildings. This criterion must be necessarily simple to apply, as in principle it should not need a specific expertise. It is therefore based on quite rough information, not needing a professional consultancy, such as the age of the building, the type of structure, the human lives exposure, the seismic hazard of the site.

The state of advancement of the national Plan for Seismic Prevention can be found in http://www.protezionecivile.gov.it/jcms/it/piano_nazionale_art_11.wp

In order to verify the use of the fund, to each municipality a "class" was assigned, based on the level of knowledge and realization of activities for the mitigation of seismic risk (seismic micro-zoning, analysis of the Emergency Limit Condition (ELC) and intervention for vulnerability reduction).
Classes are 5 (from A to E), where E is the lowest class and indicates "the absence of studies of seismic micro-zoning". The class D is assigned when there are studies of MS, and the class C if there are analyses of ELC. The class B is assigned when it has been verified the emergency management condition of system identified by ELC. Finally, the class A indicates the existence of programs and initiatives aimed at improving the operability (for example interventions on strategic buildings).

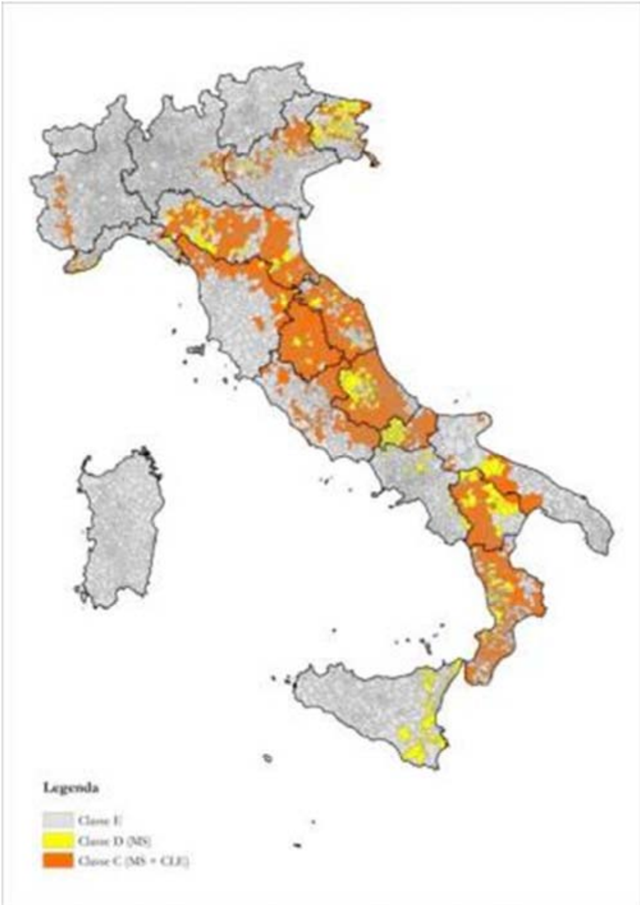


Fig. 1.24. – Italian municipalities with classes (December 2015)

The total amount of about 1 billion euro represents a very low percentage, probably lower than 1%, of the budget required in Italy for the seismic retrofit of all private and public buildings and strategic infrastructures. However, it is definitely a step forward for an increase of the knowledge of the importance of seismic prevention.

At the end of 2016 the Law 11 dicembre 2016 n. 232, i.e. the Budget Law for 2017, allocated funds for important tax incentives for the next five years, the so-called “sismabonus”. It allows private owners to be reimbursed of the expenses carried out to make seismic retrofit of their buildings, up to 80% (85% for co-owner buildings) through tax deduction in 5 years. This rule can be applied in zones 1, 2 and 3.

In order to calibrate the reimbursement according to the seismic improvement attained with the retrofit intervention, the Italian “Guidelines for the seismic risk classification of constructions” were approved in February 2017 by the Ministry of Infrastructure. It defines the technical principles for exploiting tax deductions with respect to seismic strengthening interventions on existing buildings (Sismabonus). The guidelines are very simple and allow practitioners to deal with the sophisticated concepts behind modern seismic design, such as expected annual losses (EAL) and repair costs. The seismic risk classes of buildings and the class upgrade due to strengthening interventions can be assessed using the principles included in the guidelines (Cosenza et al. 2018).

Within the framework of the PON Governance 2014-2020 "PROGRAM FOR SUPPORTING THE STRENGTHENING OF THE GOVERNANCE IN THE FIELD OF REDUCING RISK FOR THE PURPOSES OF CIVIL PROTECTION" special attention was paid to intervention actions aimed at achieving minimum standard conditions for the system of management of the emergency and, therefore, of the minimum conditions for the seismic risk reduction. In particular, reference was made to the document approved in 2015 by the CPD "Minimum standards for the planning of measures to reduce the risk for civil protection (and socio-territorial resilience)". The project is aimed at the less developed Regions, and in particular the Regions that have invested resources in the OT5 (Basilicata, Calabria, Campania, Puglia, Sicily).

The proposed approach consists in the development of minimum standards for the programming of models and criteria to support the public decision-maker for the correct and effective allocation of the resources available for the objective of risk reduction for civil protection purposes, also with institutional support interventions and the use of specific professional skills to accompany the regional governments in the process of adoption and effective application of the tools that will be developed.

With regard to seismic risk, the initiative is in direct continuity with the activities developed with the funds of art. 11 of Law 77/2009, re-using schemes and procedures already tested and adopted by the Regions: completion of seismic microzonation studies and ELC analysis, guidelines for the use of study results and applications for land use planning and efficiency assessments of the structural emergency management system.

The activities started are divided into:

- Definition of "standard projects" and guidelines for the planning of measures to reduce the risk for civil protection and dissemination among the regional offices; Development of evaluation models;
- Preparation, support and monitoring of "standard projects" aimed at reducing risks (i.e. article 11 of law 77/2009); flanking of the Regions on the correct application of the guidelines for the reduction of seismic risk;
- Organization of workshops and seminars for information purposes.

Improvement of the preparedness through information to population and school education

A crucial point in the risk mitigation policies is to increase the awareness of the population on seismic risk in order to urge people to worry about the safety of their homes and to implement strengthening and reclamation building works. Very important is also to teach the people basic behaviour codes to reduce the earthquake consequences on the population. Figure 1.25 shows an example of several awareness campaigns, recently realized by the CPD to inform people on risk and prevention by describing the behaviour to adopt in case of earthquake (before, during and after). As an example, “Cinema and earthquakes” consists of two audio-visuals addressed to high schools, which include famous documentary film sequences in order to explain the Mercalli scale, what happens during an earthquake, and what is the best behaviour to adopt. Examples of educational tools are the brochure “Se arriva il terremoto” (If an earthquake occurs) and the book “A lezione di terremoto” (In an earthquake lesson), mainly addressed to primary and high school students.

Fig. 1.25 – Examples of awareness campaigns realized by the CPD

Another initiative, promoted in 1997 by CPD and the Ministry of Cultural Heritage, is the scientific travelling exhibition “Terremoti d’Italia” (Earthquakes in Italy) (http://www.terremotiditalia.it) aiming at awaking the public opinion and the school audience to the problems connected to the seismic risk (Figure 1.26). The exhibition has the purpose to stimulate citizens to play an active role in the prevention, by making them aware of the fundamental characteristics of the seismic phenomenon, and by informing them on what to do in case of danger. The itinerant exhibition moved through the territories damaged by some of the most relevant events in the last century (Ancona, Gibellina, Roma, Messina, Napoli, Udine, Benevento) and was also presented to the EC in Bruxelles. Documents, images, scientific instruments, technical anti-seismic devices, libraries, all over Italy are shown in the exhibition. Special attention is paid to the learning activities for students, which are organized in a dedicated didactic laboratory. The core of the exhibition is the area called “l’esperienza” (the experience), where, thanks to two big vibrating tables reproducing the seismic shaking, the visitor can understand what an earthquake is like, through the sensorial perception of its effects on people and objects.

Fig. 1.26 – Travelling exhibition “Terremoti d’Italia”.

Finally, the campaign “Io non rischio - Terremoto” (I don’t take risks - Earthquake) has to be mentioned, a national initiative for seismic risk reduction promoted and carried out by the CPD, the National Association for Public Assistance, the INGV and the ReLUIS Consortium, in agreement with the involved regions and municipalities.

The initiative started in 2011 in collaboration among civil protection volunteers, institutions and the world of scientific research. The campaign takes place in localities exposed to high seismic risk and in some large cities, where strong earthquakes can be perceived. The volunteers are the main protagonists of this initiative, citizens who take on personal responsibility in the prevention of risk and take to the streets to raise awareness with respect to seismic risk.

The 2018 edition of the campaign “I don’t take risks - Earthquake” was held on the weekend of October 13 and 14 in about 300 places all over Italy.

In 2014 there were two editions of the campaign on 14 and 15 June and on 11 and 12 October. In June, in fact, the campaign could be held only in some places in central and southern Italy, because of severe adverse weather conditions. On the weekend of 11 and 12 October, the volunteers who couldn’t hold the campaign or that only partially made it, took to the streets again to inform citizens on seismic risk. In the two editions of 2014, volunteers have been engaged in over 200 squares to raise awareness among their fellow citizens on seismic risk. Along with “I don’t take risks - Earthquake”, the initiative “I don’t take risks - Tsunami” took place in June and October in more than 20 squares of Calabria, Campania, Puglia and Eastern Sicily, to talk to citizens and also promote their active role in prevention about the tsunami risk. In addition, in October the campaign “I don’t take risks - Flood” started on an experimental basis.

In 2013 "I don't take risks - Earthquake" was conducted in 208 squares in 197 Italian municipalities of almost all Italian regions, in 2012 in 102 squares, and in 2011 it was tested in nine squares of six Italian regions.

In addition to the days in the squares, the campaign "I don't take risks" includes also events dedicated to the world of work and schools.

Technical training of experts

The CPD has developed in the last years a set of training paths finalized to create specific professional workers able to timely operate in the case of a seismic event. Specialized course programs (60÷120 hours) have been designed, with different deepening levels, according to the different professional profiles, in the following macro areas:

- Application of the seismic building code.
- Damage survey and post-earthquake safety assessment.
- Emergency planning and management.
- Seismic risk assessment and reduction.

The final goal is to create a "task force" of technicians (engineers, architects, geologists) working in the public administrations or in the private sector, specialized in the use of the new Italian building code and in carrying out damage and safety assessment surveys after an earthquake.

Very useful for the implementation of the training course are multi-medial tools such as "MEDEA", a CD-ROM containing a technical dictionary, a pictures archive, and a section of analysis of seismic damages connected to the collapse mechanism, plus a section of virtual reality trip inside some buildings damaged by recent Italian earthquakes (Figure 1.27).

Fig. 1.27 – Example of CD-ROM "MEDEA": multimedia and didactic handbook for seismic damage evaluation

In the field of technical training, several national and international activities were also carried out by the CPD, particularly within national and international emergency management exercise.

PHASE 2 – EVENT

When: at the occurrence of an earthquake, from the time of the event up to some days after.

Objectives - Improving emergency management and prompt intervention after destructive earthquakes and optimize the technical actions to be undertaken (Table 1.21). Rapid collection of information on the event, including all seismological, engineering, economic and social issues, in order to:

- Optimize the emergency operations (loss scenarios, S.A.R.).
- Plan the re-construction action.
- Improve the knowledge and promote activities for a better risk understanding.

Time after earthquake	**ACTIONS**	
2'→ 15'	Epicenter and magnitude evaluation	Collection and processing of: seismometric RSN network data (INGV); accelerometric RAN data (CPD); accelerometric OSS data (CPD)
15'→60'	Simulated damage and loss scenarios	Software simulation of the earthquake impact on constructions
6 h →150 h	Site surveys of macroseismic and coseismic effects	Site evaluation of Mercalli Intensity. Geological surveys of landslides, surface faulting, and soil liquefaction
6 h → 3 months	Temporary monitoring of soil and structures	Installation of temporary additional accelerometric ground stations (Mobile RAN) and monitoring systems of strategic buildings (Mobile OSS)
24 h →6 months	Post – earthquake damage and safety assessment	Building inspections for damage and safety assessment

Table 1.21 – Post-event timetable of technical activities

Simulated damage and loss scenarios

In the first hours following an earthquake, it is of primary importance to know the consequences of the event for the emergency management and rescue organization. Such a target can be achieved not only by means of OSS and RAN outcome (damage indices computed in real time from OSS recordings for the monitored "sentinel" buildings, and respectively seismic intensity and response spectra estimated in real time from RAN recordings), but also by simulating damage and loss scenarios, based on the focal parameters of the event and on the information related to the seismicity and vulnerability of the affected area.

In case of an earthquake of magnitude 4 or higher on the national territory, the INGV transmits (within 3 minutes) to the CPD the focal parameters of the ipocenter (magnitude and coordinates). An automatic procedure, the *Informative System for Emergency Management (SIGE),* is immediately activated to produce data, maps, and information concerning the epicentral area. On the basis of the attenuation relations, several ground motion parameters (macroseismic intensity, PGA, PGV, values of the response spectra, etc.) are calculated for each municipality within a radius of 100 km from the epicenter. These values are used to give a preliminary evaluation of the expected damage and loss. Several maps and data giving a complete description of the main features of the stricken area (territory, population, lifelines, hospitals and schools, building vulnerability, seismicity, expected structural damage, expected number of casualties) are compiled and ready as a report, within 30 minutes from the causative event. The current central unit of SIGE application consists of:

- a client server architecture based on Oracle DBMS and ARC/INFO G.I.S., in an integrated environment.
- a data bank for seismic risk evaluation, including both cartographic and thematic information. Nowadays the databank includes 80 different indicators (600 cartographic layers and 500 alpha numeric attributes) for each of the 8100 Italian municipalities. Every database is homogeneous for the whole Country, has the same format and the same projection system (UTM -Zone 32).
- a metadata structure, built according to European standard.
- a decision support system for the seismic emergency management.

Figure 1.28 shows an example of the maps provided by SIGE and Table 1.22 a comparison between losses predicted and verified on field in case of the L'Aquila earthquake of April 6, 2009. As it is evident, the uncertainties (min, max) associated with the scenario estimates are quite large but the principal aim of a scenario simulation, i.e., to catch the order of magnitude of the real losses, is actually achieved.

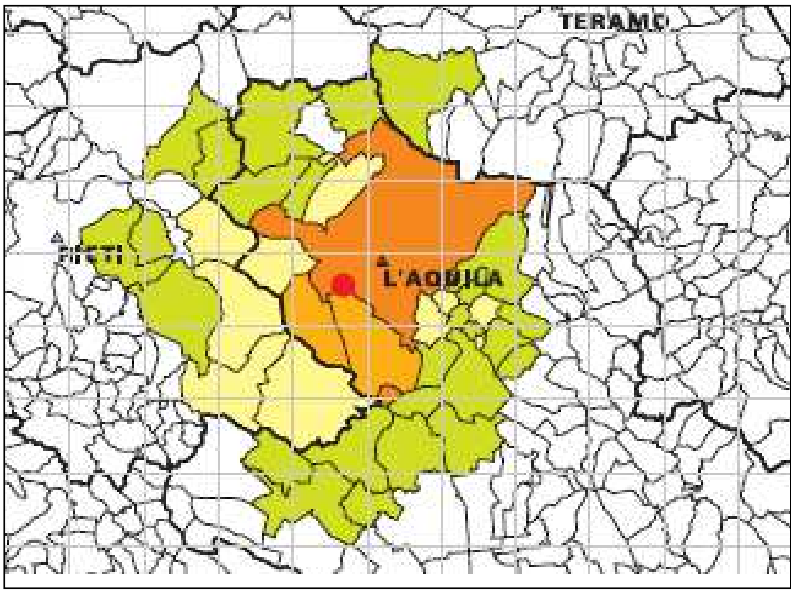


Fig. 1.28 - Expected number of people involved in building collapse in the simulation scenario (SIGE) of the L'Aquila earthquake of April 6 2009

	Estimates of the simulation scenario			**Real data** (source DPC www.protezionecivile.it)
	Min	**Mean**	**Max**	
Maximum Mercalli Intensity (MCS)	VIII	VIII-IX	IX	IX
People involved in building collapse	200	1.200	2.200	1.900*
Homeless	8.700	31.000	54.000	62.000**
Unusable dwellings	6.700	22.000	38.000	39.000***

** Sum of Injured and victims*
*** Obtained from the 22867 private buildings classified as unusable (usability classes E and F) multiplied by a mean ratio of 2.7 inhabitants/building resulting for the 57 municipalities with IMCS ≥VI*
**** Obtained from the buildings classified as unusable multiplied by a mean ratio of 1.7 dwellings/building resulting for the 57 municipalities with IMCS ≥VI*

Table 1.22 - Comparison between losses predicted by the simulation scenario (SIGE) and real values, for the L'Aquila earthquake of April 6 2009.

Another example of the application of SIGE system is shown in Table 1.23, reporting the expected losses in case of the repetition nowadays of the disastrous 1908 Messina earthquake (causing at that time 86000 victims) with an epicenter placed on the seismogenic fault, in the position maximizing losses.

	lat	**long**	**Mag. max fault**
Epicenter (located on Messina fault ITIS013)	38.23	15.68	7.0
	Min.	**Mean**	**Max**
Collapsed dwellings	46332	94677	176270
Unusable dwellings	137481	181574	210822
Damaged dwellings	311196	517716	759794
People involved in building collapse	98772	201208	374592
Homeless	277267	345832	371184
Total damaged building surface (mq)	15978207	24811932	35737176
Total unusable building surface (mq)	11873278	15359372	17384354

Table 1.23 - Expected losses, estimated by SIGE, in case of the repetition of 1908 Messina earthquake with an epicenter located on the seismogenic fault, in the position maximizing losses.

Currently SIGE is undergoing a complete re-engineering within the CPD internal network, so that it will be accessible online by the on-call seismic staff. Moreover, connecting SIGE to RAN and OSS it will be possible for it to be started in real time by RAN alert data (1-2' after the event); RAN and OSS output will be included in SIGE maps and even the outcome of the probabilistic SIGE approach will be possibly automatically optimised against the deterministic RAN and OSS results.

An important upgrade of SIGE database is in progress, by implementing data from the Italian 2011 census provided by the Italian Statistics Institute ISTAT. Moreover, an agreement has been made with the Ministry of Health, aiming at exchanging data on the consistency of livestock and related activities: in exchange of SIGE seismic intensity, in real time the Ministry will return the specific impact scenario, to be added to SIGE description of the consequences of the earthquake. Similarly, an agreement has been made with the Ministry of Environment, too, concerning the seismic scenario for industries at risk of major environmental accidents.

PHASE 3 – POST-EVENT

When: after an earthquake, from some days up to some months after the event.

Objectives - Setting up and monitoring the reconstruction activities in order to optimise the allocation and distribution of funds for the reconstruction, in particular through:

1. Damage survey and safety assessment of buildings in order to limit the population disease.
2. Microzoning and land use planning.

Damage survey and safety assessment of buildings

Among post-earthquake activities, a significant issue is the damage and safety assessment for post-earthquake usability. Usability actually defines the limit between people coming back to their houses and people waiting in provisional shelters or in temporary houses. This turns out in the limit between the continuity of the administrative and economic functions and the slowing down of the activity of an entire and complex social context. The consequences in terms of social and economic impact are apparent. However, usability also represents a delicate diagnosis moment for a given building, in view of possible strong aftershocks on which the safety of all the resident people relies.

Since 1997 a specific form (AeDES) is used in Italy for damage assessment, short term countermeasures and evaluation of the post-earthquake usability of ordinary buildings. The AeDES survey form was optimised in order to limit the time required for each inspection, avoiding the request of information difficult to get during a visual inspection. However, it collects the information needed for an expert judgement on usability, based on data on vulnerability and damage. This choice results in a required inspection and evaluation time of the order of some hours. It is not, therefore, a tool for a fast usability assessment to be accomplished in the first hours or days after an earthquake, but rather for more sounded decisions, once the immediate emergency needs have been fulfilled. Figure 1.29 shows the Handbook for the compilation of AeDES form.

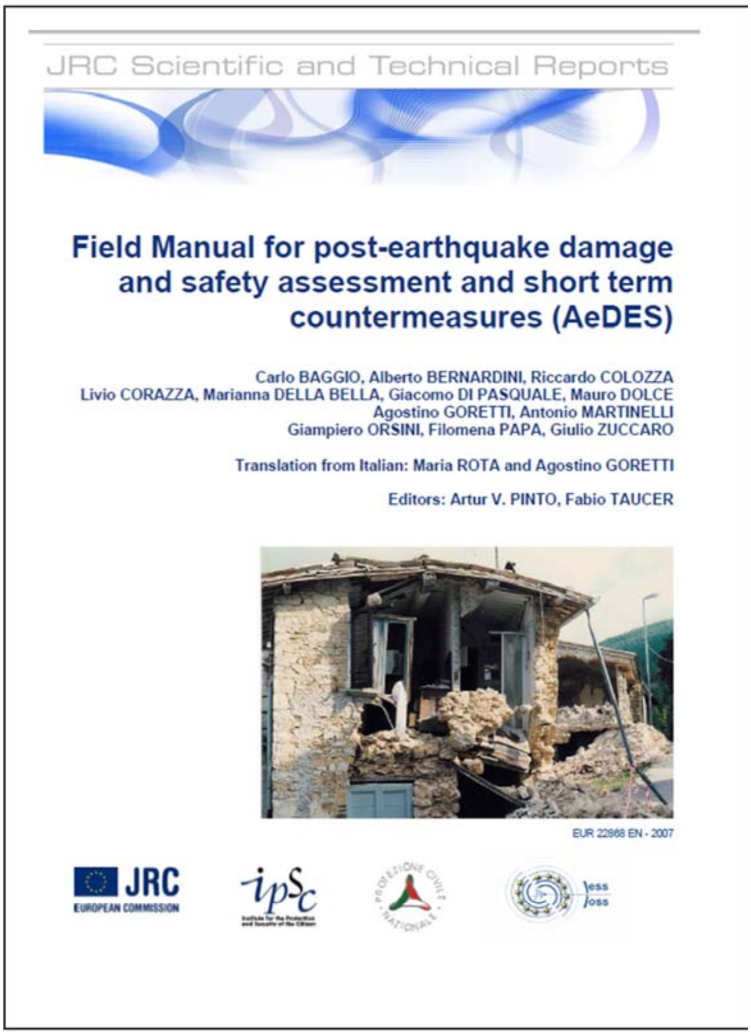
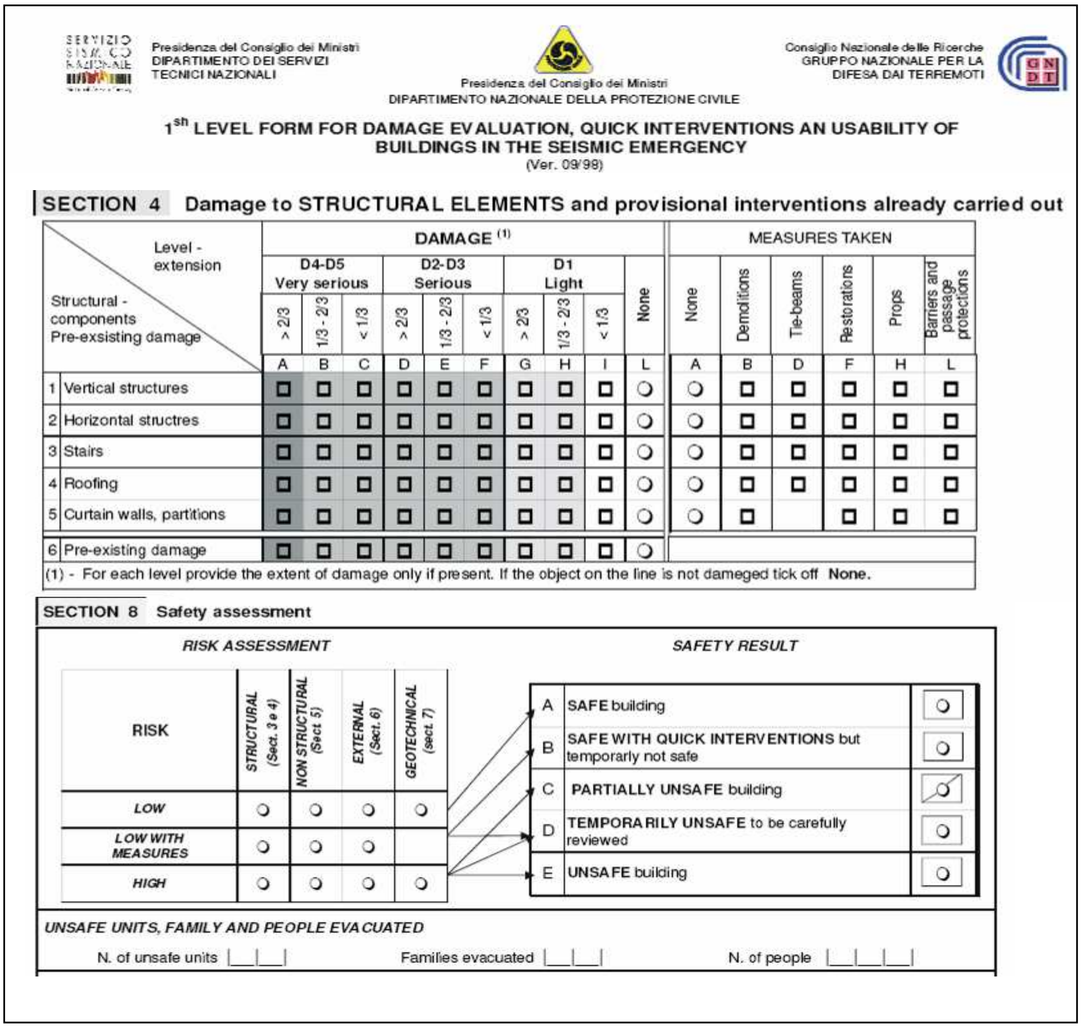


Figure 1.29 - Handbook for the compilation of AeDES form for post-earthquake emergency (Baggio et al. 2007).

The form is divided into 8 sections, some of which are illustrated in Figure 1.30: sections 1, 2, and 3 contain the building identification and description; sections 4 and 5 the damage classification of structural and non-structural elements; section 6 the external damage; section 7 the geological and geotechnical condition; section 8 provides the outcome in terms of risk assessment and safety result. The meaning of the 6 possible safety outcomes (from A to F) is illustrated in Table 1.24.



SERVIZIO SISMICO NAZIONALE

Presidenza del Consiglio dei Ministri
DIPARTIMENTO DEI SERVIZI TECNICI NAZIONALI

Presidenza del Consiglio dei Ministri
DIPARTIMENTO NAZIONALE DELLA PROTEZIONE CIVILE

Consiglio Nazionale delle Ricerche
GRUPPO NAZIONALE PER LA DIFESA DAI TERREMOTI

1sh LEVEL FORM FOR DAMAGE EVALUATION, QUICK INTERVENTIONS AN USABILITY OF BUILDINGS IN THE SEISMIC EMERGENCY
(Ver. 09/98)

SECTION 4 Damage to STRUCTURAL ELEMENTS and provisional interventions already carried out

Structural - components / Pre-exsisting damage \ Level - extension	DAMAGE (1) D4-D5 Very serious > 2/3	1/3 - 2/3	< 1/3	D2-D3 Serious > 2/3	1/3 - 2/3	< 1/3	D1 Light > 2/3	1/3 - 2/3	< 1/3	None	MEASURES TAKEN None	Demolitions	Tie-beams	Restorations	Props	Barriers and passage protections
	A	B	C	D	E	F	G	H	I	L	A	B	D	F	H	L
1 Vertical structures	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
2 Horizontal structres	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
3 Stairs	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
4 Roofing	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
5 Curtain walls, partitions	□	□	□	□	□	□	□	□	□	○	○	□		□	□	□
6 Pre-existing damage	□	□	□	□	□	□	□	□	□	○						

(1) - For each level provide the extent of damage only if present. If the object on the line is not dameged tick off **None**.

SECTION 8 Safety assessment

RISK ASSESSMENT

RISK	STRUCTURAL (Sect. 3 e 4)	NON STRUCTURAL (Sect 5)	EXTERNAL (Sect. 6)	GEOTECHNICAL (sect. 7)
LOW	○	○	○	○
LOW WITH MEASURES	○	○	○	
HIGH	○	○	○	○

SAFETY RESULT

A	SAFE building	○
B	SAFE WITH QUICK INTERVENTIONS but temporarily not safe	○
C	PARTIALLY UNSAFE building	○
D	TEMPORARILY UNSAFE to be carefully reviewed	○
E	UNSAFE building	○

UNSAFE UNITS, FAMILY AND PEOPLE EVACUATED

N. of unsafe units |__|__| Families evacuated |__|__| N. of people |__|__|__|

Fig. 1.30 - Example of sections 4 and 8 of the AeDES form

A) USABLE	Building can be used without measures. Small damage can be present, but negligible risk for human life.
B) USABLE WITH COUNTERMEASURES	Building has been damaged, but can be used when short term countermeasures are provided
C) PARTIALLY USABLE	Only a part of the building can be safely used
D) TEMPORARY UNUSABLE	Building to be re-inspected in more detail. Unusable until the new inspection.
E) UNUSABLE	Building cannot be used due to high structural, non-structural or geotechnical risk for human life. Not necessarily imminent risk of total collapse.
F) UNUSABLE FOR EXTERNAL RISK	Building could be used in relation to its damage level, however it cannot be used due high risk caused by external factors (heavy damaged adjacent or facing buildings, possible rock falls, etc.)

Table 1.24 – Outcomes of the safety assessment of the AeDES form

Post-earthquake microzoning

After strong earthquakes, quite often -in the past- seismic microzonation activities were carried out in order to support the reconstruction process in the most affected areas. The most recent example is relevant to the 2016-16 seismic sequence.

The enlargement of the area affected by the seismic sequence of central Italy, started on 24 August 2016, after the shocks of 26, 27 and 30 October 2016 and 18 January 2017, determined the decision of the Government Extraordinary Commissioner for the reconstruction to promote SM level 3 studies for all the 138 municipalities involved (Article 1 DL 9 February 2017 No. 8), entrusting the CNR SM Center (SMC) with the scientific support and coordination of the study activities. On behalf of the Government Extraordinary Commissioner for the reconstruction, the SMC has carried out technical-scientific support activities, aimed at the preparation of criteria and the coordination of level 3 SM studies.

With subsequent Commissioner Ordinance (No. 24 of 15 May 2017), funds were allocated to municipalities for assignments to professionals in charge of level 3 SM studies. The activity is coordinated by the SMC for Territorial Groupings identified by the aforementioned Ordinance (Abruzzo, Lazio, Marche 1, Marche 2, Marche 3, Umbria).

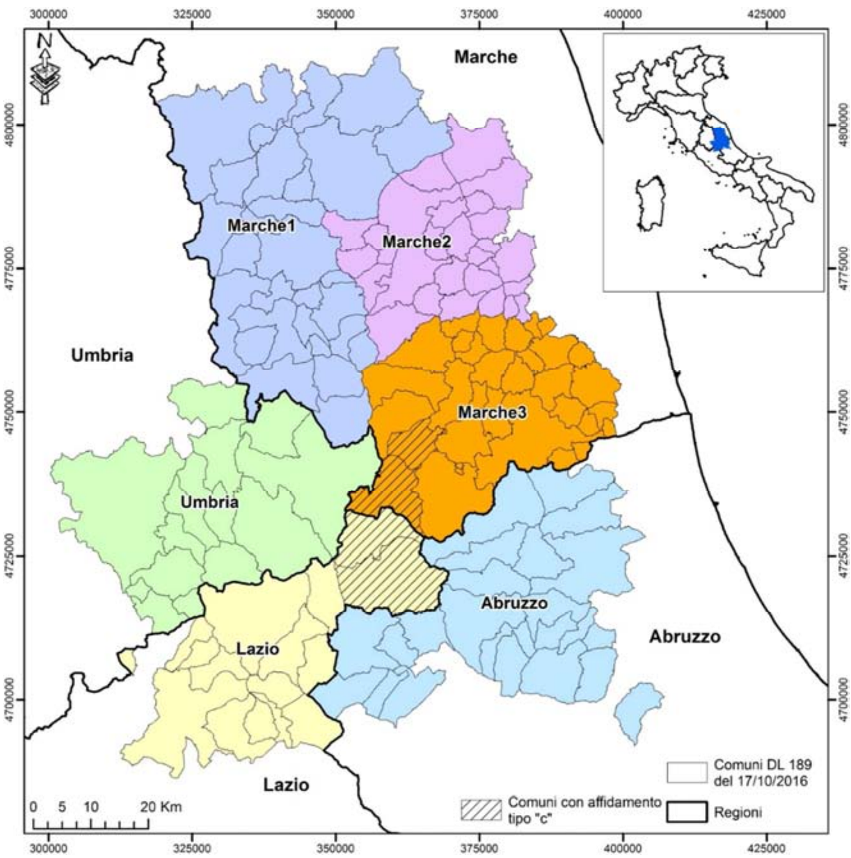


Figure 1.31 – 138 Municipalities where the level 3 SM studies have been carried out after the 2016-17 earthquake sequence.

The SM studies were all assigned between May and June 2017 and, after a period of training of professionals by the SM Center, completed at the end of July 2017, the realization of the studies began. All the studies will be delivered to the Municipalities within the year for the subsequent evaluation and validation by the Technical Working Group established at the Commissioner's Office. The conclusion of the activities, including validation, was completed by June 2018.

The experience gained in Central Italy allowed to prepare a document of general criteria for the use of the results of seismic microzonation studies level 3 for the reconstruction in the territories hit by the earthquakes, containing some important indications for planning but also for the support of designers for repair/strengthening or reconstruction of damaged buildings.

A similar experience was also launched for the reconstruction of the territories of the island of Ischia affected by the earthquake of 21 August 2017.

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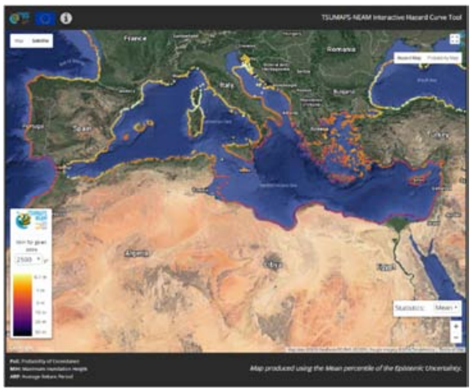
Chapter 2

Tsunami risk



National Civil Protection Department

FOREWORD

In these years, Italy is approaching for the first time the tsunami risk at national scale. This initiative follows the need to establish a national alert system for the tsunamis caused by earthquakes, i.e., the only ones that, at the moment, can be forecasted based on the earthquakes characteristics. As the effectiveness of a tsunami alert is strictly related to the availability, at the municipality level, of local civil protection plans, which include alert zones where citizens and authorities are expected to do specific actions, the National Civil Protection Department has focused its efforts on the adoption of a probabilistic tsunami hazard model, provided by the National Institute of Geophysics and Volcanology (INGV) within the European project TSUMAPS-NEAM, and on the definition of the consequent alert zones, traced and made available through an *ad hoc* webGIS by the Italian Institute for Environmental Protection and Research (ISPRA). Both these Institutes are Competence Centers of the National Civil Protection Department. In the meanwhile, a specific regulation has been issued along with the related implementing indications. Finally, research is ongoing to define the vulnerability of buildings and infrastructures with respect to the tsunamis. These studies pave the floor for future tsunami risk models at national scale.

INTRODUCTION

Every stretch of coast of the Mediterranean Sea is exposed to tsunami hazard due to high seismicity, steep sea floor slopes and several active volcanoes, both emerged and submerged. Being the coastline often densely inhabited and rich of infrastructures, the consequent risk is very high.
Over the past thousand years, tens of tsunamis have been documented along the Italian coasts. For the most recent among them (e.g., 1627, 1693, 1783, 1887, 1908), we know from historical sources the amount of destruction they caused. The most affected coastal areas were those of Southern Italy (Eastern Sicily, Calabria, Puglia). The most recent event (caused by a landslide from the flank of the Stromboli volcano during its last strong eruption) hit the Aeolian islands in 2002. Minor tsunamis were recorded also along the Ligurian and Adriatic coasts. The Italian coastline can also be reached by tsunamis generated far from our country, e.g., following a strong earthquake in the waters of the eastern Mediterranean Sea.

Italy has a very extensive coastal territory (sea coast extension km 7,375 - source ISTAT, 2015), where many inhabited areas are located, including cities, areas of historical, archaeological, environmental heritage, and industrial plants at risk of major accident. Because of the broad exposure of the Italian coastal territory to this risk, a National Alert System for tsunamis caused by earthquakes has been established – as a follow-up of the participation of Italy to the Intergovernmental Coordination Group of UNESCO for the establishment of a Tsunami Warning System in the NEAM region, the North East Atlantic, Mediterranean and connect seas (ICG/NEAMTWS; link:
http://www.ioctsunami.org/index.php?option=com_content&view=article&id=10&Itemid=14&lang=en).

THE TSUMAPS-NEAM HAZARD MODEL AND A PERSPECTIVE ON THE NATIONAL TSUNAMI HAZARD MODEL OF ITALY

A tsunami is a large sea wave caused by the sudden displacement of the sea floor. This displacement can be caused by an earthquake, a submarine landslide, or a volcanic eruption. The impact of meteorites or other impacts upon the sea surface can also generate tsunamis. Earthquakes are the primary cause of tsunamis, especially the largest ones, amounting to more than 80% both globally and in the Mediterranean. They can be especially large and dreadful when occurring along a subduction zone, an area where a tectonic plate is being drawn down under another. Tsunamis are rare, but their occurrence can cause wide destruction.

Establishing a regional long-term probabilistic tsunami hazard assessment for seismic sources is the first step to be undertaken for starting local and more detailed hazard and risk assessments and then risk management. Coastal regulation and planning, building code definition, and safety of critical infrastructures all depend on these actions. The main advantage of the probabilistic approach in comparison with classical scenario-based methods is that it allows engineers to perform spatially-homogeneous quantitative risk-analysis, and decision-makers to base their choices on quantitative cost-benefit analysis and comparative studies between different areas.

The Italian hazard model (*Modello della Pericolosità da Tsunami di origine Sismica*, MPTS) is currently in preparation by INGV and will be finalized in 2019. It will deal only with tsunamis generated by earthquakes. The method adopted to build the model is largely the same as that of the EU, DG-ECHO project TSUMAPS-NEAM (http://www.tsumaps-neam.eu/), coordinated by INGV.

The TSUMAPS-NEAM is a probabilistic, region-wide, long-term, time-independent, hazard model and is based on a Poisson model for the earthquake occurrence. The model is structured in "STEPs" and "Levels".

There are four STEPs as follows:

- STEP 1: PROBABILISTIC EARTHQUAKE MODEL
- STEP 2: TSUNAMI GENERATION & MODELING IN DEEP WATER
- STEP 3: SHOALING AND INUNDATION
- STEP 4: HAZARD AGGREGATION & UNCERTAINTY QUANTIFICATION

Each STEP is subdivided into several Levels. The Levels detail the data, methods, codes, and output quantities that are needed to reach the goal of the STEP. Level 0 at each STEP contains the definition of the datasets used in all subsequent Levels. Alternative implementations are possible for any Level.

In a probabilistic hazard assessment, the main results of all calculations are the hazard curves. Probability and hazard maps can be derived from them. The hazard curve expresses the probability of exceedance versus a "hazard intensity level" for a given time period, called the "exposure time". Probability and frequency of an event in time are linked together so that at each probability value corresponds a so-called average return period (ARP), which is the average time span between two consecutive events exceeding the same intensity. The probability of exceedance is always a number between 0 and 1.

In TSUMAPS-NEAM and in MPTS, the adopted exposure time is 50 years, whereas the adopted metric for the hazard intensity is the tsunami maximum inundation height (MIH). MIH is evaluated at a point of interest (POI). The POIs are almost evenly distributed along the coastlines. In TSUMAPS-NEAM the POIs are rather evenly spaced at ~20 km, in MPTS the spacing will be reduced to ~5 km. The MIH represents an average, as it may vary laterally along the (~20 or 5 km length) stretch of coast behind the POI. Local maxima of MIH (and maximum run-up) values along the inundated coast can be 3-4 times larger than the MIH estimated by the hazard model.

To represent the uncertainty of the hazard model, called epistemic uncertainty, several curves are shown in a single plot, corresponding to different percentiles of the hazard distribution (Figure 2.1). The epistemic uncertainty reflects our limited knowledge about past tsunamis and about the various physical processes that govern tsunamis.

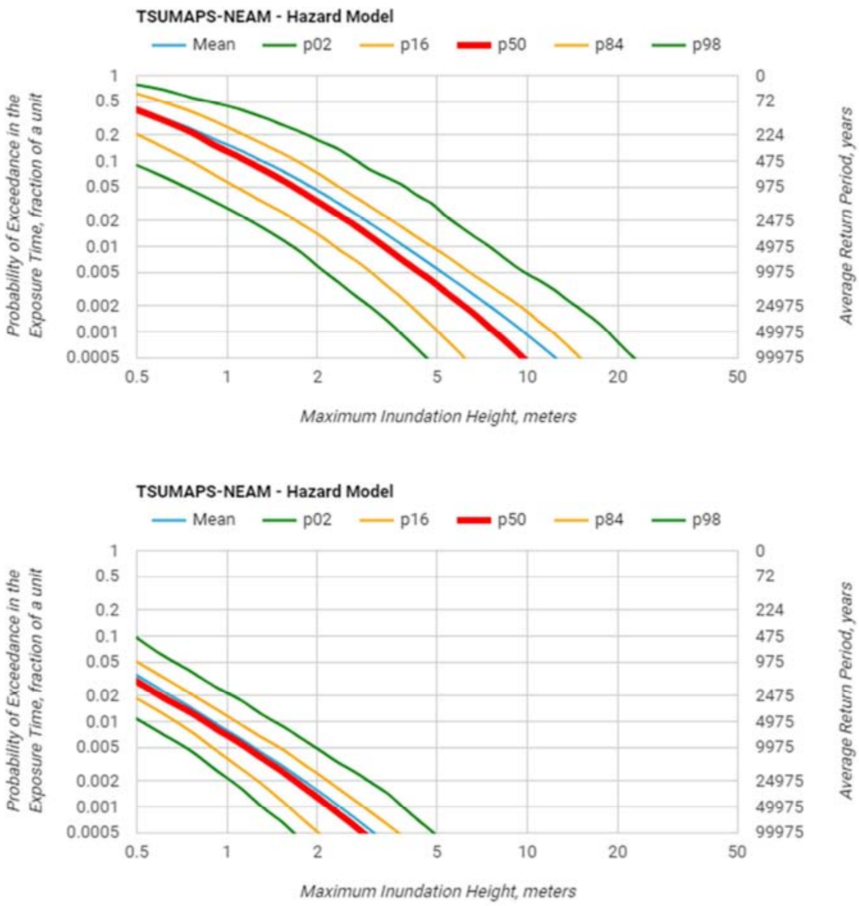


Fig. 2.1 - Examples of hazard curves from the TSUMAPS-NEAM hazard map for two localities in Calabria, southern Italy: Soverato Marina (upper panel) on the Ionian Sea, and Vibo Valentia (lower panel) on the Tyrrhenian Sea. Each plot provides values for the mean, 2nd, 16th, 50th, 84th, and 98th percentiles of the whole ensemble of hazard models.

The primary results derived from the hazard curves are the hazard and probability maps. To make such maps, each POI takes a different color according to a value of the intensity measure level or the probability of exceedance (Figure 2.2). Figure 2.3 shows the hazard and probability maps for Italy, derived from mean hazard curves.

To make a hazard map, we extract the MIH corresponding to a chosen design probability (y-axis of hazard curves) at each POI. The POI colors on the hazard map scale according to the MIH measured in meters. Engineers and other hazard specialists generally use this type of maps.

To make a probability map, we extract the probability of exceedance in 50 years corresponding to a chosen value of the MIH (x-axis of hazard curves) at each POI. The POI colors on the probability map scale according to the probability expressed by a number between 0 and 1. This type of maps is more useful to communicate the hazard to administrators, decision makers, and the general public.

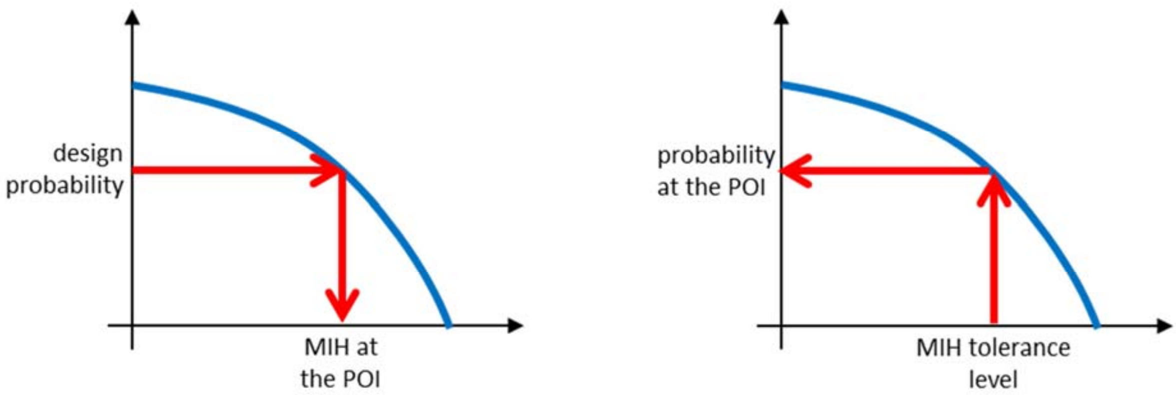


Fig- 2.2 - Left, sampling the hazard curve to make a hazard map; Right, sampling the hazard curve to make a probability map.

The highest hazard is found along the coasts facing the Ionian Sea and involving the regions of Sicily, Calabria, Basilicata, and Puglia. These regions are not only exposed to the local earthquake sources, but also to sources in the eastern Mediterranean, especially the Hellenic Arc and the Ionian islands. Tsunami waves can in fact travel long distances without losing their destructive power. Therefore, the coasts of Italy are exposed to tsunamis generated by any seismic source within the Mediterranean basin, and relatively-high hazard can even affect places that are very far from the earthquake sources that generate tsunamis.

Notice Calabria, this is one of the most seismically active regions of Italy, but despite its narrowness, its tsunami hazard on the Tyrrhenian side is much lower than on the Ionian side. Considering the mean hazard curves shown in Figure 2.1, one may observe that the MIH of 1 m can be exceeded with an ARP of 300 years in Soverato Marina, Ionian side, and with a much longer ARP of 5,000-6,000 years in Vibo Valentia, Tyrrhenian side. If we instead consider the maximum runup (say ca. three times the mean MIH for that stretch of coast), and the 84^{th} percentile of the epistemic uncertainty, we may estimate an ARP of 30 years or shorter for the Ionian side, and an ARP of 400 years or shorter for the Tyrrhenian side.

Relatively-high hazard is found in the southwestern coast of Sardinia. This region has little to negligible contribution from local earthquake sources and its hazard is driven almost exclusively by earthquake sources in northern Africa.

Considering an ARP of 2,500 years and a mean model of the entire Italian region, altogether the cases of MIH larger than 3 m remain within the 1-2%, whereas the cases of MIH smaller than 1 m exceeds the 80% (Figure 2.4).

We recall, however, that these results also have several limitations. Here is a list of the most compelling ones. The few observations summarized above cannot substitute for an in-depth analysis of the hazard and probability maps and curves at local levels. Uniform region-wide hazard mapping allows the user to compare the hazard of places that are very far apart from each other. However, even if two places have the same mean hazard, the actual hazard can be very different for different percentiles. The spreading of the hazard curves at every POI conveys the information about the uncertainty that affects these estimates.

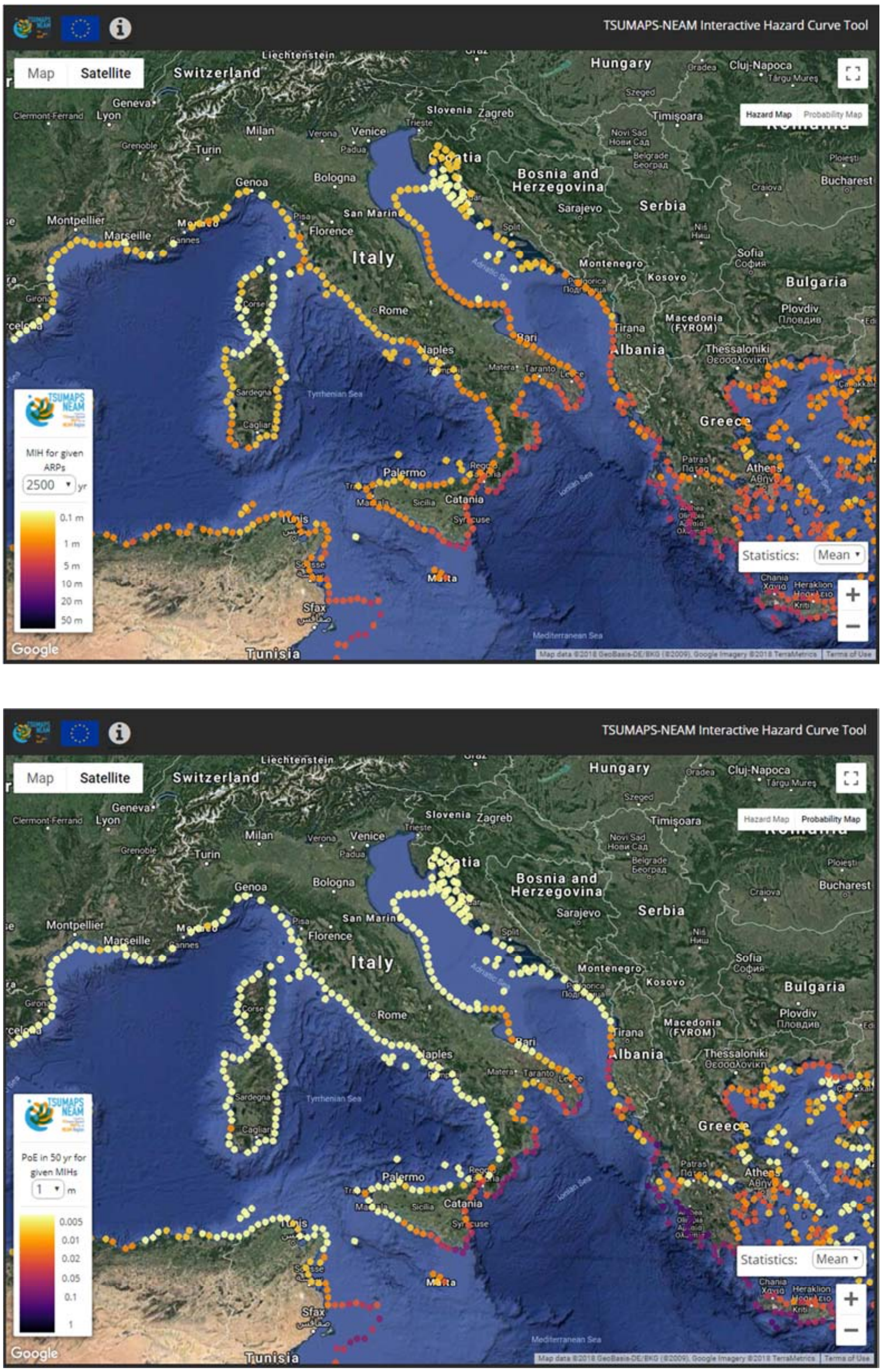


Fig. 2.3 - View for hazard, ARP = 2500 yr (top) and probability, MIH = 1 m (bottom) maps of the Italian coasts, sampled from the results of the TSUMAPS-NEAM project.

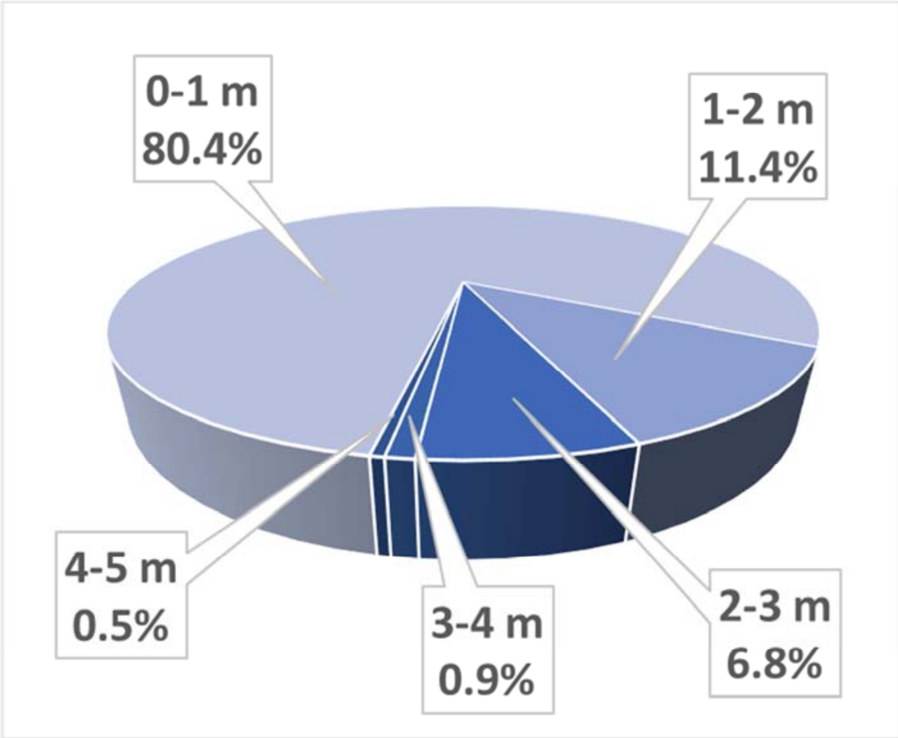


Fig. 2.4 - Pie chart showing the percentage of Italy's coastlines that correspond to different tsunami intensities MIHs for an average return period (ARP) of 2500 yr. Notice that this percentage decreases with increasing MIH because larger events are rarer than smaller events.

As discussed above, an MIH of 1 m at one POI may indicate 3-4 m of maximum run-up as local maximum. Yet some inter-POI residual variability – i.e., higher and lower hazard between two consecutive POIs – not caught at the resolution of the regional assessment may exist. Moreover, the discretization of the earthquake parameters typically done for a regional assessment may be too coarse for describing hazard variations at the local scale. Lastly, the amplification factors used for converting offshore tsunami waves into MIH are also very coarsely defined. These are some of the reasons why a region-wide hazard assessment cannot replace detailed local hazard assessments. Finally, we recall that re-using hazard data for risk-management applications and decision making is not necessarily straightforward and should always rely on the work of specialists.

LEGISLATIVE FRAMEWORK AND NATIONAL TSUNAMI WARNING SYSTEM

Italian Alert System for Tsunamis caused by seismic events

The Italian Alert System for Tsunamis caused by seismic events (SiAM – Sistema di Allertamento nazionale per i Maremoti) has been officially established in 2017, after a Directive issued by the Prime Minister.

The SiAM is composed of three institutions with different tasks, which contribute together to the implementation of a common objective: to alert with the available tools all the administrations (including local authorities) and operational bodies potentially involved in a tsunami event. In particular, these institutions are:

- INGV-National Institute of Geophysics and Volcanology (which operates through the Tsunami Alert Center - CAT) assesses the possibility that a particular earthquake, with epicenter in the sea or in the immediate vicinity of it, may generate a tsunami, and estimates the expected arrival times, wave height and alert levels (red, orange, no alert) along the exposed coasts;

- ISPRA - Italian Institute for Environmental Protection and Research provides the data recorded by the National Tide Gauge Network to the CAT-INGV, to confirm or not the actual occurrence of the tsunami;
- DPC – the Italian Civil Protection Department has the task of ensuring the prompt and simultaneous dissemination of the alert messages to the entire National Service of Civil Protection, i.e., to all its components (central government of the State, Regions and Autonomous Provinces, Provinces, Municipalities) and operational bodies (e.g., National Fire Department, Armed Forces, Police, scientific community, Italian Red Cross, the structures of the National Health Service, voluntary Organizations, …).

The SiAM System fully implements the principles established within the Intergovernmental Coordination Group of UNESCO for the establishment of a Tsunami Warning System in the NEAM region, i.e., the North East Atlantic, Mediterranean and connect seas (ICG/NEAMTWS). In this framework, since 2016, not only is the CAT-INGV the National Tsunami Warning Centre for Italy, but it is also an official Tsunami Service Provider for the entire Mediterranean region, operating within the regional system for tsunami warning and releasing alert messages in case of a tsunami in the Mediterranean Sea to several European, African and Asian countries/institutions of the EuroMed region.

SiAM also takes into account two fundamental aspects that affect the entire architecture of the alert system for the Italian coasts: the small size of the Mediterranean basin, which makes the time for any alert limited, and the causes of triggering of the tsunami event. Earthquakes are the main cause of tsunamis (about 80%). Although tsunamis may have different triggers than seismic ones, at the moment the phenomena behind these additional causes are not systematically detectable in advance of the event and, therefore, do not allow the activation of a warning system. The SiAM, therefore, has the task of monitoring and alerting only in case of possible tsunamis characterized by seismic origin that may occur in the Mediterranean Sea.

National operational guidelines on how to update Emergency management plans

To support the authorities, above all at local level, in the effort of establishing alerting procedures for the population within the respective civil protection plans, the Civil Protection Department has issued national guidelines on how to update the civil protection plans of public administrations and operational bodies with respect to the tsunami risk (in Italian, downloadable here: http://www.protezionecivile.gov.it/jcms/en/view_prov.wp?request_locale=en&contentId=LEG71075). These guidelines have been written also with the contribution of INGV and ISPRA.

In the guidelines, alert levels and corresponding expected tsunami inundation areas are defined for the entire national coastline with a 10 m resolution and, for the time being, for Sicilia and Calabria regions with 5 m resolution (http://sgi2.isprambiente.it/tsunamimap/). The inundation areas with 5 m resolution for the rest of the coastal regions are under production and will be progressively released in the coming months.

In particular, the national guidelines include the following:
- a detailed explanation of the tsunami early warning system at national level;
- tsunami inundation areas for the different alert levels, with 10 m resolution for the national coastline and 5 m resolution for Sicilia and Calabria regions, provided through the aforementioned webGIS;
- expected contents of the emergency plans, suggestions on the procedures, reference material for the tsunami signage, which is recommended to be installed, and best practices on the tsunami public alert communication measures.

The starting point for the definition of the evacuation zones has been the regional seismic probabilistic tsunami hazard analysis (SPTHA) described before, developed within the TSUMAPS-NEAM project, co-funded by the European Union Civil Protection Mechanism.

Evacuation zones have been designated adopting a given return period and epistemic uncertainty level based on the definition of the acceptable risk level, taking into account international experiences on the tsunami risk as well as national experiences for the management of other types of hazards/risks. A simplified GIS-based methodology has been adopted to define the inundation areas and derive two reference alert zones (for the two alert levels, i.e., advisory and watch) for each Italian municipality.

Local authorities and interested national operational bodies are expected to update their civil protection plans within a year from the national guideline's publication date. The local plans shall include a public risk communication plan to increase the community awareness and preparedness with respect to tsunami hazard and risk not only at institutional level, but also among the citizens.

To alert as soon as possible all the administrations and operational bodies potentially involved in a tsunami event, SiAM has developed a dedicated technological platform for automatic, real time dissemination of alert messages to the entire emergency response system at all levels through emails and SMS messages.

OTHER TOOLS

The national communication campaign on best practices of civil protection

"Io non rischio" (I don't take risks) is a national communication campaign on best practices of civil protection. Each year, during the second weekend of October, civil protection volunteers meet the citizens throughout Italy to talk about seismic, flood and tsunami risks in hundreds of squares. The campaign "I don't take risks - Tsunami" (http://iononrischio.protezionecivile.it/en/tsunami/the-campaign/) was first tested in 2014, in occasion of the international drill Twist – Tidal Wave In Southern Tyrrhenian Sea, financed by the European Commission. On 13 and 14 October 2018 volunteers informed the population on how to raise awareness on tsunami and what they can do in terms of prevention and self-protection. The awareness raising national campaign "I don't take risks - Tsunami" will be held also in the coming years, since the process of sensitizing the population and channelling the important message of the safe behaviours takes necessarily a medium-long term effort.

The informative materials of the campaign can be downloaded at: http://iononrischio.protezionecivile.it/en/tsunami/informative-materials/

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Chapter 3

Volcanic risk

National Civil Protection Department

INTRODUCTION

Italy is a very active volcanic region. The volcanism is mainly related to the subduction of the African tectonic plate below the Euro-Asiatic plate. Three main clusters of volcanism exist: a line of volcanic centers running northwest along the central part of the Italian mainland (see the Campania region); a cluster in the northeast of Sicily (Aeolian Islands and Etna); and another cluster in the Sicily channel around the Mediterranean island of Pantelleria (Fig. 3.1).

Fig. 3.1 – Location map of volcanoes, emerged and submerged, along the Italian peninsula.

There are many volcanic complexes located along the Italian peninsula and they can be divided in three main categories: extinct, dormant and active.

- Extinct volcanoes are those that have not erupted over a period of 10,000 years. These include the Amiata, Vulsini, Cimini, Vico, Sabatini, Pontine Islands, Roccamonfina and Vulture volcanoes (Fig. 3.1).
- Dormant volcanoes are active volcanoes that have erupted during the last 10,000 years but are currently in a dormant state (Colli Albani, Campi Flegrei, Ischia, Vesuvio, Salina, Lipari, Vulcano, Ferdinandea and Pantelleria). Amongst these, Vesuvio, Campi Flegrei, Ischia and Lipari have had a very low eruptive frequency and their conduits are now obstructed. Not all the dormant volcanoes have the same risk level, both in terms of hazard of expected phenomena and in terms of the extent of the population at risk. Furthermore, some are subject to secondary volcanic phenomena (degassing from the ground, fumaroles, etc.) which may well cause situations of risk.
- Active volcanoes are those that erupted over the last few decades. These are Etna and Stromboli which frequently erupt and represent a reduced hazard at short term due to their open conduit activity.

Volcanic activity in Italy is also concentrated in the underwater areas of the Tyrrhenian Sea and Sicily Channel. Several **submarine volcanoes** are still active, others, now extinct, represent submarine mountains.

The National Civil Protection Department appointed a "working table", made up by marine geologists and volcanologists, to assess the geohazards of the active submarine, insular and coastal volcanoes in Italy. The aim was to define the state-of-the-knowledge, identify potential scenarios, measure and rank hazard conditions, highlight knowledge gaps and to evaluate possible monitoring systems. Yet, since the beginning it was clear that existing data and knowledge were absolutely not homogeneous and

generally not adequate to perform a full and "classic" hazard assessment, mainly due to the extreme difficulties in analyzing type and age of products present in the seafloor and sub-seafloor. Notwithstanding this, the adoption of a novel iterative process of collective discussion based on data, and cross-comparison/inter-calibration of results, made it possible to reach a set of important results. Ten different kind of hazard were defined, 5 related to mass wasting 5 to volcanic or exhalative processes. Seventeen active apparatuses or group of apparatuses were identified; two volcanic islands were added to the original list, as recent volcanic activity was only submarine and therefore they were previously classified as non-active. Finally, for each hazard and each apparatus minimal recurrence time and hazard intensity were defined.
In Italy, there is not a risk map for volcanic activity but the hazard posed by each volcano is monitored and assessable. The most dangerous volcanoes are Vesuvio, Campi Flegrei, Ischia, Stromboli, Etna and Vulcano.
This assessment is due to different considerations: possible scale of future eruptions, frequency of eruptions, and the population at risk.
In particular, Vesuvio and Campi Flegrei represent the higher risk for Italian Civil Protection, for different reasons:
– they are characterized by strong explosive activity (Plinian and sub-Plinian eruption in the past);
– they are very close to highly populated areas (more than 2 million people live in the proximity of the volcanoes);
– the last eruptions are respectively about 500 and 70 years ago, respectively for Campi Flegrei (1538 a.d.) and Vesuvio (1944 a.d.).

A brief description for each volcanic complex follows:

Campi Flegrei is a caldera approximately 12-14 kilometers long, located 25 kilometers west of Vesuvio and 15 kilometers west-southwest of Naples. The caldera formed after a large eruption 35,000 years ago that produced 80 cubic kilometers of Pyroclastic deposits. Several other eruptions of decreasing intensity have occurred since then. Much of the post caldera volcanism occurred between 10,000 and 8,000 years B.P., and between 4,700 and 3,000 B.P. Its most recent eruption was in 1538. The caldera has a long history of uplift and subsidence as recorded in the geological record. Since Roman times, the elevation of the caldera floor has varied by more than 12 meters; in the 48 hours before the most recent eruption in 1538 *(Monte Nuovo)*, the floor rose by at least 4-5 meters. The last well documented episode of several ground upheaval and subsidence events were reported during 1982-85.

Vesuvio is one of the best-known volcanoes in the world. The AD 79 eruption responsible for the destruction of the Roman cities of Pompei and Ercolano is an indicator of its potential destructive capabilities.
The Somma-Vesuvio complex is a strato-volcano located in the southern sector of the Campania Plain (southern Italy). The Vesuvio morphology is characterised by a volcanic cone (Gran Cono) built within the older Somma caldera. During the last 20,000 years it has been characterised either by long quiescence periods, interrupted by plinian or subplinian eruptions, or by periods of persistent Strombolian activity, lava effusions and phreato-magmatic eruptions, such as the one that started after the 1631 AD eruption and lasted until 1944 AD, the date of the last eruption. Since that time the Vesuvio has not shown any major signs of unrest apart from moderate volcano-tectonic seismicity and fumarolic activity. Presently the only indicators of the internal dynamics of this quiescent volcano are given by summit low temperature fumaroles and a weak seismicity. Nonetheless, the explosive style of its past activity and the proximity of densely urbanized areas make Vesuvio one of the most dangerous volcanoes in the world. This recognized volcanic hazard has prompted numerous efforts aimed at the upgrading and improvement of a monitoring system.
Half a million people live in a near-continuous belt of towns and villages around the volcano, in the zone immediately threatened by future eruptions.

Etna is one of the most active volcanoes in the world and is in an almost constant state of activity. Etna, towering above Catania, Sicily's second largest city, has one of the world's longest documented records of historical volcanism and it is the highest active volcano in Europe, currently standing 3,350 meters high. Persistent explosive eruptions, sometimes with minor lava emissions, take place from one or more of the four prominent summit craters, the Central Crater, NE Crater, SE Crater and the new SE Crater. Flank vents, typically with higher effusion rates, produce eruptions from fissures that open progressively downward from near the summit (usually accompanied by strombolian eruptions at the upper end). Strombolian activity generally affects a restricted area around the eruptive vent and does not represent a matter of risk for the villages nearby but only for the tourists on the summit.
Lava flows, due to their viscosity and low flow speed, do not represent a threat to the population. In case of a lava effusion from the summit areas, there is a very small chance of reaching the villages and only in case of long lasting eruptions this could become a real possibility.
Ash emissions and fallout are very frequent and even if they don't represent a threat for human life, they could cause many problems to transportation, crops, economic losses and also breathing problems for long periods of exposure. Ash fall also affects air traffic control to the nearby airports of Catania-Fontanarossa, Sigonella and Reggio Calabria.

Stromboli, the northern most island of the Eolian Archipelago, north of Sicily, is one of the most active volcanoes in the world and famous for its normally small, but regular explosions of glowing lava from several vents located into the summit crater. Its population ranges from 500 to 10,000 people in summer during the tourist season.
According to historical records, Stromboli has been constantly active, which makes it almost unique among the volcanoes in the world. Most of its activity consists of small bursts of glowing lava fragments to heights of 100-200 m above the craters. Occasionally, much stronger explosions or periods of more continuous activity can occur. The most violent eruptions during the past 100 years, were large enough to take lives and/or destroy property even at considerable range from the craters, reaching as far as the inhabited areas. Apart from explosive activity, effusive eruptions with outflow of lava occur at irregular intervals ranging from a few years to decades. The most recent effusive eruptions occurred during the volcanic crisis on 2002, 2007 and 2014. Occasionally (at least 6 in the last 100 years), large submarine or sub-aerial landslides can produce tsunamis that are able to affect the entire Eolian archipelago and the Tyrrhenian sea.

The Island of **Vulcano** is the southernmost of the seven islands of the Eolian archipelago. The island covers an area of approximately 21 km^2 and it is exposed to different natural hazards (such as volcanic eruptions, landslides, earthquakes, tsunami, etc.). Its population varies from 800 people to 15,000 people in summer during the tourist season.
Vulcano is now considered a dormant volcano (last eruption occurred in 1888-1890). Since the end of the last magmatic eruption in 1890, activity at La Fossa cone has consisted of fumarolic emissions, weak earthquakes and accompanying landslides and deformation of the ground. Two major episodes of volcanic unrest have occurred since the magmatic eruption of 1888-1890. The first occurred in 1913-1923 with an increase in the crater-fumarole temperature from 200°C to 615°C. The second one started in 1977 and has been characterized by several fluctuations in fumarole temperature and chemical composition.
In 2004 and 2005 La Fossa crater was affected by new phases of local anomalous seismicity with characteristics similar to the episodes of 1985, 1988 and 1996 and coinciding with peaks of CO_2 flux. Nevertheless all the preceding episodes of volcanic unrest which have occurred since the last eruption in 1888-1890 did not result in eruption, they clearly demonstrate that the volcano has shown evident signs of potential reactivation, with a slow but constant evolution towards an increasing probability of eruption. The risk on the Island is mainly due to high explosive types of volcanism and by the number of people living there, especially during summer.

VOLCANIC RISK REDUCTION

The cooperation with the scientific community

Since 1992 the scientific community of Italy is considered by law as an essential component of the National Civil Protection Service. Over the last decades the National Department of Civil Protection and the scientific community have been collaborating on many aspects to improve volcanic risk forecasting, prevention, response and management. This cooperation reaches its climax during the management of emergency phases, when the interaction becomes continuous and often hectic to ensure timely and accurate scientific information to decision makers. This is possible thanks to the cooperation of a variety of entities: research institutes including the volcanic observatories, university departments and centers, the experts of the specific volcanic system and the Commissione Grandi Rischi (National Advisory Committee). Nevertheless, what mentioned above would be extremely difficult without a continuous and constant collaboration between the different actors through the carry out of applied research projects, development of pre-operational tools for civil protection purposes, maintenance and upgrade of monitoring and surveillance systems, activities finalized to the elaboration of hazard maps, event and impact scenarios, alert levels, etc.. It is also necessary to take into account that, according to the Italian law, decision making aimed at volcanic risk mitigation is under the responsibility of different levels of Civil Protection authority, depending on the intensity and extension of the expected impacts. For this reason Regions and local authorities have their specific role and are involved in the decision-making process. Therefore the Italian Civil Protection Service represents a complex collaborative system in which the daily work of each of its components is crucial for the effective management of future volcanic crisis.
In particular, the scientific community give its support in identifying hazard scenarios, monitoring and surveillance activities, vulnerability assessment.
The National Civil Protection Department have been promoting together with the Regional and local administration in several activities aimed at volcanic risk mitigation. A few example are provided below related to Sicilian and Campanian volcanoes.

Alert Levels System

For quiescent volcanoes, like Vesuvio and Campi Flegrei, alert level systems established since long time are based on the increase of monitoring parameters, considered as possible precursors of an imminent volcanic activity. Increasing operational phases for civil protection response are linked (after evaluation of the operational component) to the corresponding scientific alert levels.
For permanently active volcanoes, like Etna and Stromboli, some scenarios require the activation of the civil protection at national scale, whereas other scenarios affect only small portions of the surrounding territory and can be managed at local or regional level.
Alert levels for these volcanoes must therefore take into account not only a general increase of parameters toward national scenarios, but also possible minor scenarios that are sometimes produced within a short time interval and with very short-term precursors.
Over the last years the National Civil Protection Department, in cooperation with the Regione Siciliana and the scientific community, developed an alert level system that includes a number of potential events these volcanoes can produce with increasing possible effects and the related civil protection response at different level of competence and responsibility. Regione Siciliana has consequently introduced an advice system to timely inform Mayors and local authorities.

Early Warning System at Etna and Stromboli

Eruption forecasting is always a challenging task and requires at least a basic knowledge of the volcano behaviour and the presence of a well-structured monitoring network. In fact, although all the monitoring signals are useful to understand the general behaviour of a volcano, only a few of them are usually decisive in providing significant indication that an eruption is going to occur.
The challenge can be even more demanding at open conduit volcanoes, where precursor monitoring parameters can vary only when the eruption is imminent. In these cases early-warning systems can make the difference in ensuring a timely alert to civil protection authorities and to stakeholders, especially in touristic areas.

Depending on the time of development of the phenomena civil protection response can be different. In some cases an evaluation phase is possible and hopeful, in some others an automatic alert can be needed.
Over the last few years an early-warning system has been developed for Etna and for Stromboli, thanks to the contribution of the Centri di Competenza University of Florence and INGV. Together with the Regione Siciliana the different related operational procedures have been also developed.

Civil Protection Plans

The National Emergency Plan was originally drawn up in 1984 for Campi Flegrei and successively in 1995 for the Vesuvio area. Over the years Civil Protection Plans have been periodically updated. The Plans identify a Red zone subject to pyroclastic flow hazards and heavy ash fallout for which preventive evacuation is provided as the only safety precaution for the population, and a Yellow zone exposed to smaller amounts of ash fallout providing for evacuation measures in delayed time and only in the areas directly affected by disaster (Fig. 3.2).
The Red and Yellow zones have been identified by the National Civil Protection Department, in collaboration with the Campania Region and the Municipalities concerned, based on research studies on hazard and vulnerability as well as guidelines issued by the scientific community. The Evacuation Plans for the Red zones population are currently being drawn up by the Campania Region, with the support of ACaMIR Infrastructures Mobility and Networks Agency of Campania, in collaboration with the Municipalities involved.
The overall strategy for the transfer of the population from the Red zones to the twinned Regions and Autonomous Provinces has been identified.

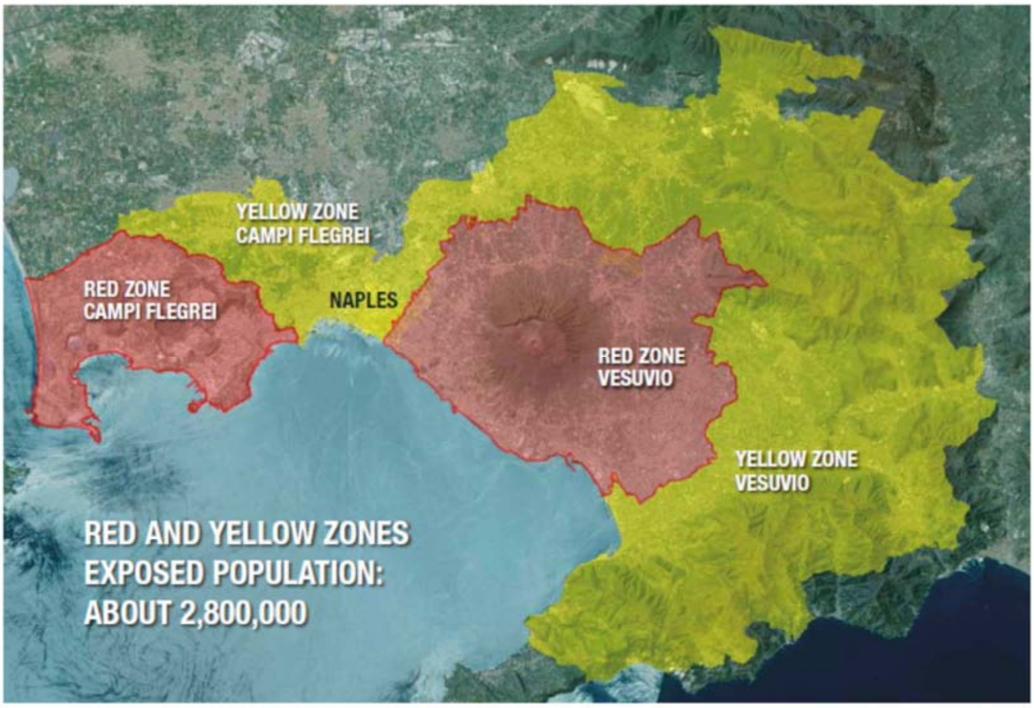
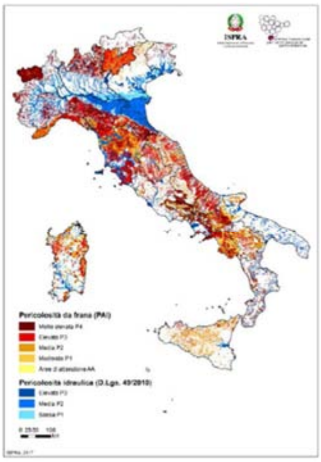
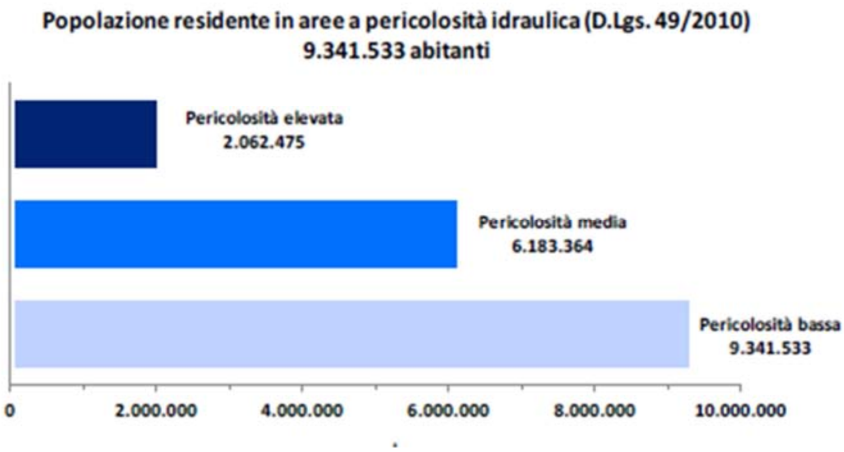


Fig. 3.2 – Vesuvio and Campi Flegrei red and yellow zones.

Chapter 4

Hydro-geological/hydraulic risk and extreme weather events





National Civil Protection Department

HYDRO-GEOLOGICAL RISK

Flooding and landslides are the phenomena that most often affect Italian territory. The constitution and geological characteristics of the Peninsula and in particular of the Apennines produce hydro- geological instability.
Most of the Italian territory is exposed to hydrogeological and hydraulic risks: there are 7,275 (out of about 8,000) Italian municipalities exposed to the risk of landslides and/ or floods, 16.6% of the national territory is classified as being more dangerous, 1,28 million inhabitants are exposed to landslide risk and more than 6 million are exposed to flood risk.
Regions with the highest values of population at risk landslides and floods are Emilia-Romagna, Tuscana, Campania, Lombardia, Veneto and Liguria.
The new "*National Hazardous Mosaics*", realized on the basis of the Hydrogeological Plans - PAI Frane and the hydraulic hazard maps according to the scenarios of Legislative Decree 49/2010, take into account the updates provided by the District Basin Authorities. Compared to the 2015 edition, a 2.9% increase in the total surface area classified as landslide hazard and 4% of the average hydraulic hazard surface area emerges.

LANDSLIDE RISK

About a third of the total landslides in Italy are rapid phenomena (collapses, rockfall, mud and debris flows), characterized by high speeds, up to a few meters per second, and by high destructiveness, often with serious consequences in terms of human lives loss.
Other types of movement (eg slow flows, complex landslides), characterized by moderate or slow speeds, can cause extensive damage to residential areas and transportation network infrastructures.
The most important factors for triggering landslides are short period and intense rainfall, persistent precipitation and earthquakes.
The total area of landslide hazard zones and attention zones in Italy is 59.981 km2 (19.9% of the national territory).
Taking into account the most dangerous classes (high P3 and very high P4), subject to the restrictions of use of the most restrictive territory, the areas amount to 25.410 km^2, equal to 8.4% of the Italian territory.

Landslide hazard zones			
		km²	*% of national territory*
H4	**Very high**	9,153	3.0%
H3	**High**	16,257	5.4%
H2	**Medium**	13,836	4.6%
H1	**Moderate**	13,953	4.6%
AA	**Attention zones**	6,782	2.2%
Total		**59,981**	**19.9%**

Tab. 4.1 - National mosaic of landslide hazard zones (River Basin Plans PAI).

The comparison between the national mosaic ISPRA 2017 and that of 2015 national mosaics shows an increase of 2.9% of the total area classified by the PAI (classes H4, H3, H2, H1 and AA) and 6.2% of the classes with greater danger (high H3 and very high H4).
These variations are mainly linked to the integration / revision of the perimeters, also with more detailed studies, and to the mapping of new landslides.

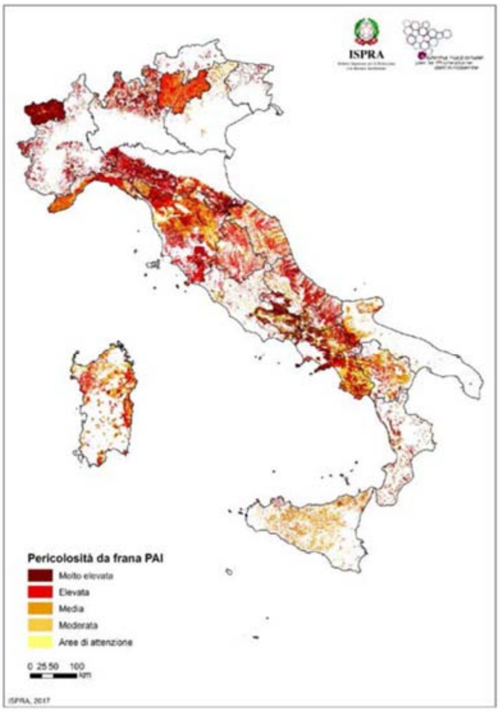


Fig. 4.1 - Landslide hazard zones (River Basin Plans).

Region	Region area	High and very high landslide hazard zones	
		H4 + H3	
	km²	km²	%
Piemonte	25,387	1,230.8	4.8%
Valle D'Aosta	3,261	2,671.7	81.9%
Lombardia	23,863	1,538.2	6.4%
Trentino-Alto Adige	13,605	1,476.7	10.9%
Bolzano	7,398	131.7	1.8%
Trento	6,207	1,345.0	21.7%
Veneto	18,407	105.6	0.6%
Friuli Venezia Giulia	7,862	190.5	2.4%
Liguria	5,416	751.9	13.9%
Emilia-Romagna	22,452	3,277.7	14.6%
Toscana	22,987	3,367.6	14.7%
Umbria	8,464	492.9	5.8%
Marche	9,401	735.5	7.8%
Lazio	17,232	953.3	5.5%
Abruzzo	10,831	1,678.2	15.5%
Molise	4,460	716.9	16.1%
Campania	13,671	2,678.2	19.6%
Puglia	19,541	594.8	3.0%
Basilicata	10,073	511.6	5.1%
Calabria	15,222	545.6	3.6%
Sicilia	25,832	394.6	1.5%
Sardegna	24,100	1,497.6	6.2%
Total	**302,066**	**25,410**	**8.4%**

Tab. 4.2 - High and very high landslide.

FLOOD RISK

A flood is the temporary flooding of areas that are not normally covered with water.
The flooding of these areas can be caused by rivers, streams, canals, lakes and, for coastal areas, by the sea.
The Directive 2007/60/EC on the assessment and management of flood risks (Floods Directive or Floods Directive - FD), aims to establish a framework for the assessment and management of flood risks. It was implemented in Italy with Legislative Decree 49/2010.
On 3 March 2016, the Flood Risk Management Plans - PGRA were approved on 17 December 2015, were approved in the Integrated Institutional Committee (Article 4, paragraph 3 of Legislative Decree 219/2010).
The approval of the PGRA by the Council of Ministers took place on October 27, 2016, for almost all river districts, except for that of Sicily, adopted by Decree of the President of the Sicilian Region of February 18, 2016, but not yet approved.
Once the first management cycle has been completed, the activities necessary for the revision/updating of the obligations of the FD regarding the second management cycle have been started.
In 2017 the new national mosaic of the areas with hydraulic danger, created by the District Basin Authorities according to the three hazard scenarios of Legislative Decree 49/2010: high probability scenario P3 with return period between 20 and 50 years (frequent floods), P2 medium probability scenario with return period of 100 and 200 years (infrequent floods) and low probability scenario P1 or extreme event scenarios.
The high flood hazard areas in Italy amount to 12,405 km^2, the medium flood areas with amounted to 25,398 km^2 and the low hazard zones (maximum scenario expected) to 32,961 km^2.
The Regions with the highest values of surface with average hydraulic hazard, based on data supplied by the District Basin Authorities, are Emilia-Romagna, Toscana, Lombardia, Piemonte and Veneto.

Aree a pericolosità idraulica - Scenari D.Lgs. 49/2010		
	km²	*% su territorio italiano*
Scenario pericolosità Elevata P3	12.405,3	4,1%
Scenario pericolosità Media P2	25.397,6	8,4%
Scenario pericolosità Bassa P1	32.960,9	10,9%

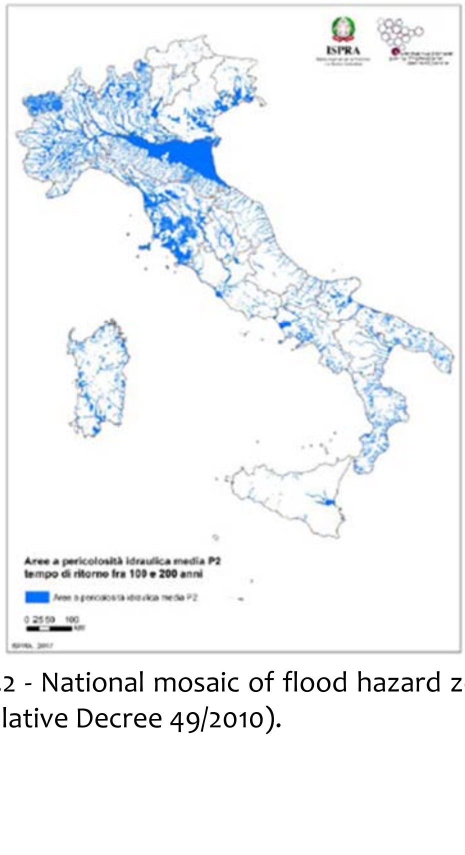


Fig. 4.2 - National mosaic of flood hazard zones (Legislative Decree 49/2010).

Regione	Area Regione	Aree a pericolosità idraulica media P2 (D.Lgs. 49/2010)	
	km²	*km²*	*%*
Piemonte	25.387	2.066,0	8,1%
Valle D'Aosta	3.261	239,2	7,3%
Lombardia	23.863	2.405,7	10,1%
Trentino-Alto Adige	13.605	78,9	0,6%
Bolzano	7.398	33,2	0,4%
Trento	6.207	45,7	0,7%
Veneto	18.407	1.713,4	9,3%
Friuli Venezia Giulia	7.862	610,3	7,8%
Liguria	5.416	153,5	2,8%
Emilia-Romagna	22.452	10.252,5	45,7%
Toscana	22.987	2.790,8	12,1%
Umbria	8.464	336,7	4,0%
Marche	9.401	241,0	2,6%
Lazio	17.232	572,3	3,3%
Abruzzo	10.831	149,9	1,4%
Molise	4.460	139,4	3,1%
Campania	13.671	699,6	5,1%
Puglia	19.541	884,5	4,5%
Basilicata	10.073	276,7	2,7%
Calabria	15.222	576,7	3,8%
Sicilia	25.832	353,0	1,4%
Sardegna	24.100	857,3	3,6%
Totale Italia	**302.066**	**25.398**	**8,4%**

Tab. 4.3 - Medium flood hazard zones.

From the comparison between the national mosaic 2017 and that of 2015, an increase of 1.5% of the surface with high hydraulic hazard P3, of 4% of the surface with average danger P2 and of 2.5% of the surface with low hazard P1 emerges .
The increases are linked to the integration of the mapping in previously unexplored territories (eg minor hydrographic network), to the updating of the hydraulic modeling studies and to the perimeter of recent flood events. The most significant increases in the area classified as medium hazardous have concerned the Sardegna region, the Po basin in the Lombardia region, the Marche basins, the Tevere basin in the Lazio region, the Arno basin and the tuscan regional ones, the basins of the Puglia.
In summary we provide the overall picture of landslide hazard areas (very high P4, high P3, medium P2, moderate P1 and AA attention areas) and areas with hydraulic hazard (high P3, medium P2 and low P1) for entire national territory.

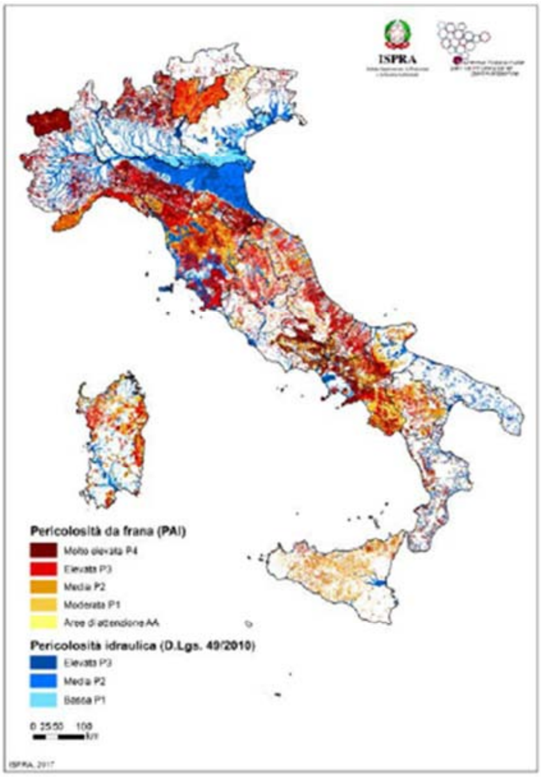


Fig. 4.3 - National mosaics of landslide hazard zones and flood hazard zones.

The municipalities affected by landslide hazard zones (high and very high hazard) and/or flood hazard zones (medium probability scenario, return period of 100-200 years) are **7,275** equal to 91.1% of Italian municipalities. The area classified as high and very high landslide hazard and/or medium flood hazard in Italy amounted to **50,117** km^2, equal to 16.6% of the national territory.

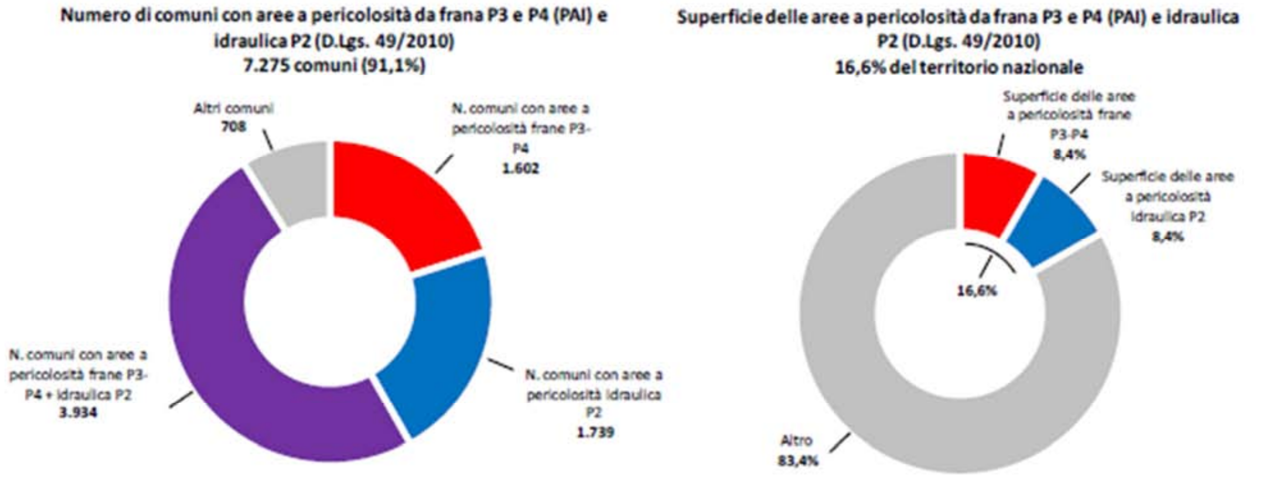


Fig. 4.4 - Number of municipalities and area of high and very high landslide hazard zones and/or medium.

With regard to risk indicators, they represent a useful tool to support risk mitigation policies.

In Europe, the indicators have been selected for the evaluation of the effectiveness of the Structural Fund measures 2014-2020.

The indicators "Population at risk landslides" and "Population at risk of floods" were carried out as part of the multi-year project "Environmental statistics for cohesion policies 2014-2020", launched in 2018 as part of the 2014 PON Governance and Institutional Capacity - 2020.

EXPOSURE OF THE POPULATION TO LANDSLIDE RISK

The population exposed at the landslide risk in Italy, residing in high (H3) and very high (H4) PAI areas, amounts to 1,281,970 inhabitants, equal to 2.2% of the total (Italian resident population: 59,433,744 inhabitants, ISTAT 2011 census).

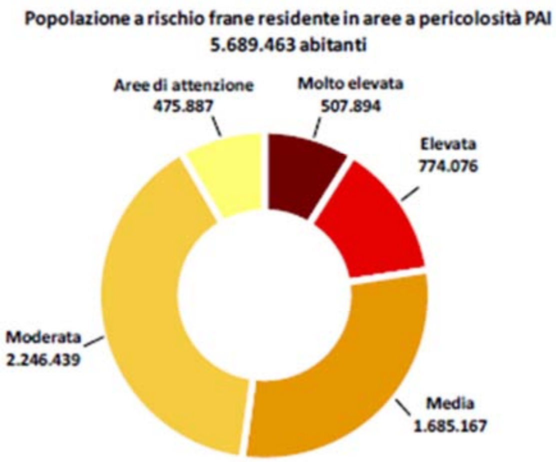


Fig. 4.5a - Population exposed to landslide risk in Italy.

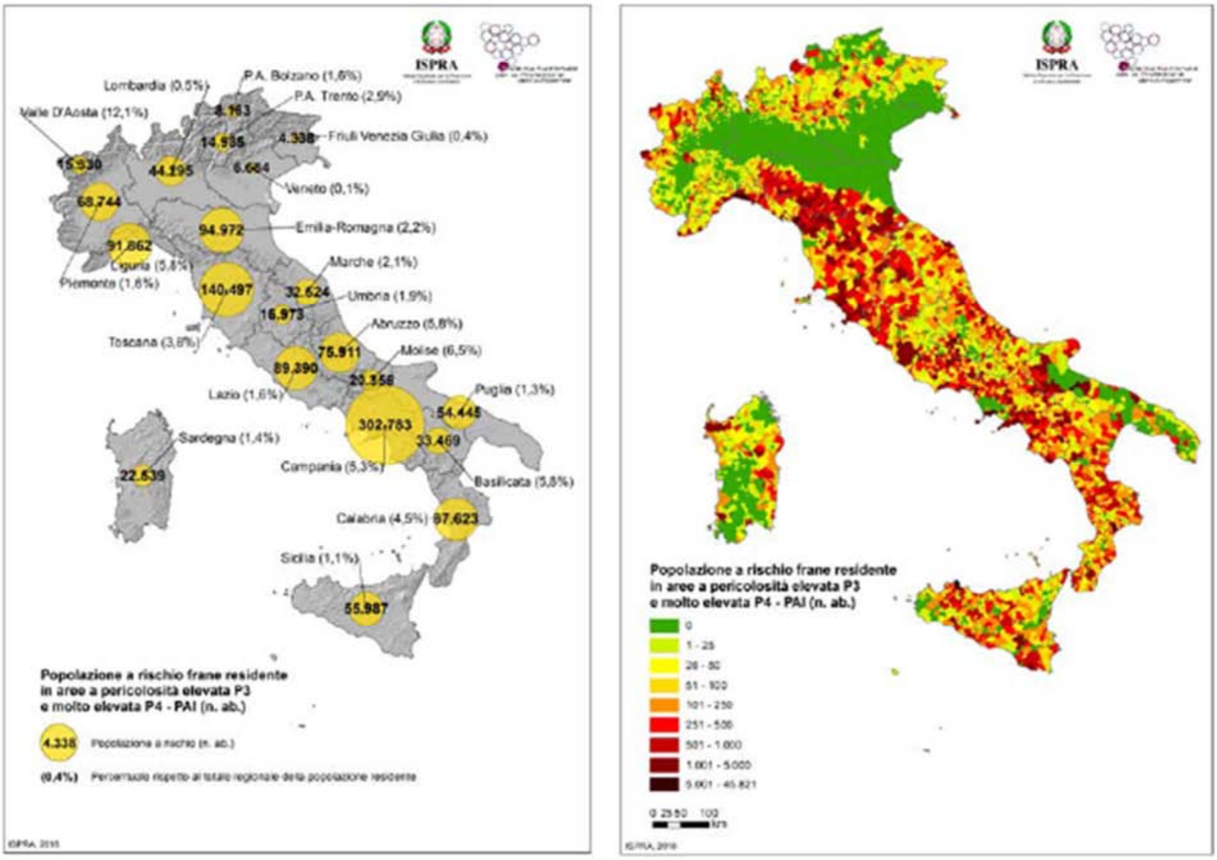
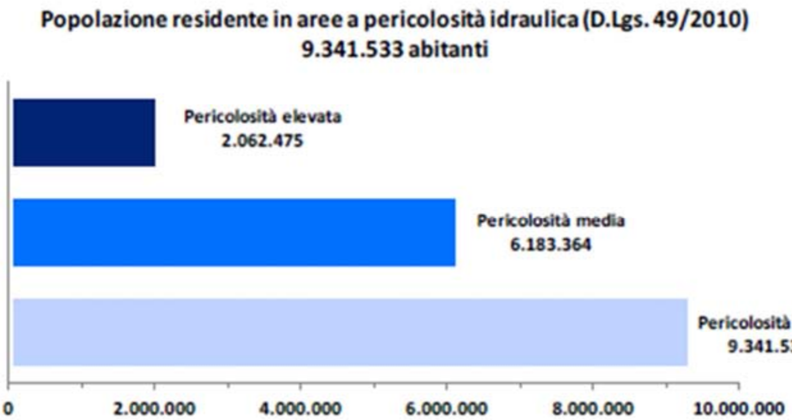


Fig. 4.6b - Population exposed to landslide risk in Italy.

Campania, Toscana, Emilia-Romagna and Liguria Regions have the highest values of population at risk living in H3 and H4 landslide hazard zones. The increase of 4.7% in population at risk compared to 2015 data is due to the integration/revision of the hazard zoning maps by the River Basin District Authorities

EXPOSURE OF THE POPULATION TO FLOOD RISK

The resident population exposed to flood risk in Italy is: 2.062.475 inhabitants (3.5%) in the scenario of high hydraulic danger P3 (return time between 20 and 50 years); 6.183.364 inhabitants (10.4%) in the scenario of average danger P2 (return time between 100 and 200 years) and 9.341.533 inhabitants (15.7%) in the scenario P111 (low probability of floods or extreme events scenarios).



Tab. 4.4 - Population exposed to flood risk in Italy.

The regions with the highest population levels at risk of flooding in the medium hydraulic hazard scenario are Emilia-Romagna, Tuscany, Veneto, Lombardy and Liguria.

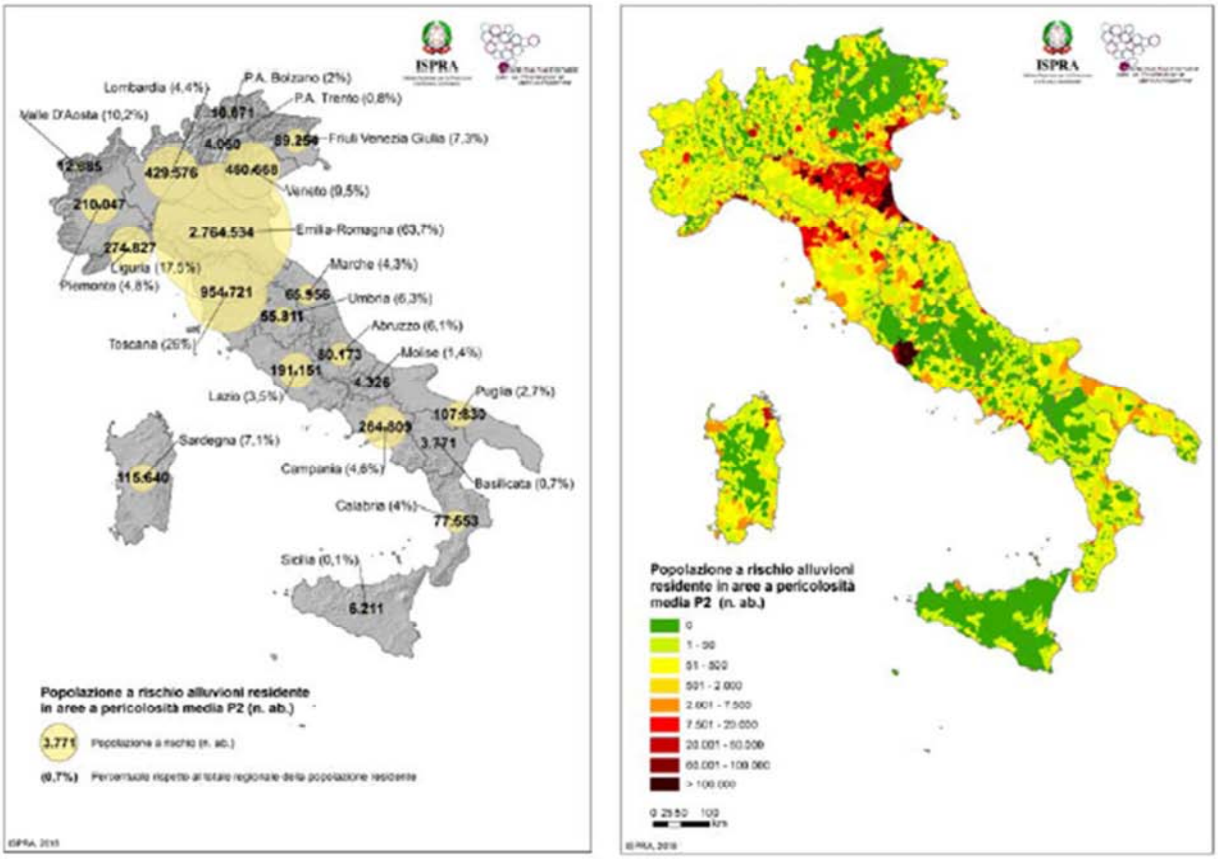


Fig. 4.7 - Population at risk living in medium flood hazard zones on regional and municipal basis.

PON GOVERNANCE

The synthetic data provided previously do not fully photograph the situation of hydraulic and hydrogeological hazards present in the Italian territory.
In fact the perimetrations of the danger contained in the Hydrogeological Plans (PAI), drawn up by the former Basin Authorities pursuant to Law no. 267 of 1998, and in the Alluvial Risk Management Plans (PGRA), drawn up by the district basin authorities pursuant to Directive 2007/60 / EC, do not include all the alluvial and hydrogeological phenomena that may occur within a municipal territory . In these perimeters no phenomena are considered such as, for example, floods connected to the minor river network or with stretches of water courses, floods with a return time of less than 30 years, uncensored landslides, which, also based on historical information on the calamitous events of the past, they can create serious damages to the territory with consequences also on the safety of people.
The Civil Protection Department is currently implementing the "Program to support the strengthening of Governance in terms of risk reduction for civil protection", as part of the achievement of the objectives set by the PON Governance and institutional capacity 2014-2020.
As part of this Program are being developed and tested in five Italian regions (Calabria, Campania, Puglia, Sicily and Basilicata), with the collaboration of local authorities, methods for assessing and perimetrating the hazard for hydraulic and hydrogeological phenomena that by type o return times are not included in the PAI and the PGRA.
The Program in question is the object of the agreement stipulated on 28 June 2016 between the CPD and the Territorial Cohesion Agency and falls within the Specific Objective 3.1 of the PON Governance, in particular in Action 3.1.1 of Axis 3, with a five-year duration. The objective to be achieved is to improve strategies for the reduction of hydrogeological, hydraulic, seismic and volcanic risks for civil protection

purposes, strengthening Governance, cooperation between the different levels of government, territorial capacities and skills.

GENERAL OVERVIEW: THE FLOODS DIRECTIVE AND THE CATALOG OF FLOOD EVENTS

The Directive 2007/60 / EC, *Floods Directive* - FD, implemented in Italy with Legislative Decree 49/2010, has the purpose of establishing a reference framework for the assessment and management of flood risks. The main purpose of this Directive is the reduction of potential negative consequences on: human health, environment, cultural heritage and economic activities.

The Directive provides for a series of implementation phases that lead to the drafting of the Flood Risk Management Plan (PGRA). This path takes place within a management cycle that is renewed through an iterative process with a periodicity of 6 years.

In each management cycle, the following products corresponding to the different stages of subsequent implementation are envisaged at the Hydrographic District or Management Unit level: preliminary assessment of flood risk (art.4), areas with potential significant risk of floods (art. 5), flood hazard and flood risk maps (art. 6) and, at last, flood risk management plans (art. 7). Compared to each of these products, the fulfillment of the FD requires that a series of information structured according to specific formats and schemes (*schema*) be sent or "*reported*" to the European Commission (EC) within 3 months from the deadlines indicated in fig. 2.1.

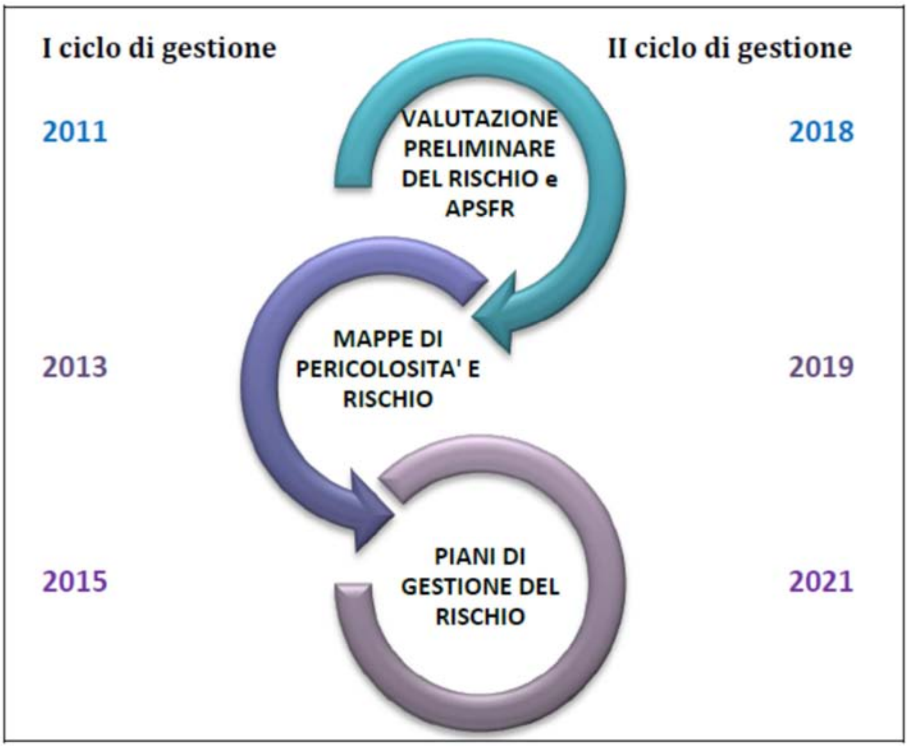


Fig. 4.7 – Implementation phases of the Floods Directive and deadlines for the first and second management cycles.

The activities related to the first management cycle were completed with the sending to the EC, in March 2016, of the information required for the *reporting* of the Flood Risk Management Plans (PGRA), the activities necessary for the revision/updating of the FD's compliance with the second management cycle were started, starting from the Preliminary Flood Risk Assessment - PFRA assessment.
In the first management cycle Italy had made use of the transitional measures referred to in art. 13.1.b of the FD choosing therefore not to carry out the PFRA, but to proceed directly to the drafting of the maps

of danger and flood risk (art.6). Starting from the second cycle, it is necessary to prepare the PFRA and identify the areas of potential significant risk (Areas of Potential Significant Flood Risk - APSFR), the results of which must be reported to the European Commission (reporting activity) within March 22, 2019 according to the methods and formats adopted by the EC in accordance with art. 12.2 of the FD.
In order to support the PFRA, which has the purpose of identifying areas for which there is a significant potential risk of floods or is likely to be generated, the FloodCat flood events catalog (Flood Catalog) was conceived. Web-GIS platform , carried out by the DPC to allow the systematic collection of information on past flood events in accordance with articles 4.2 (b) and 4.2 (c) of the FD. The DPC, in fact, in compliance with the provisions of point 8 of the Dir.P.C.M. 24 February 2015, containing the operational guidelines regarding the preparation of the part of the management plans relating to the national, state and regional warning system, for the hydraulic risk for civil protection purposes pursuant to Legislative Decree 49/2010 for the fulfillment of the FD, has made and made available to Regions, Autonomous Provinces and District Basin Authorities, the FloodCat platform, not only for the purpose of cataloging information on flood events in a unitary and homogeneous manner at national level but also to be able to reuse this data, for the purposes of reporting for the PFRA, by simple export.
The structure of the FloodCat database was defined in collaboration with ISPRA in a manner compliant with the provisions of the document "Technical support in relation to the implementation of the Floods Directive (2007/60 / CE) - A user guide to the floods reporting schemas" and Guidance Document No. 29 of the European Commission (EC) in 2013. Subsequent adjustments were made in the light of: the observations deriving from the testing phase; changes to the plans introduced starting from 2017 (FD - Reporting Guidance and Spatial Data Reporting Guidance); of the indications contained in the "NOTES for reporting art. 4 and 5 of Dir. 2007/60 / EC: Preliminary Assessment of the Flood Risks and identification of the Potential Areas of Potential Flood Risk ", drafted by ISPRA. However, taking into account the needs of the country and the characteristics of some databases already available at national and regional level, various additions have been made to the data structure defined in the "reporting to the EC", which allow to preserve the remarkable amount of additional information available. The use of the platform has found a good consensus among the Italian Competent Authorities defined under the FD, and the uploaded situation, which is underlined to be still "in progress", can be summarized as shown in the following Figure 4.8.

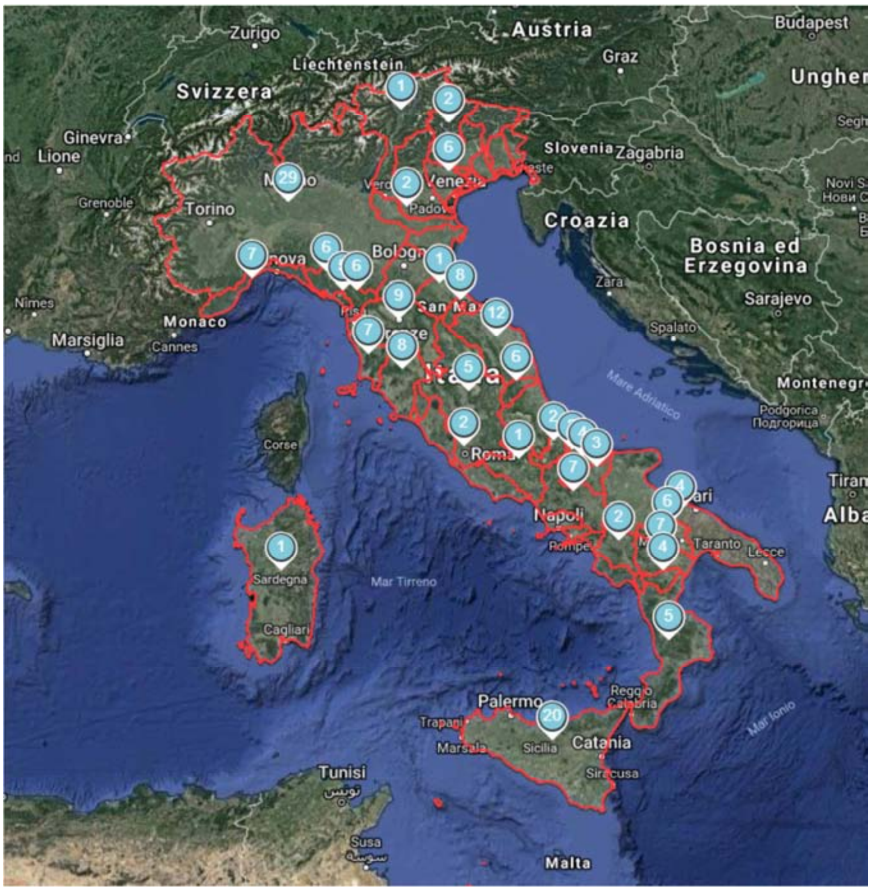


Fig. 4.8 – Past floods data available in the FloodCat platform.

The picture shows the situation, aggregated by Unit of Management, of past floods data available in the FloodCat platform. The update is mid-December 2018. The localized markers report the number of events published per single Unit Of Management. Currently, a total of 190 past floods have been published in the time window between 22/12/2011 and 17/12/2018. These past floods include both the main flood events under the FD for which a national state of emergency has been declared, and events managed only at the local level in which human losses have occurred.

AN INNOVATIVE APPROACH TO A TRANSPARENT AND TECHNICALLY BASED RESOURCE ALLOCATION.

The optimization of the reduction of hydrogeological risk in relation to available financial resources, systematically insufficient, constitutes a technical challenge of fundamental importance, as well as the indispensable prerequisite for rigorously tackling the need for transparency of choices towards the various stakeholders involved.

With this objective, since 2014, our country has started a regulatory, technological and procedural path that has made it possible to systematize and make particularly efficient not only the system for requesting funds to combat hydrogeological instability by all Local Authorities. titled, but also the procedure for selecting interventions to be implemented with funds that become progressively available, with transparent, homogeneous and fair criteria and parameters with respect to the entire audience of requesting subjects.

The process focuses on the preparation of a specific regulatory provision, the Prime Ministerial Decree of 28 May 2015, which identifies the criteria and procedures for establishing the priorities for allocating resources to actions to mitigate the hydrogeological risk, also through the allocation of different weights on different categories of factors that contribute to defining the levels of danger and exposure on which the projects are to take action, then integrated by the development of a specific technological tool engineered on the basis of the criteria and system of weights identified by the provision, which are the result of an intense and effective comparison between the technical structures of the State and those of the Regions and Autonomous Provinces.

This technological tool, called ReNDiS - National Repository of Land Defense Interventions - is a data management system, on a web-GIS platform, created with the aim of providing, to the Administrations involved in the planning and implementation of the interventions, a framework constantly updated and shared of the planned works and resources committed for the mitigation of the hydrogeological risk. In this sense, the ReNDiS has undoubtedly established itself as a fundamental support to improve the coordination and, therefore, the optimization of national land defense expenditure, as well as to promote transparency and citizens' access to information.

Through the navigation interface ReNDiS-web (www.rendis.isprambiente.it) the main data of the interventions recorded in the system are freely available, even in geographical context.

The bodies and administrations involved in each of the mitigation projects, after registration and authentication, have access to the complete set of information relating to the interventions under their responsibility and have a series of functionalities that allow consultation and updating in real time. both information on the state of implementation of the interventions as well as administrative or project documents.

The number of communications (transmission of data or documents) sent via ReNDiS-web is constantly growing: over the past five years more than 60,000 have been acquired and as of November 2018 there are almost 1,600 registered users, distributed among more than 1,000 different Administrations. With regard to access to the web platform in general, more than 23,000 user sessions were recorded in the first 10 months of 2018.

The main core of the information on which the structure of the data base is focused is the interventions financed in different ways by the Ministry for the Environment and for the Protection of the Territory and the Sea from 1999 to today. At present, there are 5,227 interventions (financed with 5,605 million euros) for which the database allows to manage information on the state of implementation, type of works and failures, geographical position, economic and financial frameworks, documentation of inspections, reports, project drawings, documentation of inspections, etc.
The Repertory was then supplemented by an "Investigation Area" that allows the acquisition and online management of project proposals for the financing of new national programming interventions. Access to the Investigation Area is currently reserved only for users of the Regions and Autonomous Provinces (and only for the respective competences) in accordance with the aforementioned D.P.C.M. May 28, 2015.
Thanks to the automatic processing functions, integrated into the platform, the summary of the proposed interventions is available in real time and, at the same time, the whole process of analysis and evaluation of the projects can be managed in clear, efficient, shared and verifiable ways. Overall, net of amendments and cancellations, the fact sheets uploaded and validated at the end of November 2018 (Tab. 4.5) are 8,800, for a total requirement of about 26.4 billion euro, of which 457 have been hitherto been instructed and financed for the execution of the works, while 147 are being designed; about 8200 of the interventions requested by the bodies entitled to do so, do not currently have any financial coverage.

tipo dissesto	Idraulico	Costiero	Frana	Misto	Non definito	Valanga	Totale
INTERVENTI GIA' FINANZIATI							
Importo	€ 791.953.327	€ 29.256.873	€ 153.713.040	€ 75.791.568		€ 2.785.000	€ 1.053.499.808
Numero interventi	181	29	234	10		3	457
INTERVENTI IN FASE DI PROGETTAZIONE							
Importo	€ 875.981.197	€ 52.990.384	€ 183.847.048	€ 51.295.061			€ 1.164.113.689
Numero interventi	74	8	57	8			147
INTERVENTI NON FINANZIATI							
Importo	€ 12.790.586.831	€ 1.010.929.407	€ 6.684.795.309	€ 2.523.369.783	€ 95.038.729	€ 114.900.703	€ 23.219.620.762
Numero interventi	3049	174	4433	472	41	27	8196
Importi totali	**€ 14.458.521.355**	**€ 1.093.176.663**	**€ 7.022.355.397**	**€ 2.650.456.412**	**€ 95.038.729**	**€ 117.685.703**	**€ 25.437.234.259**
Numero interventi totali	**3304**	**211**	**4724**	**490**	**41**	**30**	**8800**

Tab. 4.5 - ReNDiS-web, example of summary of the proposed interventions available in real time.

THE EXPERIMENTATION ON LARGE AREA OF A MULTI-RISK GOVERNANCE MODEL. THE RESTART PROJECT, COORDINATED BY THE DISTRICT AUTHORITY OF THE CENTRAL APENNINES IN THE AREA HIT BY THE 2016 EARTHQUAKE

Last October 1, after an intense phase of project work and consultation with the Territorial Cohesion Agency, the activities of the ReSTART project - Territorial Resilience of the Central Appennine Reconstruction of the Earthquake were started, and the completion of the works is scheduled for 31 October 2021.

The project, financed with 7.5 M € under the National Operational Program Governance and Institutional Capacity, is designed taking into account plausible scenarios of climate change and is strongly characterized on a multi-risk approach. The general objectives are 3:

1) Post-earthquake reconstruction in hydrogeological safety conditions from previous phenomena and seismic-induced phenomena;

2) Adaptation of the water supply system to the new risk conditions induced by seismic events and climate change in progress;

3) Implementation of a pilot model of governance for the continuous and constant updating of the cognitive framework of risk phenomena.

The actions directly affect the territories of 4 regions of central and northern Italy affected by the 2016 earthquake and one of the results defined with the Territorial Cohesion Agency concerns the development of a model of institutional relations that involves the collaboration of the stakeholders public and private sectors for the definition of post-earthquake reconstruction processes in the more general system of actions aimed at guaranteeing hydro-geological safety and sustainable management of water resources.

Because of the complexity and close interconnection of the issues to be addressed, as well as the need to ensure a prompt operability of the flows of actions defined by the multi-risk model at the occurrence of future events, including in other sectors of the national territory, the institutional structure involved sees the direct participation of the following institutional actors:

- Marche Region
- Umbria Region
- Abruzzo Region
- Lazio Region
- Civil Protection Department
- Ministry for Environment, Land and Sea Protection
- Ministry of Infrastructure and Transport
- Ministry of Agricultural, Food and Forestry Policies and Tourism
- Italian Institute for Environmental Protection and Research (ISPRA)
- Structure of the Post-Earthquake 2016 Reconstruction Commissioner

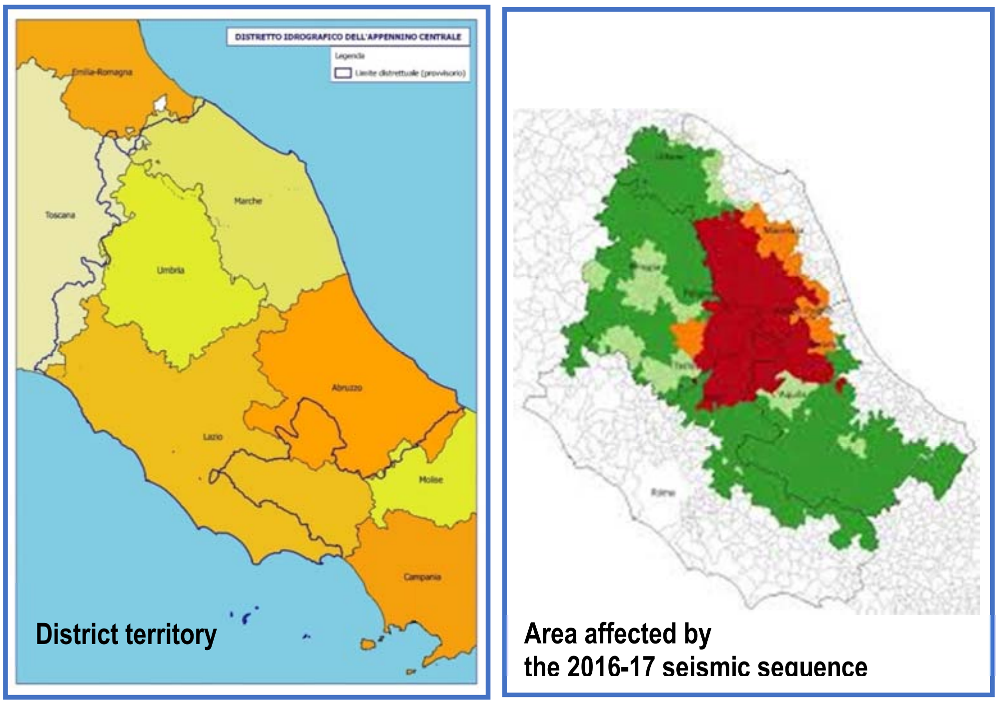


Fig. 4.9 – Study area of the ReSTART Project.

ANALYSIS OF THE EVENT REPORTS ATTACHED TO THE REQUESTS OF THE STATE OF EMERGENCY IN THE PERIOD OCTOBER 2012-OCTOBER 2018: STATISTICS OF FORCING AND OF THE INDUCED PHENOMENOLOGIES. (RESINA PROJECT)

The current national protection legislation provides that following natural or man-made events whose effects are such as to cause consequences attributable to those defined in art. 7, art. 1, paragraph c) of Legislative Decree 1/2018, the President of the Region concerned can submit to the President of the Council of Ministers the request for a state of emergency.
This procedure provides that the applicant Region produces a technical report of the event that has affected the entire regional territory, or part of it, aimed at providing the information necessary to understand the intensity and extent of the phenomena occurred and their direct consequences.
To better outline the natural dynamics that have determined emergency situations of national rank during the last 7 years (period in which the available data are sufficiently reliable, complete and standardized), 61 technical reports attached to the state request have been analyzed in detail of emergency received by the Department in the period 2012-2018: in first analysis the objective concerned the development of statistics on the causes, intended as forcing, and the consequent phenomena observed on the ground.
In particular, all forcing has been extrapolated from every technical report (on average, in each event report about 2 forcing are identified) and the phenomena caused by them, which have determined a serious impact on the ground that justify a request for state of emergency: compared to 61 reports, the sum of the forcing amounts to 133, while for the connected phenomena it corresponds to 187.
Subsequently, the percentage frequency was calculated for each forcing (Fig.4.10) and for each connected phenomenon (Fig. 4.11).

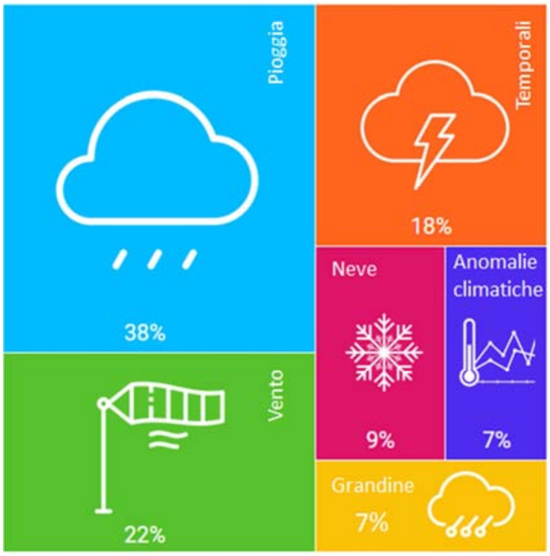


Fig. 4.10 - Percent frequency of forcing.

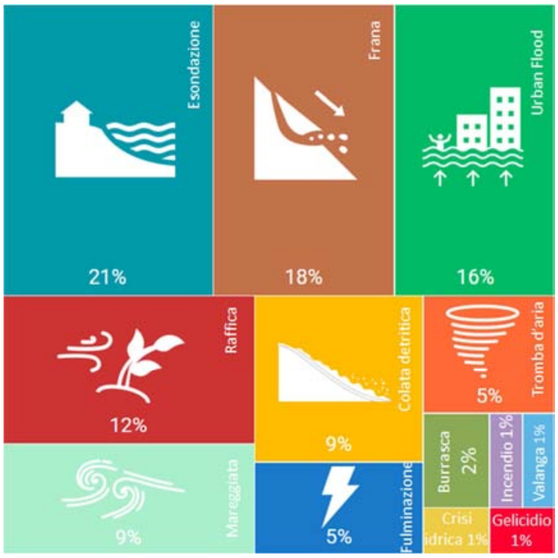


Fig. 4.11 - Percentage frequency of connected phenomena.

THE RIVER PO SCENARIO

Focusing our attention on risk assessment at a national level, it's important to take into account also scenarios which are of sufficient severity to entail involvement by national governments in the response. That could be the case of a severe event involving the Po catchment (Figure 4.12).

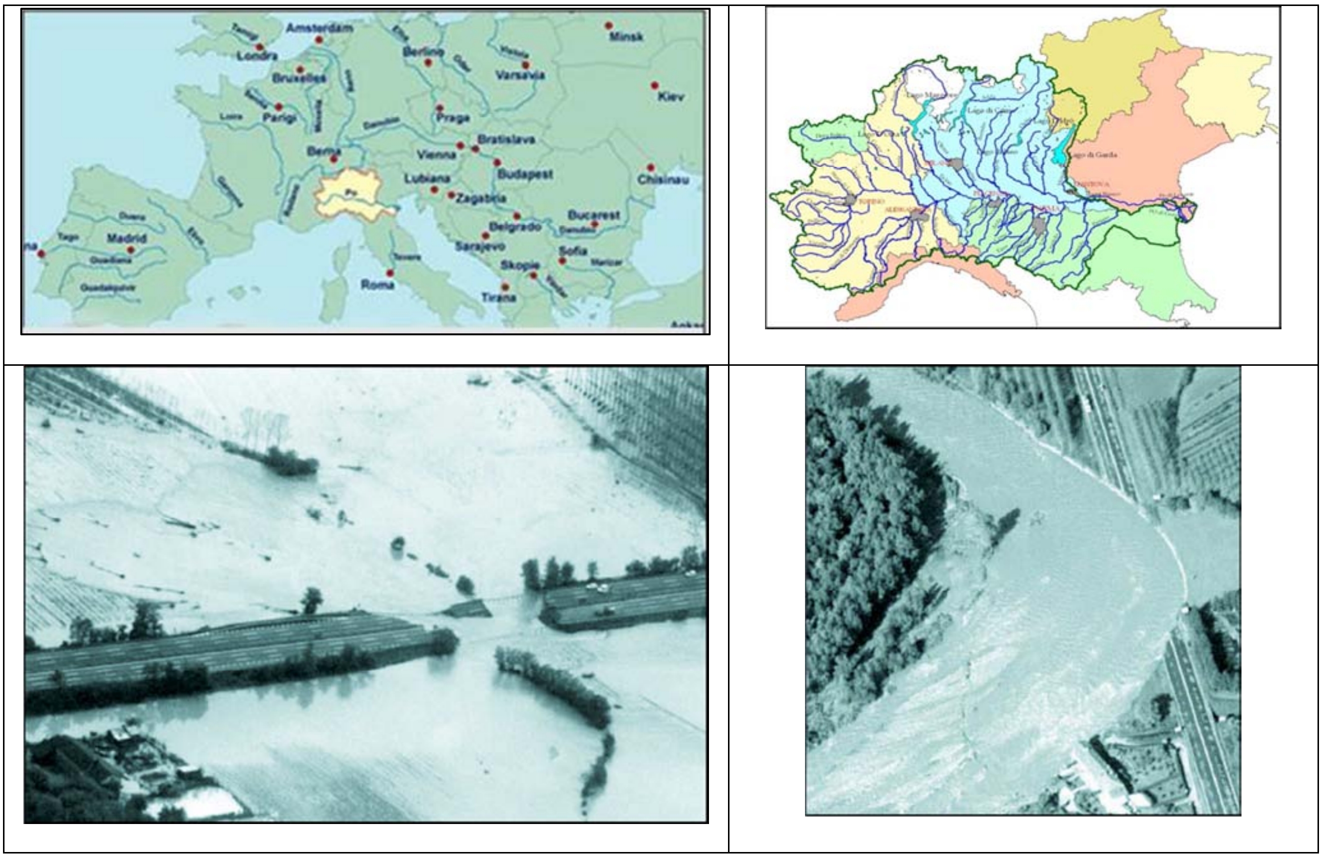


Fig. 4.12 – River Po basin and flooding events.

An important data to underline is that the single most destructive flooding event in Italy occurred along the Po river in 1705: in this event the total number of casualties remains uncertain, but up to 15000 people were killed, were missing, or were injured at multiple sites by extensive flooding (Salvati P. et al, 2010).

The Po basin, the larger one of the country and the only trans-national one, involves nearly both of the regions of the northern part of Italy. It's important to underline that it is the first Italian basin included in the EFAS (European Flood Alert System) model. Its scenario is characterized by the highest number of people involved and the most part of the economic resources of the country involved.

Dealing with the Po basin no-real time risk assessment, it's important to underline some among the most important activities by the river Po district basin authority.

- ✓ The river Po district basin authority has analyzed the most important past flood events in terms of: rain, discharge, flooded areas, return periods, damages, etc;
- ✓ The river Po district basin authority has analyzed levees break scenarios in some of the most critical points all along the river. Hazard and risk maps are the main outcomes of these analysis (Figure 4.13);
- ✓ The river Po district basin authority approved the flood risk management plan in 2015, into account what the 2007/60/CE – flood directive - prescribes. In the following years is reviewing the maps and the hydro-geological asset plan. The objective is to acquire observations and proposals for improvement on the organization of consultation activities and the active participation of interested Administrations.

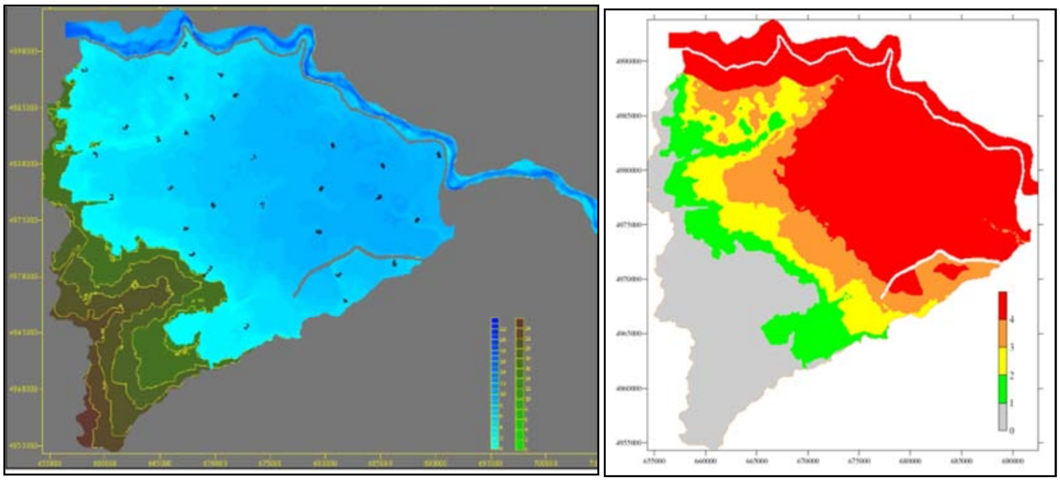


Fig. 4.13 – An example of levees break analysis (source: River Po District Basin Authority, 2005).

Dealing with the Po basin real time risk assessment it's important to underline that Italy, which was already at a good point, is now reaching a very important goal: the Civil Protection Department, according with all Italian Regions, has created a Command and Control Unit to ensure an unitary response in real time in case of an event involving more than one Region or all the catchment.

In a Directive of the President of the Council of Ministers (which is about to be signed), all the responsibilities of each competent authority are clearly defined. One of the most important point that this directive defines is the coordination between no-real time authorities and real time authorities, as a necessary instrument to face events.

Moreover, the Department of Civil Protection and all the regions have recognized an unique hydrological-hydraulic model at a large scale as a reference for the whole basin, whose name is "FEWS PO" (Figure 4.14 and Table 4.6). In addition to this, each region can use regional models to elaborate scenarios at a more detailed scale on its territory of jurisdiction.

Last, the Department of Civil Protection and all the regions have defined a single flood-warning bulletin at a catchment scale in which there are the forecasts of the water level and the related alerts for the most significant sections all along the river Po.

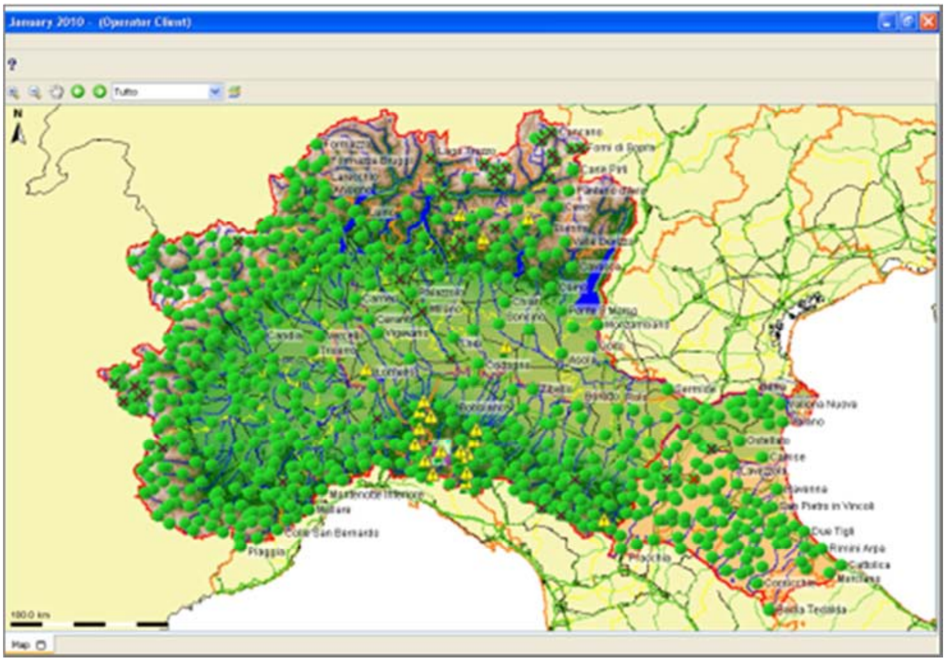
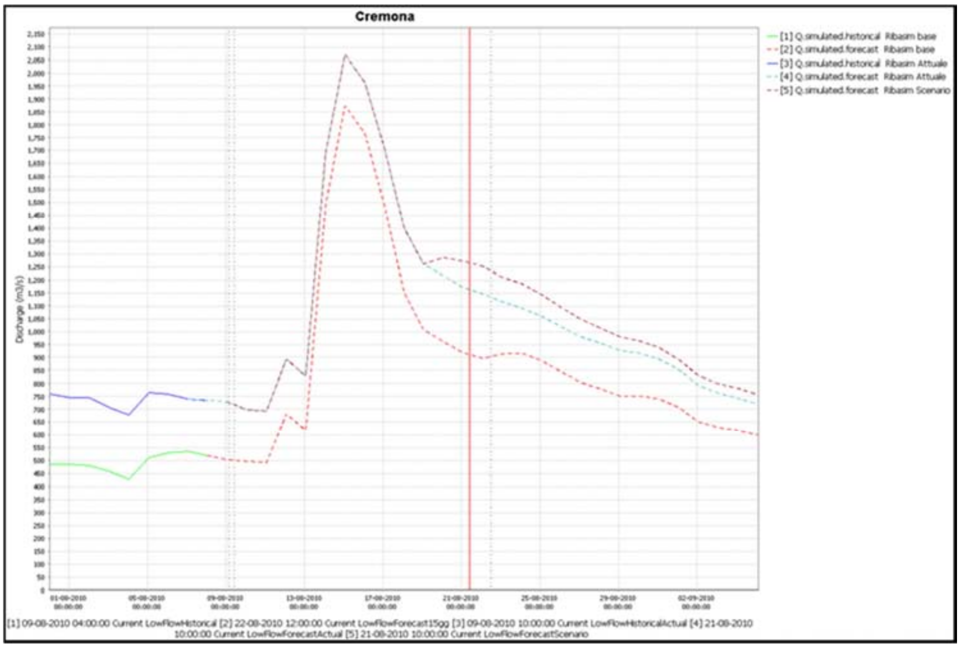


Fig. 4.14 – FEWS model: rain gauges and river gauges used by the forecast model (source: ARPA SIM, 2011).



Tab. 4.6 - FEWS model: rain gauges and river gauges used by the forecast model (source: ARPA SIM, 2011).

MONITORING ACTIVITIES OF THE HYDROGEOLOGICAL RISK OF THE TERRITORY OF THE TUSCANY REGION THROUGH RADAR IMAGES

As part of a program agreement signed between the Civil Protection Department, the Tuscany Region and the Department of Earth Sciences of the University of Florence (DST - UNIFI) for monitoring activities for hydrogeological risk in the territory of Tuscany, continuous monitoring is being carried out the deformation of the terrain of the Tuscan regional territory through satellite radar interferometry. Satellite radar interferometry is based on the analysis of long series of SAR images (Synthetic Aperture Radar) acquired from satellite platform on the same area at different times, so as to allow non-invasive and high-precision measurements of the displacements of soil and artefacts . The products obtained under this Agreement have already reached an operational level and are accessible thanks to the implementation by the Tuscany Region of a WebGIS portal in which it is possible to view the data deriving from monitoring via satellite interferometric radar data.
Satellite SAR interferometry represents the most advanced instrument for measuring surface displacements and allows the identification, mapping and analysis, also through time series of movements, of those areas affected by deformations induced by failure phenomena hydrogeological as landslides and subsidence induced by pumping of the water resource or connected to the exploitation of the geothermal resource. Although this methodology does not allow the interception of sudden and imminent phenomena, it nevertheless allows a continuous monitoring of possible displacements and deformations which, lasting over time, can be precursors and cause possible critical issues on the territory and on regional infrastructures.
The recent launch of ESA's Sentinel-1 constellation satellites (European Space Agency) has opened new opportunities for monitoring the Earth's surface and for assessing risk scenarios related to soil movements. The Sentinel-1 mission, designed as part of the European project Copernicus, consists of a constellation of two satellites (Sentinel-1A and Sentinel-1B). The Sentinel-1A satellite was launched on 3 April 2014, Sentinel-1B on 25 April 2016. Both satellites are equipped with SAR sensors in C-band (wavelength of about 5.6 cm) and have 12-day review times . The presence in orbit of the two twin satellites has allowed to reduce the review time to 6 days. This mission operates in such a way as to acquire consistent archives of images suitable for long-term monitoring programs and ensures a continuous flow of satellite radar data acquired on a regular basis over large areas of the planet and in particular on Italy. The Sentinel-1 satellite constellation is designed to provide up-to-date information, in continuity with data from previous ERS 1/2 and ENVISAT missions, but with a noticeable improvement in information, especially in terms of reliability, usability and timeliness of delivery. of the data themselves. This satellite constellation is the best operative choice for medium-resolution terrain deformation study and monitoring with regional scale coverage.
The general objective of the Agreement's activity concerns the continuous geomorphological monitoring of the deformation scenario of the territory of the Tuscany Region through satellite interferometric radar data. This monitoring approach is aimed at updating in a dynamic and continuous way the knowledge framework of the regional territory for the hydrogeological and geomorphological risk, and to promptly detect critical situations based on the identification of anomalies.
The availability of data on the whole territory of the Tuscany Region and the rapid and systematic acquisition program allow today to carry out continuous, specific and constantly updated analyzes of the deformations in progress.
Considering the precision of the measurements and the spatial and temporal coverage, the most significant fields of application are:

✓ Identification and mapping of subsidence areas: urban areas, frequently affected by both local and local subsidence, are ideal environments for the use of interferometric data. In fact, the slow vertical movements linked to the lowering of the ground and the high density of buildings and man-made artifacts make subsidence in urban areas the best scenario for an interferometric analysis;

✓ Detection and mapping of landslides: this activity is only possible if the landslide object of analysis presents reflectors inside it. Moreover, not all landslide types can be monitored: only slow kinematic landslides (very slow and extremely slow landslides according to the Cruden & Varnes classification, 1996) can be effectively measured. Fast (or even instantaneous) movements related to types such as rapid collapse or collapse can in no way be identified and measured;

✓ Large-scale mapping of deformation areas: thanks to the high amount of information provided on a regional scale, interferometric data are optimal for the large-scale identification of deformation areas. Deformation maps, contained in the geoportal, constitute a "photograph" of the territory at a given date, allowing to quickly identify the areas with the greatest deformations;

Evaluation of the deformation trend over time: the time series, graphs representing the displacement recorded at the date of acquisition, are the last and most advanced product of the interferometric analysis. They allow us to retrace the deformative history of a point measured back in time.

The monitoring therefore allows to provide useful information for the formulation of a synoptic picture of the phenomena of soil deformation on the entire regional territory, to support the Regions, Municipalities and Territorial Entities involved in the activities for the defense of the territory and management of risks.

To this end, a database representative of the regional territory has been generated, containing the measurements of the movements of the ground obtained through satellite SAR (Synthetic Aperture Radar) interferometry and made accessible through the public Geo-portal of the LaMMA Consortium.

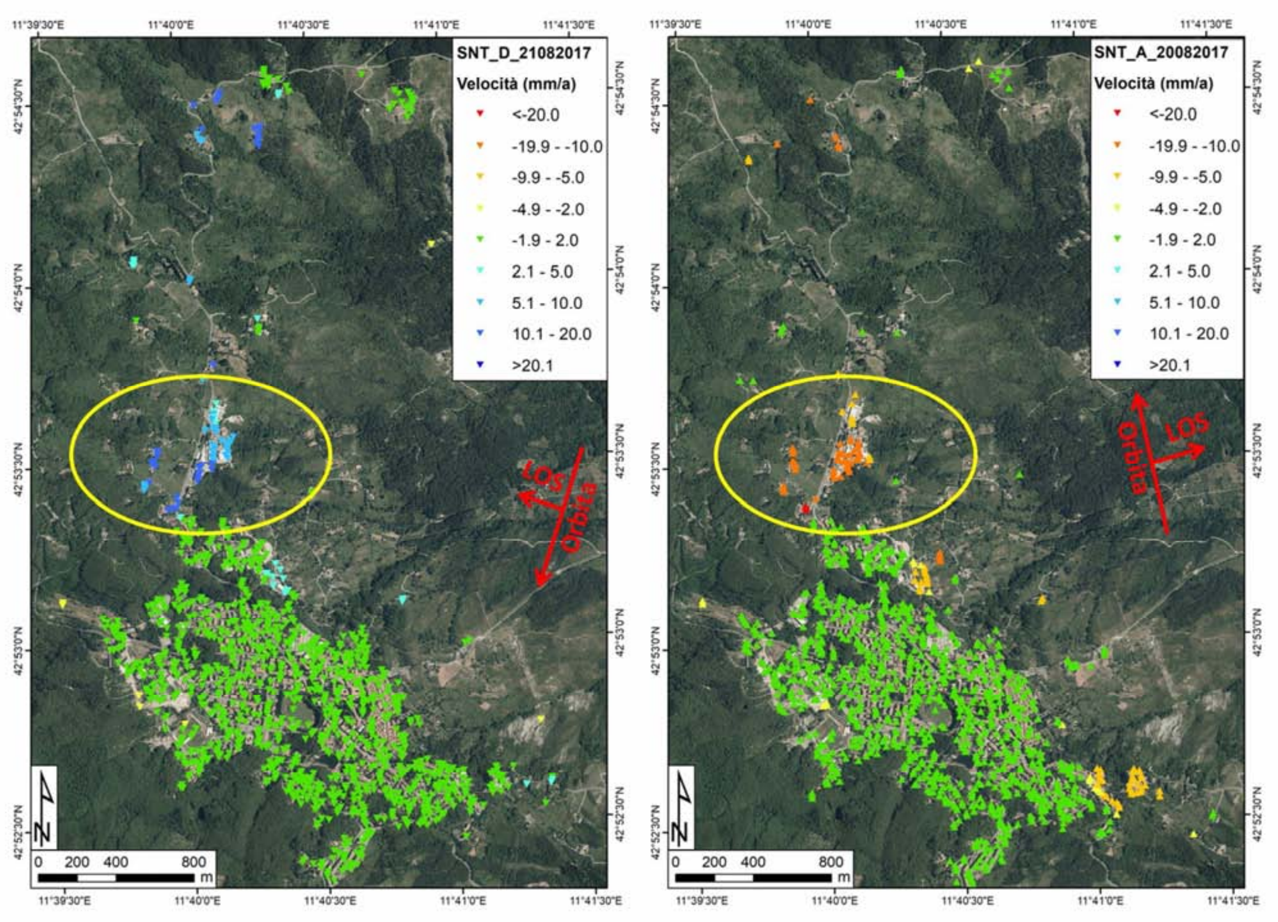


Fig. 4.15 – Example of subsidence. The velocities in both orbits have the same sign (negative, moving away from the sensor) and the same intensity.

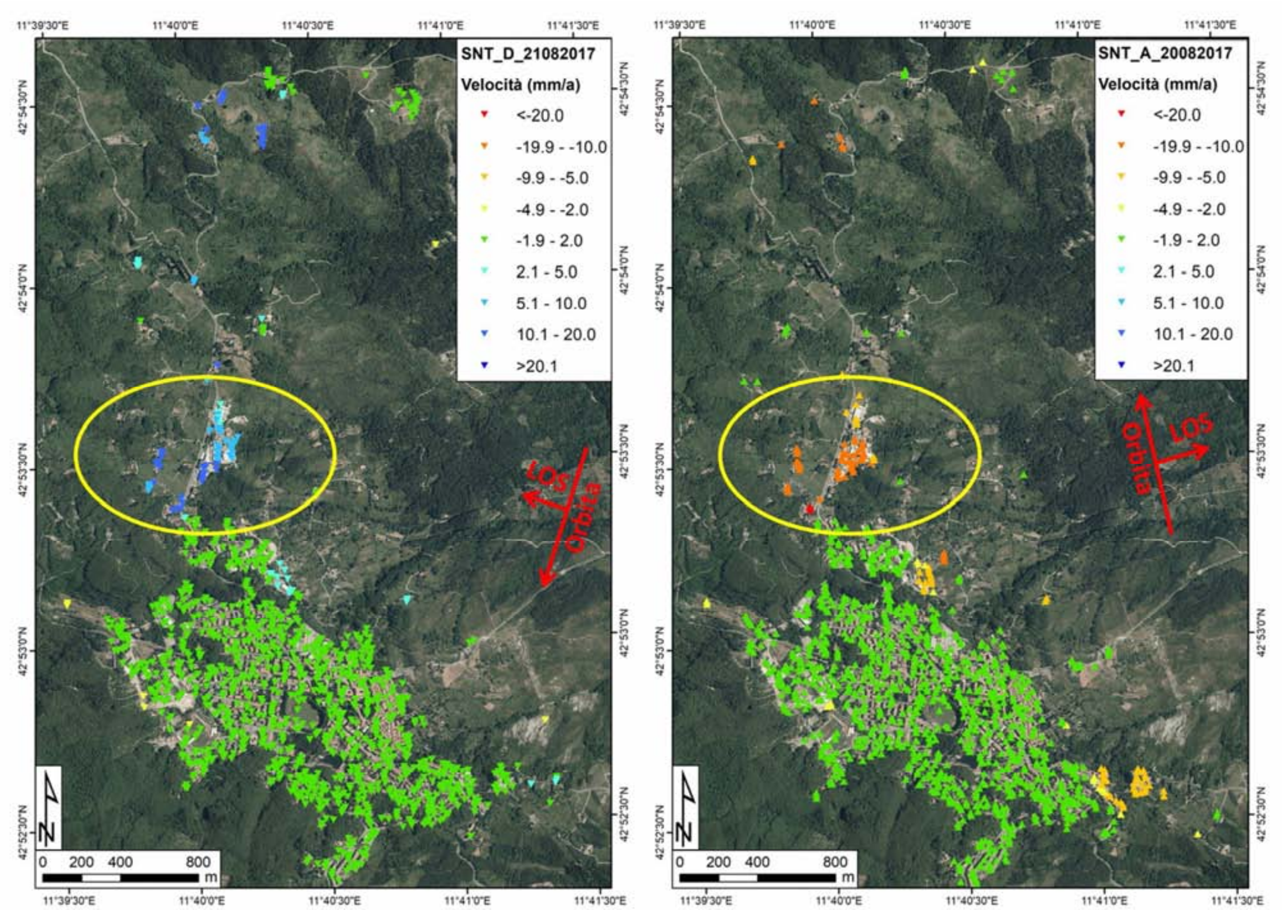


Fig. 4.16 – Example of landslide area (yellow ellipse). The speeds have opposite sign in the two orbits. Positive in downward orbit (left) and negative in upward orbit (right). The movement of the landslide is towards the East.

AVALANCHE RISK

Avalanches are gravitational phenomena that occur under some orographic and meteoclimatic conditions and involve snow masses, sometimes containing rocks, dirt, trees and ice.
The avalanche risk is the effect induced on the territory by such phenomena of snowpack instability and can affect several areas of permanent human activity, such as transport (roads, railways), constructions in general (built-up areas, pylons, etc.) or occasional (ski mountaineering activities and excursions in general).
In Italy for more than 40 years avalanche danger bulletins (in such bulletins is not considered anthropogenic exposure)are issued and drawn up by the Meteomont service (composed of the Alpine Troop Command and Carabinieri Forestali in collaboration with the Air Force Meteorological Service Military) and by the institutions belonging to AINEVA (Interregional Association for coordination and documentation for problems related to snow and avalanches. The issue of danger bulletins is diversified from region to region (from the total absence of emission, as in Sardinia, up to a redundancy of 3 avalanche danger bulletins in Veneto and Piemonte Regions).
The 27 February 2004 Directive "*Indirizzi operativi per la gestione organizzativa e funzionale del sistema di allertamento nazionale, statale e regionale per il rischio idrogeologico ed idraulico ai fini di protezione civile*" does not provide for the management of avalanche risk. Some Regions, especially in the Alps, but not only, after the implementation of the aforementioned Directive, through the Regional Directives, have included provisions and procedures that also include avalanche risk.

Consequently, about of the assessment of avalanche risk too, the situation is very uneven: Daily avalanche bulletins (Valle D'Aosta, Marche for example), warnings avalanches bulletins (Lombardia, Veneto, Marche, etc.) and civil protection prescriptions (Veneto, Lombardia, Emilia Romagna). This assessment is mainly determined by the danger levels present in the avalanche danger bulletins.
At national level, a Directive entitled "*Indirizzi operativi per la gestione organizzativa e funzionale del sistema di allertamento nazionale e regionale e per la pianificazione di protezione territoriale nell'ambito del rischio valanghe*" very similar to the one issued in 2004 is going to be approved and whose aim is to standardize the avalanche warning at national level both about alert and local planning too.
The cognitive tools available to store past avalanche phenomena and to plan are the inventory and monographic maps of the avalanches (by Carabinieri Forestali, Alpine Troop Command and Regions and Autonomous Provinces) which represent the basic tool for the documentation of avalanche events.
In addition to these a map of possible location of avalanches are available (commonly indicated with the initials CLPV): this one is a thematic map showing the avalanche sites identified either on site or on the basis of eyewitness and / or archival testimonies, or through analysis of the parameters that distinguish an area subject to the fall of avalanches, taken from the analysis of stereoscopic aerial photographs.
As for the bread-making tools, we find the Plans of the areas exposed to avalanches (commonly indicated with the abbreviation PZEV) which are true hazard maps in which areas with different degrees of potential exposure to avalanche danger are defined (generally defined as: high, moderate and low) prepared with the aid of simulation models of avalanche dynamics.

Fig. 4.17 – Avalanche at Rolle mountain pass.

Fig. 4.18 – Avalanche at Brocon mountain pass.

REAL TIME ACTIVITIES

The real time risk assessment activities in the framework of the National Early Warning System (hereinafter: EWS) for HydroMet risks are carried out by the distributed network of the Centers for Forecasting and Surveillance (Figure 12- one for each Italian Region) and the Civil Protection Department.
Functions, roles and responsibilities of each actor in the warning dissemination process are enforced through government policy or legislation at all levels.
The major aim of the real time risk assessment is to issue impact-based forecast and risk-based warnings and provide a 24/7 monitoring service increasing both preparedness and response levels of the emergency responders.
Other initiatives have been taken (Civil Protection Department guidelines on 2016) to push the harmonization of services, quality level, communication issues, among the Regions.
The early warning system is a key tool in the national risk reduction policy, both in the climate change adaptation strategy, and in the DRR strategy.
Key elements:

- a unique authority, the Civil Protection Department, is in charge for coordinating the network and the emergency response in case of a major emergency. A well-defined coordination mechanism is in place and defined by law.
- The EWS is science based: a national mechanism is in place to guarantee the interface between science community and civil protection authorities: a network of knowledge center is formally embedded into the EWS providing the Civil Protection with expert services or scientific advices.
- Emergency planning is fundamental at the local level and formally and functionally connected to the EWS.

- The active role of the citizens is a fundamental component of the EWS, stated in the new civil protection law. The importance of awareness raising and education has been also stressed and several improvements strategies, in alerting, awareness and education have been adopted: *I don't take risks* is a national communication campaign on best practices of civil protection. The introduction of civil protection matter in the school curricola, starting from the primary school is under discussion.
- Use of rapid information, big data and social media systems to establish situational awareness in the early warning and/or first response phase is under development, use of CAP-compliant warning messages is in place.

The use of IT platform to push the exchange of information among institutions, as well as to improve the access and sharing of international data (such as Copernicus services) has been successfully performed. The use of the decision support tool MyDewetra is operational in Italy since years. It also adopts the comprehensive framework of international policies and guidelines, data sharing initiatives and spatial data infrastructures with the purpose of gathering the knowledge for real time risk assessment and monitoring in both hydromet and decision makers perspective

The Key role of the EWS in the Risk Reduction strategy has been resulted in the reduction of casualties due to hydromet events. The comparison between events of similar magnitude occurred before and after the development of the EWS shows significative difference in the consequences. Audit procedure to verify and improve the system are performed. (table 6 statistics on warning dissemination data)

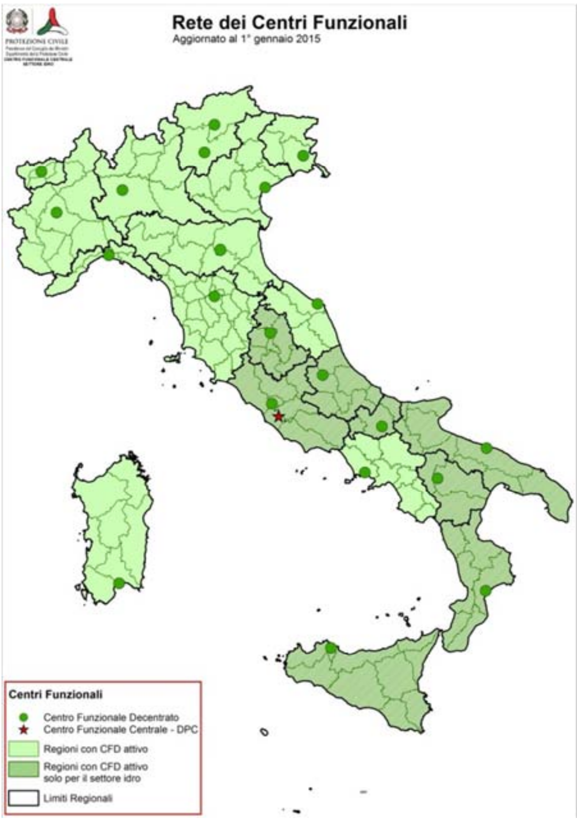


Fig. 4.19 – the Centres for forcasting and survaillance network.

	no alert	yellow	orange	red
Abru	654	389	36	0
Basi	783	239	56	1
Cala	674	319	82	4
Camp	918	125	36	0
Emil	851	177	50	1
Friu	981	79	16	3
Lazi	839	215	25	0
Ligu	989	54	27	9
Lomb	880	141	56	2
Marc	828	225	26	0
Moli	731	316	32	0
Piem	942	124	13	0
Pugl	749	285	43	2
Sard	984	70	21	4
Sici	784	260	34	1
Tosc	859	180	39	1
Tren	1036	25	15	3
Umbr	786	272	21	0
VdAo	1036	43	0	0
Vene	620	367	85	7

Tab. 4.7 - Alerts issued in the last 3 years: color code corresponds to the level of severity (no alert, yellow, orange, red)

In order to give further assessment elements about meteorological and hydrogeological risk on national scale, here are synthetically reported the events occurred in the last 5 years that, according to the Italian law, can be classified as national emergencies. These events are characterized by high intensity and affected area; typically these are floods, landslides, sea storms, wind storms and other meteorological thunderstorms. The data collected are referred at the declaration of the state of the emergency and also to the emergencies at regional scale. Data show that national territory was interested by some 115 events and every year, about 50 per cent of the country was affected; total amount of the damages stated by the Regions is about 10.000.000.000 €.

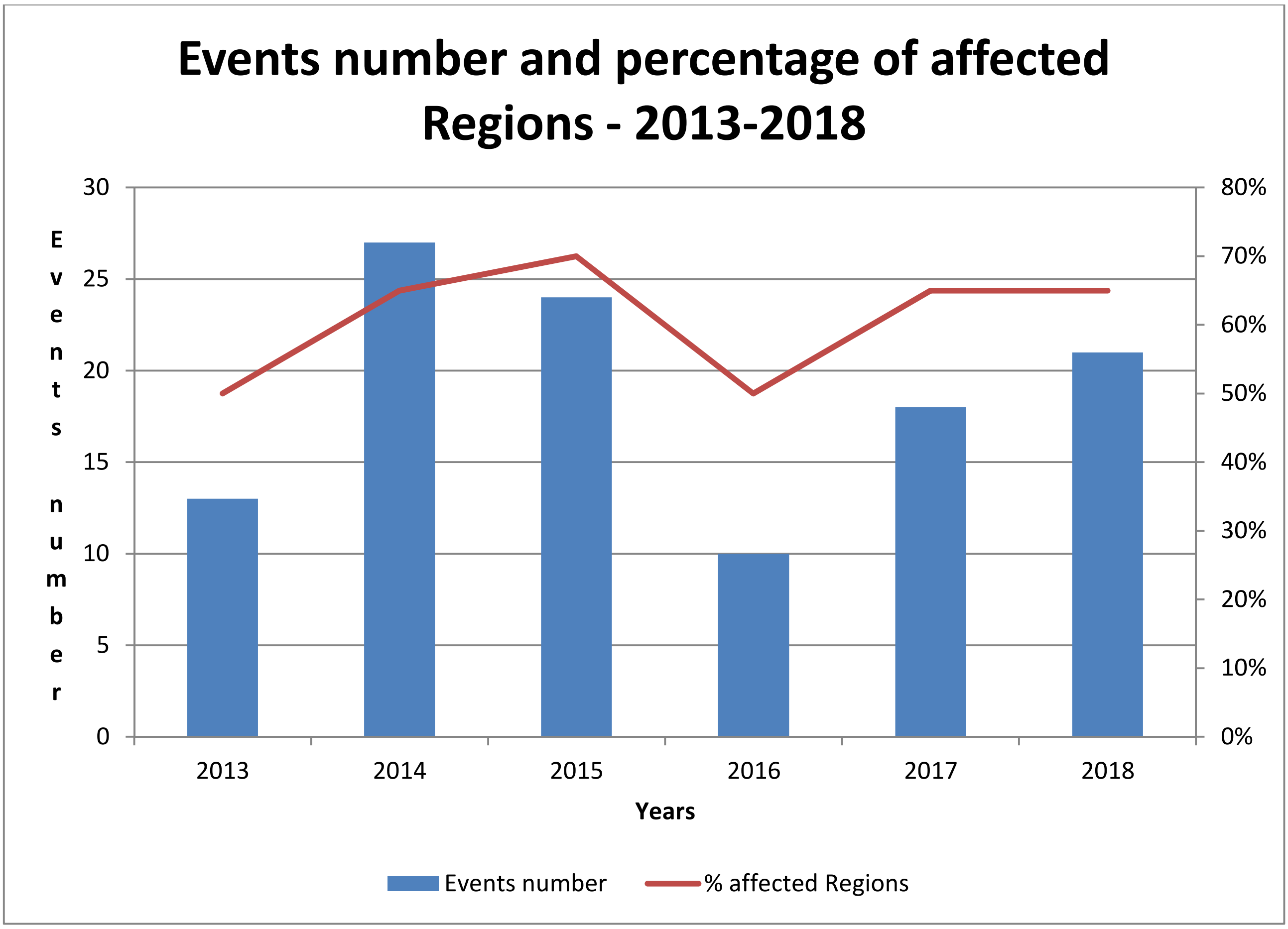
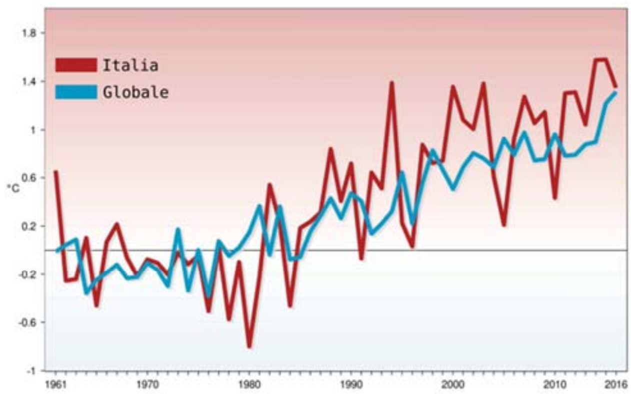
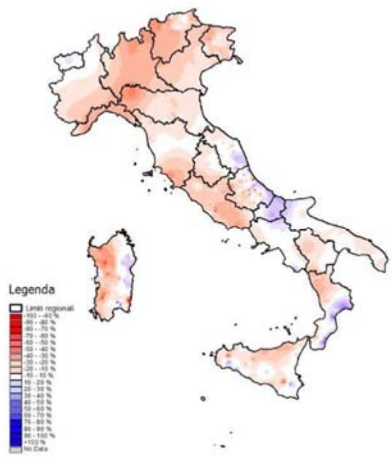


Fig. 4.20 – Events number and percentage of affected Regions – 2013-2018.

Chapter 5

Droughts





National Civil Protection Department

DROUGHTS AND WATER CRISES ASSESSMENT IN ITALY: AN OVERVIEW

In the last twenty years, Italy was interested, with increasing frequency, by many droughts and water crises. Italy was able to build its fortune precisely on the abundance of this resource, as shown by last century's rapid and massive industrialization process, which was especially based on the exploitation of water for hydroelectric production, mostly through the creation of hydroelectric basins and dam-controlled lakes in the Alpine and pre-Alpine mountain ranges.
However, in the last few years, both in the North, in the Centre and in the South of Italy, the population, the agriculture and the various manufacturing sectors have had to face ever more frequent droughts and water crises, even in areas that had rarely suffered these problems previously. Suffice it to think of the recent water crises (2003, 2006, 2007) that have hit the Po basin and in particular the area of the major dam-controlled pre-alpine lakes (Lake Maggiore, Lake Como, Lake Garda and Lake Iseo) where water has always been abundant. Po basin is the biggest Italian basin, and also the most populated and industrialized one. The 2017 water crisis struck also other regions especially in Central Italy (Lazio, Umbria, Marche) and also Emilia-Romagna and Piedmont Regions. At the beginning of 2018 another water crisis struck Sicily Region, especially the area surrounding Palermo.
The coexistence of various uses and the subsequent emergence of conflicts between the various sectors (agricultural, energetic, hydro-potable and industrial), as well as the impact of the legislation on minimum vital flow have highlighted the contradictions in the existing approach and, in particular, in the allocation of water resources, which has often ignored the complexity of the system, its impact on the territory and the consequences of our country's water and energy policy.
Despite the unquestionable progress achieved during the past century, the Italian water sector continues to be plagued by many weaknesses: unequal distribution of the resource, infrastructure backwardness, high withdrawals, high losses from the network, high managerial fragmentation, lack of wastewater treatment plants, considerable waste, etc. (figg. 5.1-2).

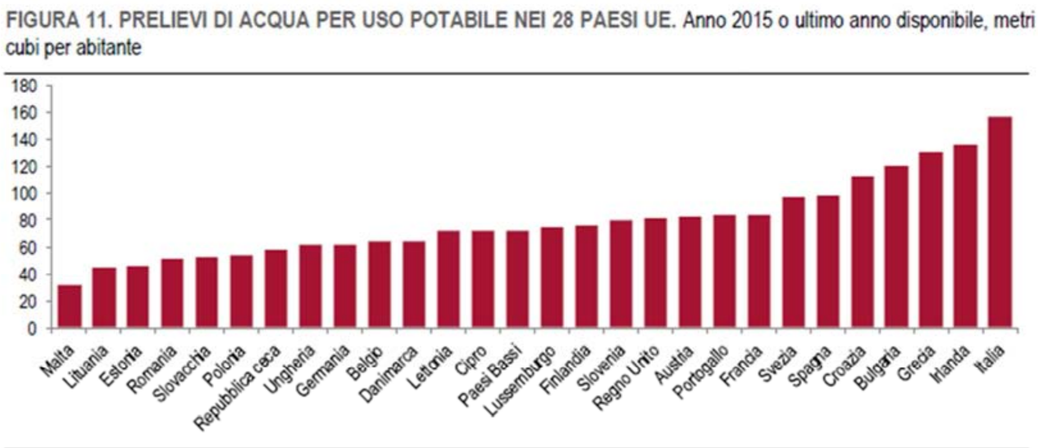


Fig. 5.1 – Water withdrawals for drinking water in the 28 EU countries. Year 2015 or last year available. Cubic meters per inhabitant. Source: National Institute of Statistics (ISTAT), based on Eurostat data.

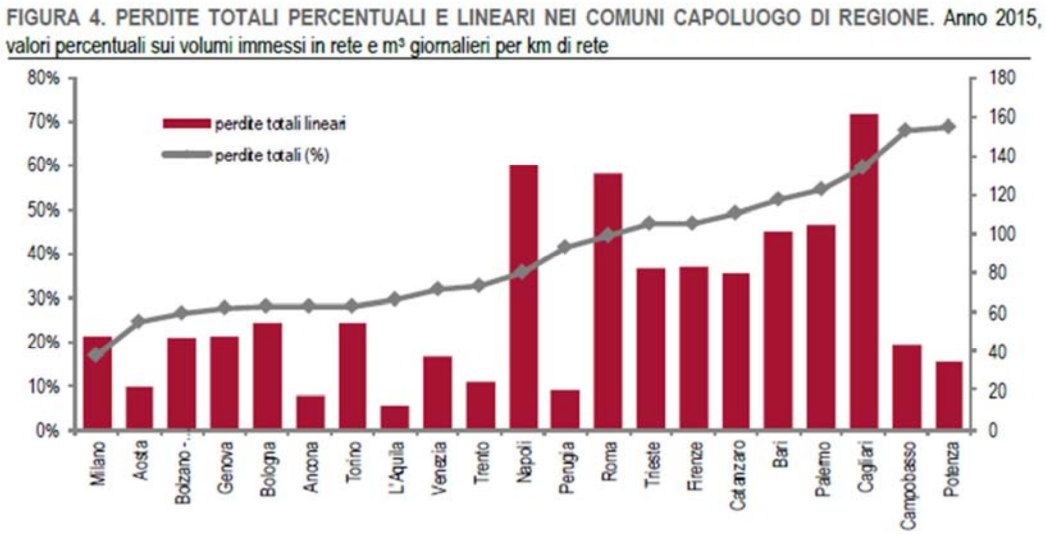


Fig. 5.2 – Total losses of water, linear (red) and in percentage (grey) in the Regional Capital. Year 2015, percentage values about the volume feeding the network and daily cubic meters per km of network. Source: National Institute of Statistics (ISTAT), based on Eurostat data.

In short, at least as far as the national territory is concerned, water crises are mostly caused by the difficulty in accessing water rather than by actual resource deficiencies. Moreover, infrastructural and managerial inadequacies have also been caused by significant planning failures, scarcity of available public funds (further sharpened by the country's ongoing public finance crisis that began in the 1990s) and water tariff/billing revenues that are among the lowest in Europe.

Lawmakers tried to redress this chaotic situation by introducing the so-called 'Galli Act' of 1994, which envisaged a clear-cut separation of roles between direction and monitoring activities, which are of public competence, and the more strictly managerial functions which could be assigned to private subjects. The implementation of the Galli Act, however, brought considerable difficulties to the forefront, mostly linked to the low economic 'appeal' of a sector, such as the water one, which has reduced profitability margins, especially if compared with other much more profitable sectors (gas, energy and telecommunications).

At a European level, the year 2000 Water Framework Directive (Dir. 2000/60/CE) was the first to introduce new paradigms in water use, breaking old-fashioned conceptual schemes and contributing to the promotion of a new water culture, more oriented towards conservation and saving.

To this end one of the most characteristic elements of droughts and water crises is represented by the phenomenon's dynamics, which unlike many other natural calamities (earthquakes, volcanic eruptions, floods, etc.) often develop over very long timeframes, in the order of months or years: that is, a prolonged period of hydrological deficit is necessary for drought to manifest all its effects. In general there is sufficient time to prepare the indispensable prevention and mitigation measures; however, the approach can more frequently be considered of a 'reactive' type, that is, contrasting measures are taken only after the emergency is already in progress.

A strategy that has proven to be undoubtedly more effective is the so-called 'proactive' one (Rossi et al. 2007), based on identifying and arranging preventive measures and interventions before the advent of the critical situation. This proactive approach is based on the accurate monitoring of water availability and long-term needs (necessary for the assessment of the water crisis risk), on a rough estimate of the impacts and on the drafting of a plan of long-term prevention measures (to reduce vulnerability). In the short and medium term the monitoring of the hydro-meteorological variables (rain, temperature, etc.) and of the available water resources (fig. 5.3) enables a warning and/or alert of a water crisis to be issued in due time, while at the same time preparing and, if necessary, implementing a plan of contingent short-term measures (distribution of water by means of water tankers or water sacks, reduction of supplies, awareness building campaigns, etc.).

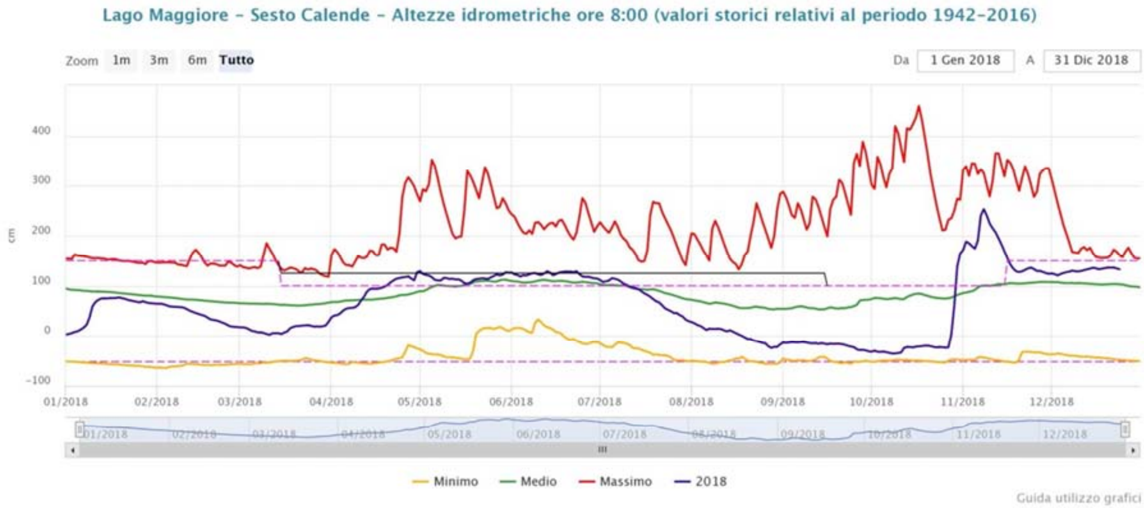


Fig. 5.3 – Graph of the hydrometric level of Lake Maggiore (blu line), compared to historical minimum level (orange line), medium level (green line), maximum level (red line). Water resources of lake Maggiore are very important for agriculture, especially rice paddies located in Piedmont and in the Lombardy Regions. Source: laghi.net website, Consortium of dam-regolated lakes ("Enti regolatori grandi laghi").

On the one hand the proactive approach guarantees a cushioning effect of the crisis encountered during the emergency stage, and on the other can prevent the insurgence of the phenomenon itself, at least in its extreme forms. For example, after a dry autumn and winter in 2006/2007, constantly monitored by Department of Civil Protection and other Institutions, Italian President of the Council of Minsters launched in march 2007 a warning directed to Ministers, Regions and other Institutions in order to constantly monitor the evolving situations and adopt the right mitigation actions: in the May 2007, the declaration of the state of emergency allowed government to adopt also extraordinary measures to mitigate impacts. Obviously, implementing a strategy that entails the constant monitoring of the phenomenon and the adoption of policies aimed at reducing the causes, and not only aimed at an emergency-type management requires greater effort but yields far more satisfactory results.

Several very important water crises, especially in 1988-90, 2003, 2006, 2007, 2012, 2017 drove Italy to adopt a more proactive approach instead of a reactive one.

The Italian legal system provides several planning tools for regional governments to address drought management, such as water protection plans ("Piani di Tutela delle Acque"), according to decree legislative n. 152 issued in 1999. Emilia-Romagna, for example, within its water protection plan has identified the areas threatened by drought risks, and is currently drafting a drought management plan, which includes the creation of a monitoring system; the analysis of economic, social and territorial impacts and vulnerabilities; and the definition of responses to drought crises (Musolino et al., 2018).

Another planning tools are the Drought Management Plans (DMPs): DMPs are regulatory instruments that establish priorities among the different water uses and define more stringent constraints to access to publicly provided water during droughts, especially for non-priority uses such as agriculture (Pérez-Blanco and Gomez, 2014). Basically, DMPs define the precise thresholds of possible drought situation and set the water constraints that will come into force in each of these cases, with the aim of guaranteeing priority uses. The drought thresholds are obtained from the historical assessment of the water supply, while the extent of the water constraints varies from one basin to other and depends largely on the ratio between water demand and water supply, being more restrictive in the more exploited basins and focusing on agricultural uses (the water use with the lowest priority) (EC, 2008). As a result, the declaration of drought would automatically reduce, in a predictable amount, the quantity of water delivered to the irrigation system from publicly controlled water sources.

An example is the DMP for the Po River Basin (Po-DMP), carried out in the context of Po Water Balance Plan approved in 2017. Po-DMP is structured to be consistent with the technical guidelines provided by the European Commission (EC, 2008). Po-DMP encompasses several activities: monitoring, forecasting, definition of the "severity scenario", definition of real-time mitigation actions, reporting and periodic revision of the activities.

After the creation of *ad hoc* technical board for water crisis management, named "Cabina di regia" (Control room) for the Po basin, for example, the Italian Ministry of the Environment promoted the creation of similar boards, named "Osservatori degli utilizzi idrici" ("Water uses observatories") within each District Authority in Italy, enlarging the area of competence to the permanent monitoring of water balance: this brought to a new Memorandum of Understanding, which has been undersigned on 13th of July in 2016 for almost all Italian District Authorities. The Water use observatories permanently monitor rainfall, temperatures, water storages, water uses and so on: they are best practices and are also examples of proactive approach. Water use observatories are essential for continuous assessment of water resources and for the development of a new water governance, based on cooperation, knowledge and continuous exchange of data and information. Water use observatories constitute also a measure of the "Piani di Gestione delle Acque" ("Water Management Plan").

The National Civil Protection Service was actively already engaged in implementing this project: in particular, the Italian Civil Protection Department, together with the Regions, has promoted and implemented a network of centres responsible for the assessment of expected and/or ongoing risk scenarios, named Centres for Forecasting and Surveillance of Effects (CFSEs), which collect, process and analyze meteorological and hydrological data etc., model and monitor events and consequent effects, in order to issue warnings to prevent and deal with different emergencies in real time, not only hydro-geological and hydraulic ones. In other words, these technical assessment activities are carried out by sharing data, information and knowledge among state, regional and local components, both public and private, present in the national civil protection system, according to a typical 'networked' collaboration model fully in line with the institutional architecture put in place by the reform of Title V of the Constitution. The role of the network of CFSEs also includes the monitoring and assessment in real time of hydro-meteorological variables and of the availability present in surface and below bodies of water, in order to warn and/or alert competent authorities of a water crisis (figg. 5.4-5).

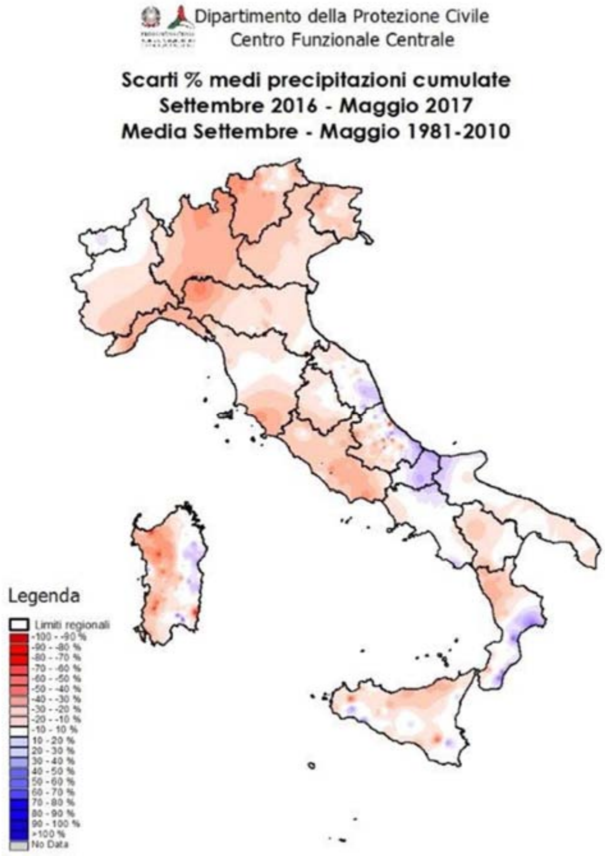


Fig. 5.4 – Rainfall percentage anomalies of the September 2016 – May 2017 period, compared to the same period in the 1981-2010 years. Source: CFSEs network; historical data given by Italian Institute for Environmental Protection and Research, ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale).

This challenge sees the involvement, besides the network of CFSEs, of Ministers, Prefectures, Regions, Basin Authorities, Local Authorities, Agencies and public and private enterprises, Research Centres, etc. The exchange of data and information among all these subjects has grown significantly in the last few years and a large amount of knowledge on water bodies/companies and on the catchment infrastructure, regulation and transportation has been streamlined. However, there is still a lot of progress to be made and, as of today, in many cases the data on withdrawal rates, influxes, losses and even on availability is not sufficient or adequately updated whereas it should be in order to recognize promptly and fight the beginning of a water crisis: one of the most important branches of activity consists precisely in identifying at best the ‘risk thresholds’ (such as, for example, reservoir volumes or well flows) and the relative critical scenarios for manufacturing systems and for users. Reaching such thresholds and the relative critical scenarios can be associated with specific stages of the emergency plans, centered on actions and/or mitigation interventions (i.e. alternative water supplies, shifts, reduction in non-essential use, etc.). In this context integration of local and scientific knowledge to support drought monitoring is very useful to support drought management (Giordano et al., 2013).

When drought and/or water crisis magnitude exceeds intervention possibilities of local communities, declaration of state of emergency is issued by national government: a commissioner is appointed to carry out extraordinary and urgent activities, coordinating several temporal government bodies at national and regional levels. Under these circumstances Civil Protection Department monitors constantly meteoclimatic and hydrological situation and supports President of the Council of Ministers and Council of Ministers for technical activities.

It is essential to underline that Civil Protection activities are directed to mitigate the effects of water crises in the short term only for civil uses and not for construction of new water infrastructures or refitting of old ones, for example for agricultural or industrial purposes. Civil Protection activities are generally directed to alleviate the impacts of the water crises for the population during the state of emergency (one year). Typical civil protection measures include, for example, use of tankers (ships, trucks), installation of provisional piping, temporary reallocation of water resources, increased diversion by relaxing ecological or recreational use constraints, restriction in some urban water uses (i.e. car washing, gardening, etc.), over exploitation of aquifers or use of groundwater reserves, restriction of irrigation of annual crops, mandatory rationing, use of additional sources, and so on.

Fig. 5.5 – Adige river flow rate (mc/s). The red dotted line is referred to a threshold minimum value about saltwater intrusion. Source: Alpi Orientali District Authority.

For these kind of measures, Italy spent 53,35 mln € during the years 2017-2018 to overcome the emergency in Emilia-Romagna, Lazio, Umbria, Marche, Piedmont and Sicily Regions.

Climate change will exacerbate the existing problems, causing an increase of withdrawals for agriculture, energy production and drinking water: this is basically due to a combination of increasing temperatures (fig. 5.6) and of decreasing and irregular rainfall. Higher temperatures will general intensify the global hydrological cycle. According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel of Climate Change (IPCC, 2014), there will be declining snow reservoir and decreasing glaciers, a reduction in the availability of groundwater for drinking water in some regions (including Italy), and also a reduction of average run-off in southern European rivers, which already face water stress. Moreover, earlier spring melts will lead to a shift in peak flow levels.

The socio-economic impacts of the changes in Europe's water resources will be very relevant for several economic sectors (EEA, 2007a, b). Low water and droughts have severe consequences on most sectors, including agriculture, forestry, energy and drinking water provision. Some activities that depend on high water abstraction and use (i.e. irrigated agriculture, hydropower generation and use of cooling water), will be affected by changed flow regimes and reduced annual water availability. There will be also impacts for wetlands and aquatic ecosystems. This will affect the sectors that depend on the goods and services they provide.

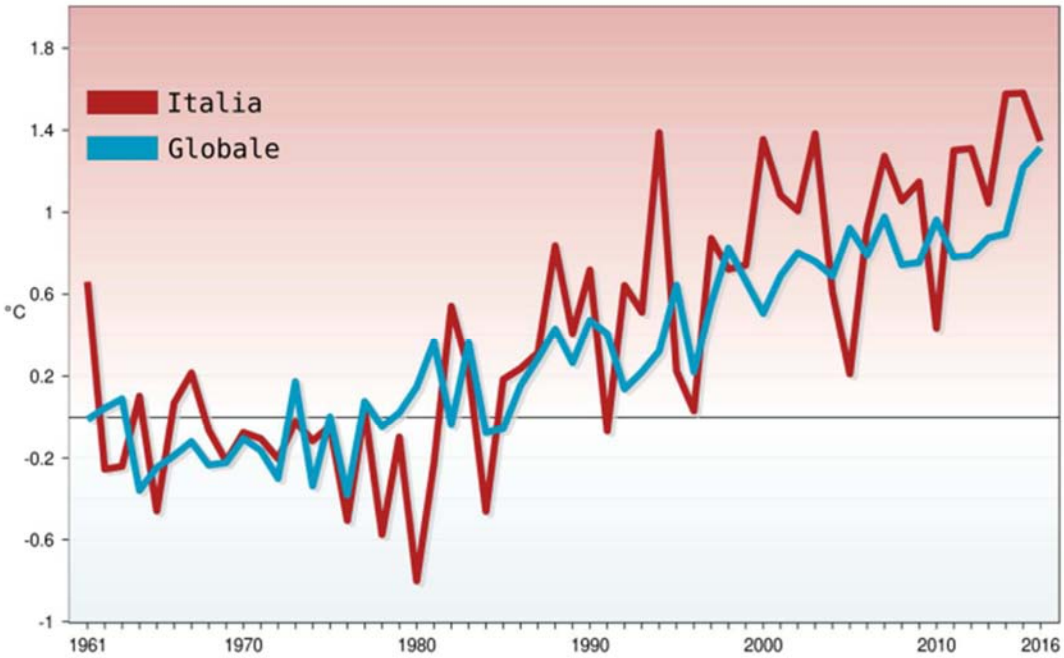


Fig. 5.6 – Medium temperatures anomalies on the mainland ("Globale", blue line) and in Italy ("Italia", red line), compared to historical data (1961-1990). Sources: NCDC/NOOA and ISPRA. Data processed by ISPRA.

In the end, it is clear from the above that forecasting and preventing water crises should be based on a careful assessment of drought and water crises and on the skillful integration of long- and short-term measures. In the first case the measures are aimed at increasing the 'resilience' of the water system vis-à-vis the crisis, i.e. to reduce the degree of vulnerability of water supply systems; on the contrary, short-term measures are mostly aimed at mitigating the impact of water crises in the various sectors involved. It is a very complex challenge, requiring considerable effort (at the institutional, organizational, technical and managerial level) and also the ability to identify innovative solutions where traditional methods and techniques have proved inadequate.

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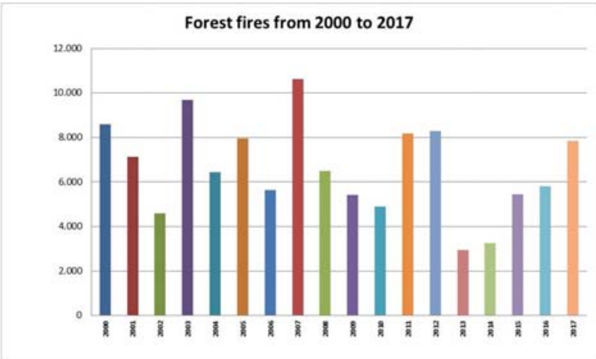
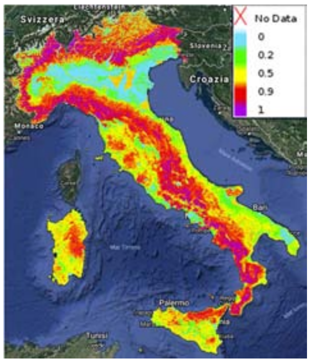
Chapter 6

Forest fire risk





National Civil Protection Department

INTRODUCTION: FOREST FIRE RISK IN ITALY

All the European Countries in the Mediterranean area are affected, in different way, by the problem of forest fires. As shown in the graph below in 2017 Italy was one of the five mostly affected European State together with Spain, Greece, Portugal and France. Since the area of each country is different, and the area at risk within each country is also different, the comparisons among countries cannot be absolute.

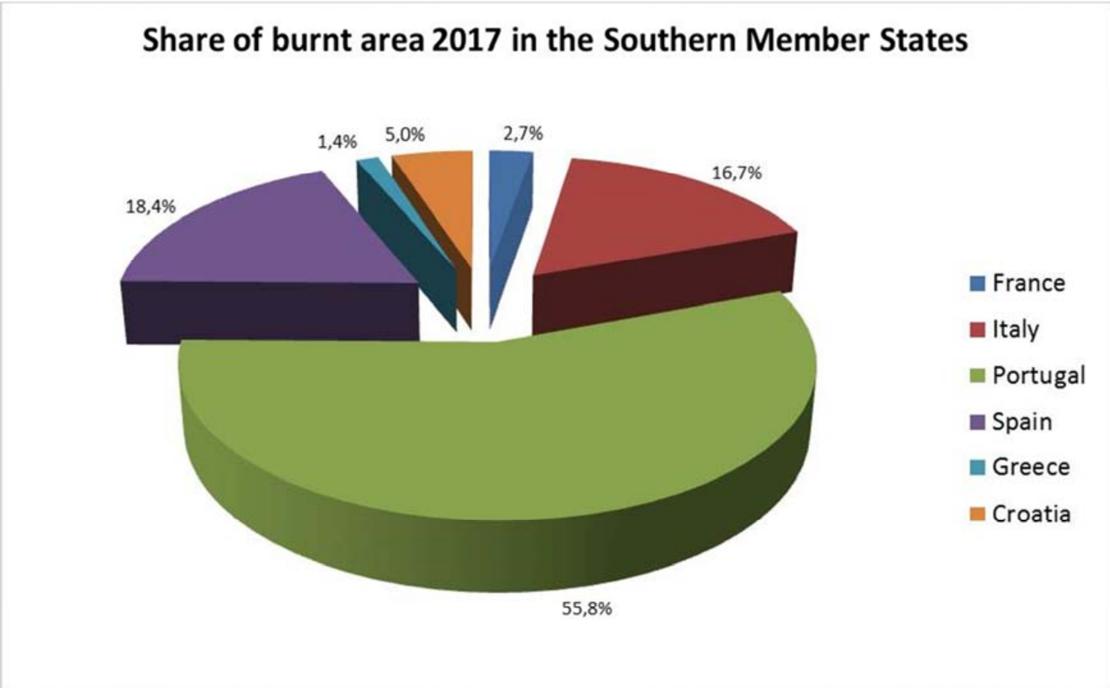


Figure 6.1: Share of burnt area 2017 in the Southern Member States (Source: JRC - Forest Fires in Europe, Middle East and North Africa 2017).

According to the provisional data, in 2018 the forest fires have affected not only the Mediterranean countries but also the European northern countries as Sweden or United Kingdom. These two countries have registered almost 40,000 hectares of burned area out of 135,000 hectares in the whole European Union.

Italy is characterized by climate and vegetational differences from north to south; these differences directly affect the distribution of forest fires along the whole territory.

In winter they are located mostly in the Alpine regions (especially the North-Western regions), while in summer they are mostly concentrated in the Mediterranean regions (Southern regions and Islands). In Liguria fires occur both in summer and winter at about the same frequency.

From 2000 there have been about **120,000 fires** that burned about **730,000 hectares of woodland**, surfaces that double if we include the non-woodland. With an average per year of about **79,000 hectares.**

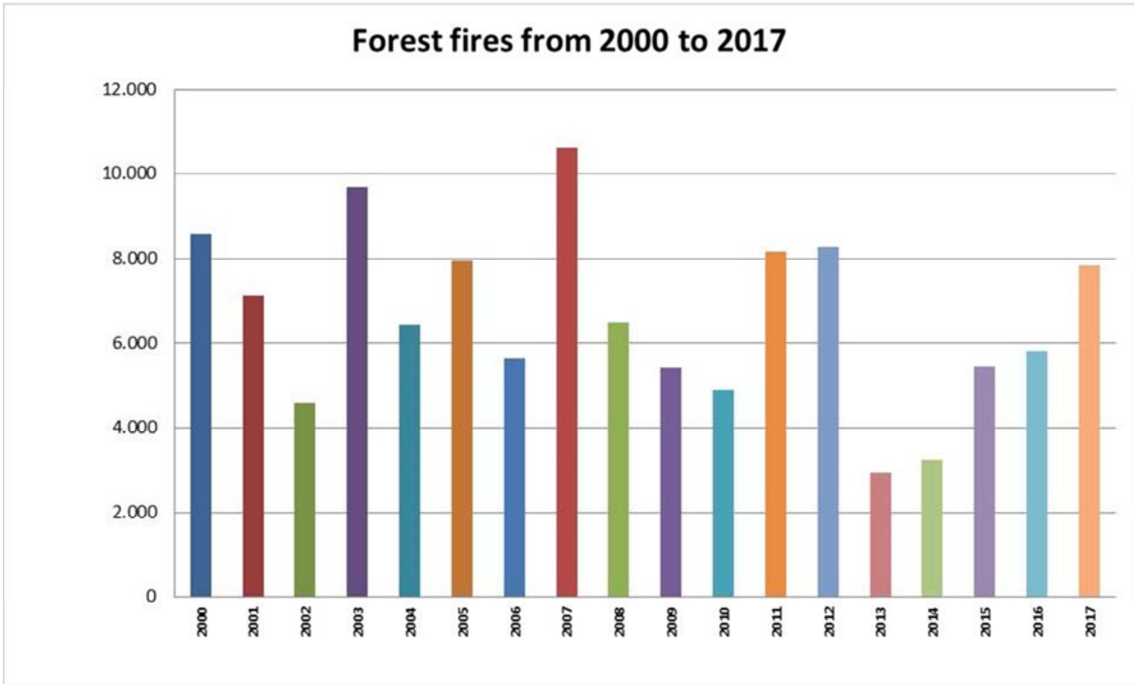


Figure 6.2: Forest fires in Italy from 2000 to 2017 (Source: State Forestry Corp & Comando Carabinieri per la Tutela Forestale, ambientale e agroalimentare, Italy)

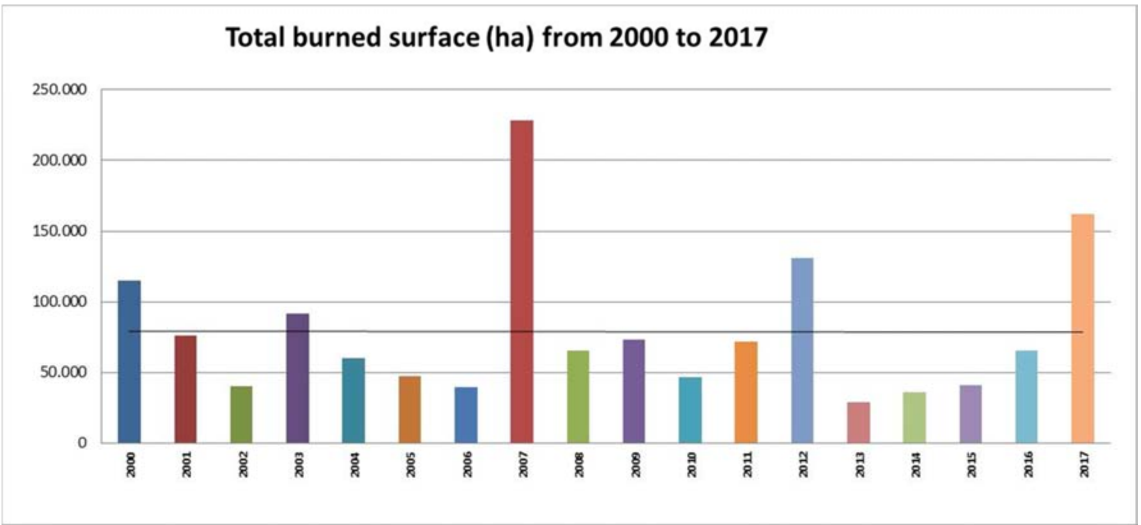


Figure 6.3: Total burned surface in Italy from 2000 to 2017 (Source: State Forestry Corp & Comando Carabinieri per la Tutela Forestale, ambientale e agroalimentare, Italy).

The threat of wildfires in Italy is not confined to wooded areas as they extend to agricultural areas and urban-forest interface areas. The agricultural and rural areas, from the 50's to now, have been gradually abandoned, both in areas with complex topography, where the mechanization of agriculture is unfavorable, and on the major islands and the south regions because of socio-economic changes.

This concept nowadays led to a greater focus on "wildland-urban interface" (WUI) fires. WUI is the area where houses meet or intermingle with undeveloped wildland vegetation and it is strictly connected with the high human presence in the Italian territory. In fact, about the 88% of total fires are man caused (voluntary or accidental), about 11% are due to unknown causes while natural causes are responsible for only a 1% of total forest fires.

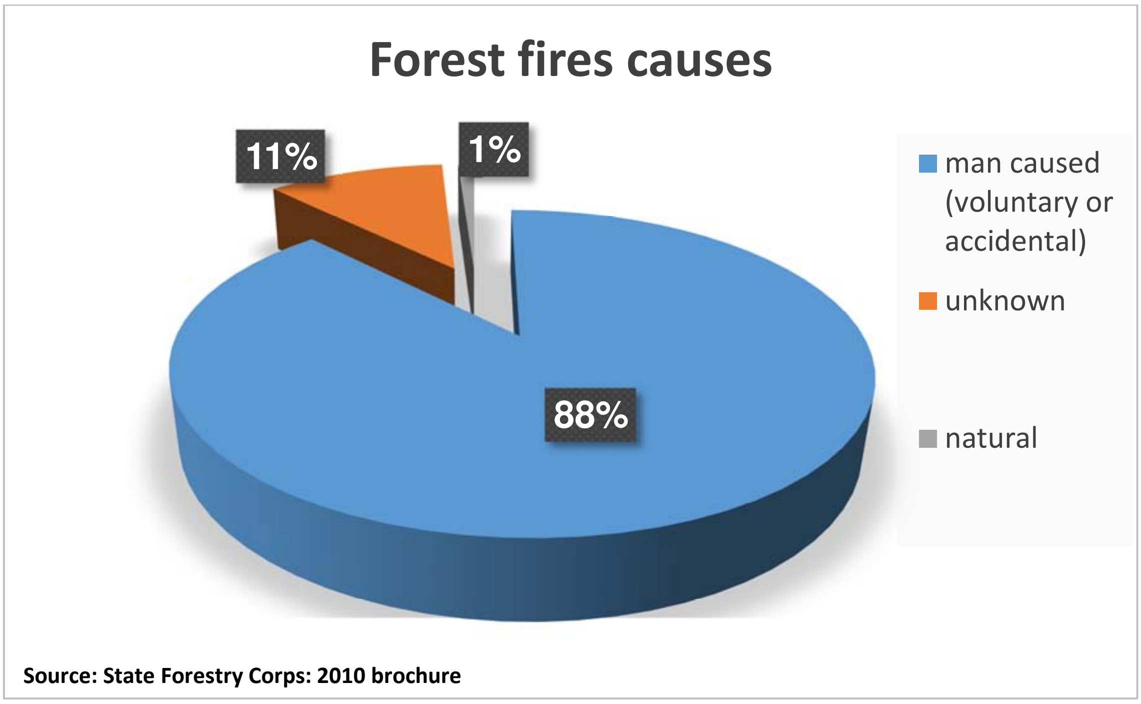


Figure 6.4: Forest fires causes (%).

LEGISLATIVE FRAMEWORK

The national Law, n. 353/2000, "Legge quadro in materia di incendi boschivi", which currently represents the national legislative framework about forest fires, was born with the specific intent to define and rearrange the responsibilities of different agencies involved, putting an end to an incomplete and fragmented normative framework by implementing the decentralization process started by the Legislative Decree n. 112/98 followed by the Law n. 3/2001 concerning the reform of 5th Title of the Italian Constitution.

In fact, pursuant to the provisions of Articles 107 and 108 of Legislative Decree, the law gives out the responsibility of the forecasting, prevention and fire-fighting activities to the Regions. To pursue the statutory tasks, Regions can use their own means and resources, including those of the National Fire Corps and of the Carabinieri Corps through agreements, and those of the volunteers.

The fire-fighting activities include the phases of reconnaissance, surveillance, alarm and fire extinguishing, through both ground and air forces. All these activities, as well as those of forecasting and prevention, are implemented in the Regional planning for the forecasting, prevention and fire fighting (AIB plans), as a strategic tool for the harmonization of different ways of intervention based on the knowledge of territory and environmental dynamics.

In those plans every regions have to define the institution, in accordance with art. 7 of the national law, of a single place, the Permanent Unified Operative Room (SOUP), where must be guaranteed the contemporary presence of all the involved actors as Regions, National Fire Corps and other territorial units; moreover, in case of fire, the Regions have to define a single coordination of ground operations in order to ensure ground and aerial means management.

National Law, n. 353/2000, gives out, in forest fire matters, two different functions to the Department of Civil Protection (DCP) of the Presidency of the Council of Ministers. The first is to manage, through the Unified Air Operational Center (COAU), the state fire-fighting air fleet. The state fleet is called to intervene in case of regional lack of ground and air means and men.

Then, with the decree of 20 December 2001, the Prime Minister gave the guidelines to prepare and approve the regional AIB plans. DCP is in charge also for the monitoring of the regional system organization with the aim to give a homogeneous approach and highlight some possible criticalities.

For this aim, DCP organizes, at least two annual technical briefings with all the actors of the system (national and regional level), one at the beginning and one at the end of summer forest fires campaigns. At political level, the Italian Prime Minister, through the DCP, every year issues operative guidelines addressed to the Regions, autonomous Provinces and National competent Authorities (i.e. National Fire Corps, Carabinieri Corps, Environmental Ministry, etc.).

THE NATIONAL RISK ASSESSMENT: FOREST FIRES

Knowing the differences on the territories and analyze, intersect and merge all different data from different sources is the first step to build the risk assessment.

Inside the regional planning, the key point is the forest fire risk mapping. The assignment of a certain level of risk to a certain portion of the region is an essential tool to plan all the prevention and fire-fighting activities against forest fires. Afterwards, the forecast activities can support the daily management of the all planned resources, in patrolling, extinguishing and monitoring.

Forest fire risk mapping

One of the Regions' aim is mapping forest fire risk. Just because of regional competences, given by the law, there is not a unique map at a national level, but every region produces a map with different methodology based on the regional knowledge and characteristics.

So, each Region uses a different approach to define the variables and the method to determine an index of risk. The differences may be in the starting partition of the territory on which leading the analysis or on the input parameters used to define the risk classes.

Following some examples of regional forest fire risk map (as gathered from AIB plans):

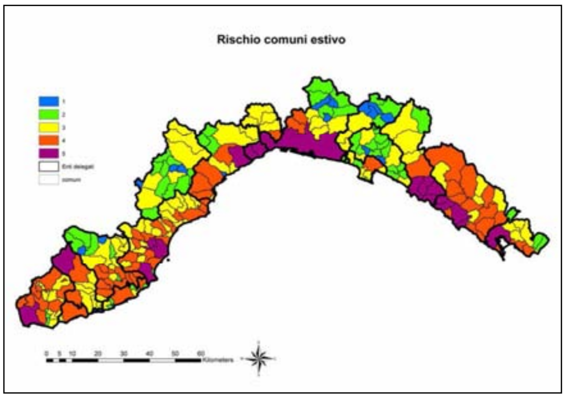


Figure 6.5: Forest fire risk map of Liguria region

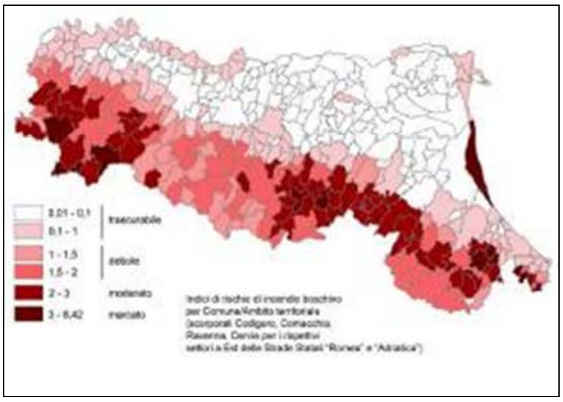


Figure 6.6: Forest fire risk map of Emilia Romagna region.

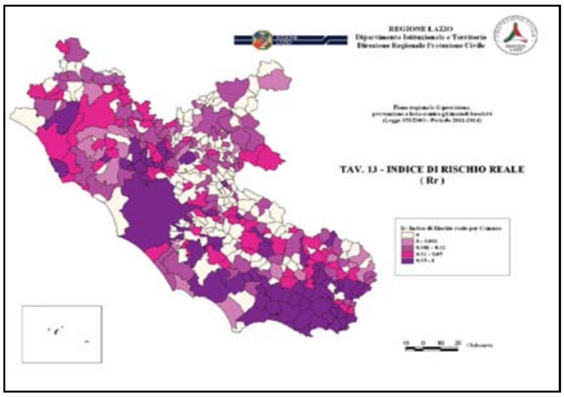


Figure 6.7: Forest fire risk map of Lazio region

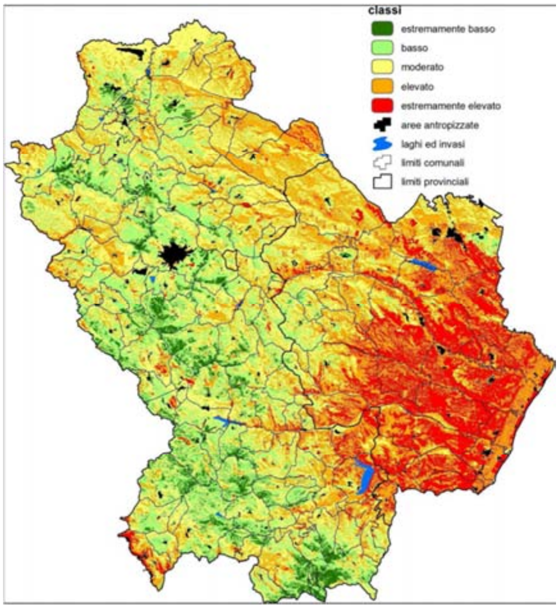


Figure 6.8: Forest fire risk map of Basilicata region

In the last years the DCP, with the support of the CIMA[2] research Foundation, has developed a methodology to obtain a national forest fires risk mapping also with the aim of improving its general daily forecast activity on fire risk.

The mapping has been defined on the basis of a statistical analysis led by using the historical data on burned areas intersected with all available data related to the characteristics of the areas like slope, elevation, exposure and vegetation coverage. Referring to the vegetation coverage, in 2017, the soil coverage map has been further improved using the last CLC (Corine Land Cover) available.

The starting hypothesis is that the same type of vegetation cover in certain terrain and climate has the same chances to be affected by fires. This is defined as the "Propagation of Fire probability" (PPF). The value of this probability is defined as the ratio between the total area burned and the total area

[2] CIMA: research organization committed to the promotion and support of scientific research, technological development and training within the fields of Civil Protection, Disaster Risk Reduction and Biodiversity.

occupied by a particular type of vegetation cover, normalized between 0 and 1. The analysis has shown that the mapping of the fire risk in the two seasons, summer and winter, is characterized by values very different from each other. In the images that follow are shown respectively the mapping in winter and in summer season.

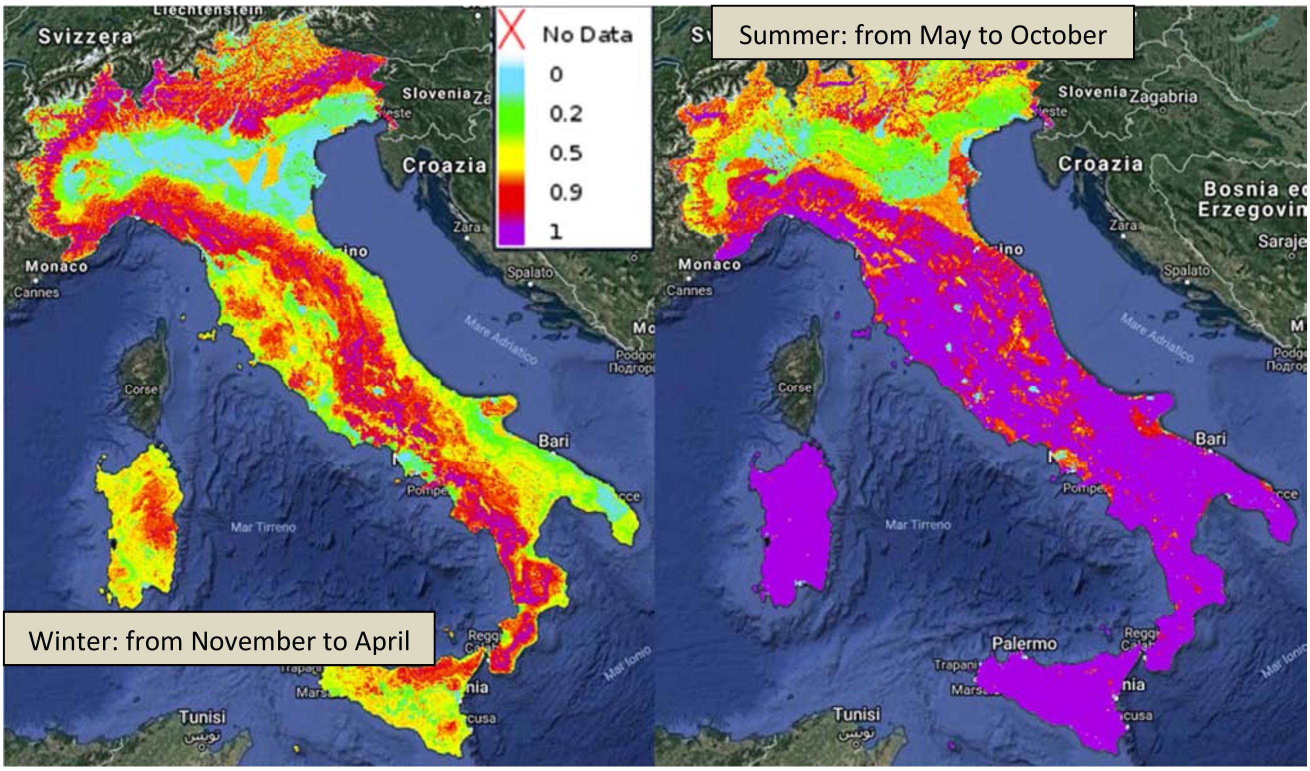


Fig. 6.9 - Static risk mapping. On the left the winter map. On the right the summer one.

The use of satellite information

The DCP is trying to further develop this kind of product integrating the methodology with satellite information. At the moment, the forest fires forecast model, better described in the following paragraph, is implemented with the information derived from satellites mainly with the aim of monitoring of forest fires on the Italian territory just to update the intervention scenarios.
Following the events, especially those extreme, DCP and Regions integrate their forest fire risk assessment using the damage maps produced by the Copernicus Emergency Management Service (Copernicus EMS) that provides all actors involved in the management of natural disasters and humanitarian crises with timely and accurate geo-spatial satellite information.

Forecast activity

The forest fire risk assessment considers as fundamental the forecast phase of the risk conditions on the territory. For the national point of view, this activity is granted by the DCP through issuing a daily bulletin where are synthesized the forest fire risk conditions at a province level.
The National Forest Fire Forecast Bulletin is the summary of different information coming from:

- Weather Forecast

- Forest fires forecast models (named "RIS.I.CO.")
- Ground data: active fires, general trend of the fire season, etc.

CONDIZIONI DI SUSCETTIVITA' ALL'INNESCO E ALLA PROPAGAZIONE DI INCENDI BOSCHIVI PREVISTE PER Mercoledì 25 luglio 2018

		BASSA	MEDIA	ALTA
NORD	VALLE D'AOSTA	AO		
	PIEMONTE	In tutte le province		
	LOMBARDIA	In tutte le province		
	TRENTINO A. A.	In tutte le province		
	VENETO	In tutte le province		
	FRIULI V. GIULIA	In tutte le province		
	LIGURIA	In tutte le province		
	EMILIA-ROMAGNA	In tutte le province		
CENTRO E SARDEGNA	TOSCANA	In tutte le province		
	UMBRIA	In tutte le province		
	MARCHE	In tutte le province		
	LAZIO	FR, RI	LT, RM, VT	
	ABRUZZO	In tutte le province		
	SARDEGNA		In tutte le province	
SUD E SICILIA	MOLISE	In tutte le province		
	CAMPANIA	In tutte le province		
	PUGLIA	In tutte le province		
	BASILICATA	PZ	MT	
	CALABRIA	CS, VV	CZ, KR, RC	
	SICILIA	ME	CT, RG, SR, TP	AG, CL, EN, PA

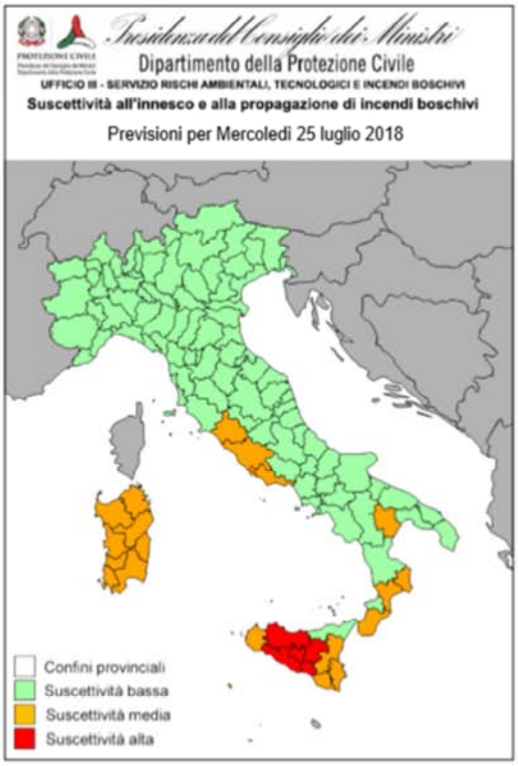


Figure 6.10: Fire bulletin issued by the Department of Civil Protection.

With the Decree issued on the 1st of July 2011, Prime Minister pointed out the main goals of the bulletin. One of them is to support the general activities of the DCP and in particular the activities of the Unified Air Operational Center (COAU):

1 Before the event: Pre- allocation of the National fire fighting air fleet

2 During the event: Re-allocation and management of the air fleet to reduce possible overtakings of the state fire fighting air fleet requests sustainable level.

The RIS.I.CO. system is a model of the potential behavior of the fires developed by the CIMA Foundation for the DCP since the first 2000's. It has a complex software architecture based on a framework able to manage geospatial data as well as time dependent information.

The regional levels issue their specific forest fires forecast bulletins in support to their local forest fire fighting system management (i.e. reconnaissance, surveillance, patrolling). In some regions these forecast bulletins support the civili protection warning system.

Forest fires Technical Board (Tavolo Tecnico Interistituzionale AIB)

As a consequence of the forest fires risk assessment after the extreme events of the summer 2017, DCP established, in 2018, a specific Technical Board focused on the monitoring of the whole fire-fighting system and to develop the improving proposals shared after the technical debriefing of the 2017 summer fire-fighting campaign.

The Technical Board is coordinated by DCP and is composed by some Regions as Liguria, Molise, Veneto, Sardegna, Toscana and Puglia and, at national level, by National Fire Corps, Carabinieri Corps, Environmental Ministry, Agriculture Ministry and by ANCI (National Association of Italian Municipalities).

In the year 2018, the Technical Board worked on different topics as:

- Definition, responsibilities and training of the DOS (the responsible figure on the ground during a forest fire);
- The homogenization process of the information included in the regional forest fires forecast bulletins.
- The best use of the EU PSR (rural development programmes) funds.
- Reconnaissance of so called "rural police regulations".
- The definition of a scheme for municipal decree containing legal obligations and prohibition about forest fires.
- Definition of procedures for information exchange among operational rooms.

Most of the activities of Technical Board are still ongoing.

Other tools

Another tool used as rapid fire risk assessment is the PROPAGATOR model, that is a fire spread model useful to evaluate the operational scenario.

I. The model is based on a 2D stochastic cellular automaton. The characteristics are :
II. a domain discretized using a square regular grid with cell size of 20x20 meters
III. high-resolution information on elevation and type of vegetation on the ground.
IV. wind speed and direction and the fuel moisture conditions for each cell are obtained respectively from a Meteorological Model (COSMO I7) and from RISICO system, and change synchronously with the fire growth simulation.

The output of the model is a series of maps representing the probability of each cell of the domain to be affected by the fire, obtained by evaluating the relative frequency of ignition of each cell with respect to the complete set of simulations. The model also provides isochrones of propagation probability > 75%, useful to assess the evolution of the wildfire in time.

The model execution is very fast, providing a full prevision for the scenario in few minutes, and it is useful for real-time active fire management and suppression, highlighting the exposed elements at risk and where the fire attack can be more effective.

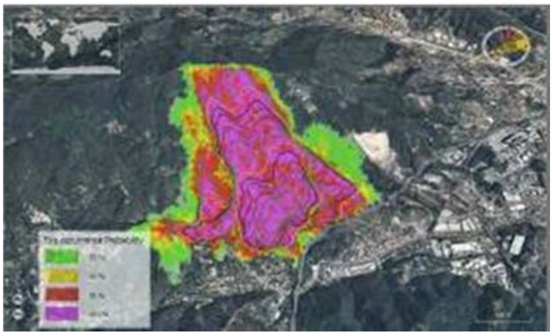


Figure 6.11 - Propagator. Final fire probability output map

Figure 6.12 - Propagator. Final 75% fire probability hourly isochronous lines

CRITICALITY OF THE NATIONAL FIRE-FIGHTING SYSTEM

With regard to the forest fire and rural-urban interface risk, cannot be assumed that a single scenario, despite its breadth and severity (in terms of both time and space) could require the intervention of foreign countries under bilateral agreements or by European cooperation.

Instead, we have to refer to a general scenario whose complexity is given mainly by the contemporary of many events all over the territory, able to absorb all available resources, both in terms of means and men, and consequently lead to the collapse of the national system. In such a case, regardless of the destructive power of the individual fire events, may require the use of international cooperation.

The DCP formalized this concept, in 2008, in its "procedures for activating in case of emergency". The maximum level of alert for forest fire risk is due to a serious fire situation that has continued for several days involving multiple regions, so as to be relevant and national interest. The same level can be reached because of a national lack of air assets.