LODE PROJECT

Summary of the results of the applications in the showcases

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1. INTRODUCTION: OBJECTIVES, SCOPE AND STRUCTURE OF THE REPORT

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The preparation of this report proved to be particularly challenging, beyond what was expected when writing the proposal. In fact, in the original plan, the data of the showcases should have been collected much faster and analysed to demonstrate the different uses of damage and loss data. However, the same data collection proved to be problematic, it took long time to obtain from stakeholders the data, most of the time the reason being the fragmentation of the latter, the need to refer to many different offices beyond those that had been included in the project initially. Other constraints were certainly due to the pandemic, however at the time of the beginning of the crisis most of the data should have been already collected, which was true for some showcases but not for all. The obtainment of data however is not the only reason for the difficulties. A significant burden has been related to the quality, the lack of homogeneity and the disparity of sectors that the data covered in each showcase. In fact, the latter look more like a collection of reports that differ for the specific data that have been collected, the granularity, the detail, the source, even the the source. In most cases official sources were preferred, however they were not always easy to find. So the first effort has been in developing a logic sequence of the showcases, renouncing rather early to the idea that they could be homogenized. This tells us something regarding the future needs: some level of standardization and harmonization is needed, not only to compare among countries, but also within countries to be able to carry out even only some of the uses that are presented in this deliverable. If something has come out of this tremendous effort is that the development of the information system, that will result from WP3 is extremely needed and urgent. In fact, even countries such as Finland where databases have been already developed, struggled with data as the databases had not been populated and data were still dispersed among agencies and organisations.

So an important step towards the development of this deliverable has been the re-organisation of data according to the multi-sectors framing of the Lode project, as shown in Deliverable 4.1. This certainly requested some time as in structuring the data sector by sector, gaps and missing information were constantly found. The second step has been then defining what type of use could be done of the data. In this regard the present deliverable is actually close enough to what imagined while writing the proposal. Each showcase is addressing one specific use; some showcases in a more convincing way than others depending also on the quality of data and on their actual being fit for the purpose for which they have been used. What is probably the most interesting result of this effort, is that some additional uses were imagined by partners that were not initially considered and that go beyond the purposes that are mentioned in the first JRC report (De Groeve et al., 2013 but also Walia ad Menoni, 2020). It can be said with reason that a lot has been achieved, especially in some showcases, in demonstrating the added value of having empirical data from real events with applications that open the floor for future research and offer also examples on how public administrations might be using their data in the future, especially if a better procedure and more comprehensive data collection is established. In this regard it can be held that a significant advancement has been made with respect to the Idea project (Improving Damage assessments to Enhance cost-benefit Analyses), G.A.N. ECHO/SUB/2014/694469) where the seeds of the current work have been developed. In the following the different uses will be discussed and the sequence of the showcases will be presented.

1.1. The different uses of damage data

Fully overlapping with the development of the concept and applications of the Lode project, we had the opportunity to contribute to the subchapter 3.1 of the new Disaster Science Report 2020 focusing on the different uses of damage and loss data which was introducing to the other subchapters regarding the variety of sectors that were considered, ranging from houses to infrastructures to agriculture. Contributing to the report constituted an important occasion to rethink in a more advanced way the different uses and a new framework was developed (the one that is actually published). It may be relevant to recall the conceptual development that occurred since the first framework that has been published in the JRC report (De Groeve et al., 2013) and that we have already presented in an amended version later on. In the original framework the following uses of damage data were considered: accounting, contribution to the improvement of risk assessment models on the basis of empirical data and evidence from real events, and forensic investigation of damage, as proposed by the Forin project in 2010[1] (Oliver Smith et al., 2016).

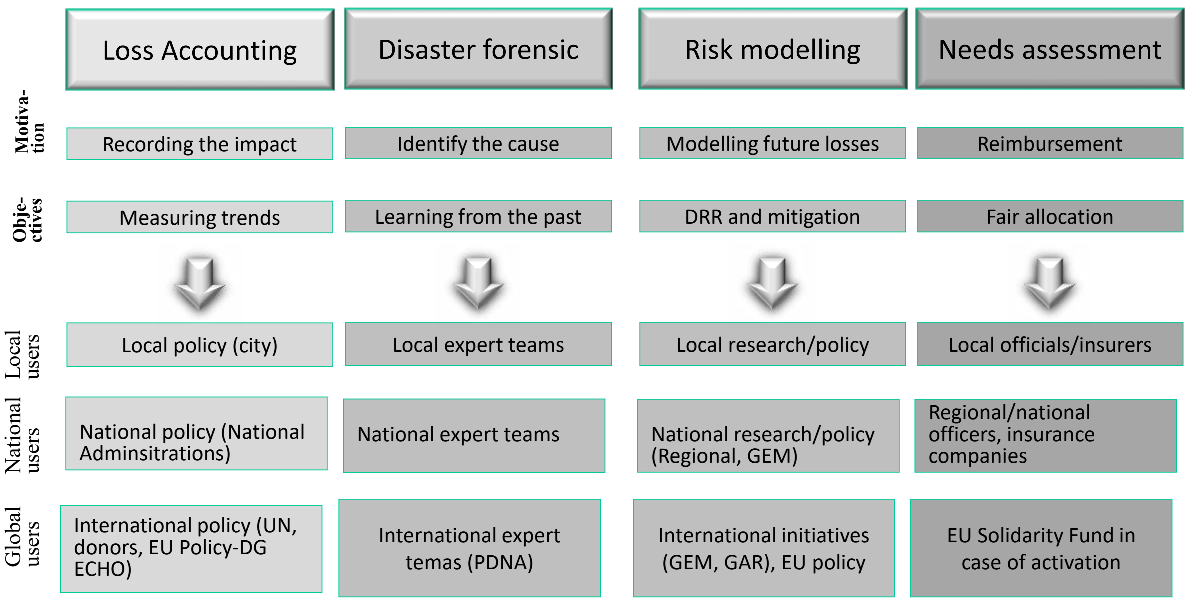

Figure 1.1. The different uses of disaster damage data following De Groeve et al. (2013)

In the amended version, that can be seen in Figure 1.1, the “needs assessment” element has been introduced, intending both material and financial needs that could be derived from a careful damage assessment. The financial needs are also those that insurance companies seek to evaluate in order to compensate insured on the basis of the subscribed policies; whilst material and financial needs for recovery are those of interest for states and for international

[1] Forin project, see http://www.irdrinternational.org/projects/forin/

aid organisations. In this regard the methodology proposed in the Idea project acknowledged the PDNA as an inspiring significant reference.

In this regard it may be relevant to recall briefly the PDNA. The latter is the acronym that stands for "the Post Disaster Needs Assessments (PDNA) (GFDRR, 2013), a method developed initially by the United Nations Economic Commission for Latin America and the Caribbean (UN-ECLAC) and then improved through the collaboration of several international entities, including the World Health Organization (WHO), the Pan American Health Organization (PAHO), the World Bank, the Inter American Development Bank, the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Labour Organization (ILO). The PDNA is made of two parts: the DALA (damage and loss assessment) and the Needs Assessment and is meant to be adopted in large disasters where international aid is required. Based on the assumption that the necessary basis for prioritizing needs is a detailed, comprehensive and multisector assessment of damages, the PDNA provides a rather precise methodology in terms of the modality of conducting surveys, the scale at which those should be carried out, and also with respect to the timing" (Walia and Menoni, 2020).

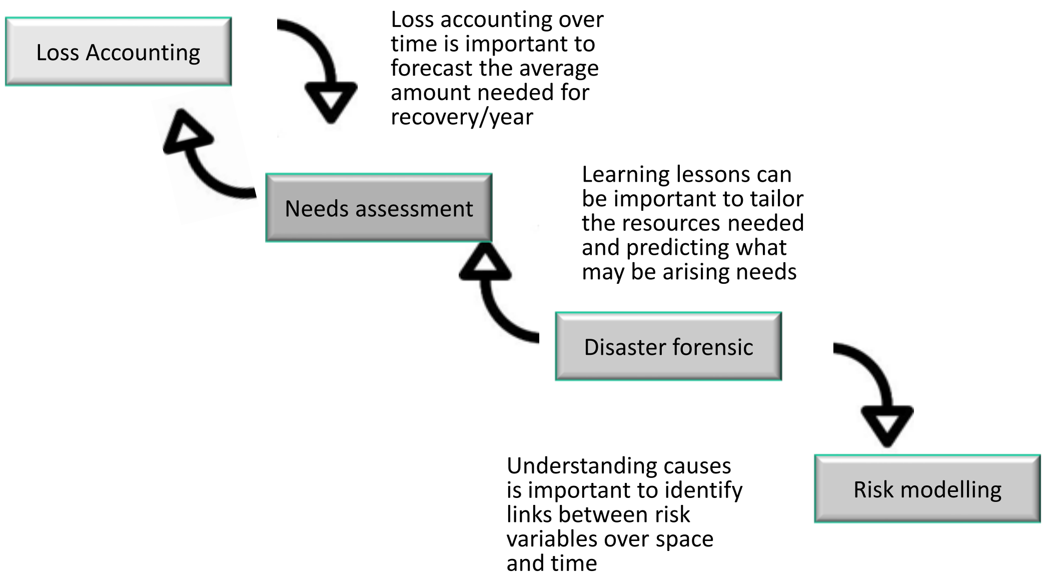

Figure 1.2. Interconnection between different uses of disaster damage data

An important step forward that we were able to make during a service requested by the Catalunya Civil Protection Authority and funded by the JRC[2] consisted in the recognition of the relationships among the different uses. This concept is illustrated in Figure 1.2 that was developed jointly by the Officers of the Catalunya Civil Protection and the researchers at Politecnico di Milano. The figure alludes to the idea that the different usages are connected to each other even though an analytical perspective was not yet provided. The latter has been achieved thanks to the Lode project, and more specifically to the initial work carried out on

[2] "Collecting and recording disaster damages and loss data according to European Directives and Guidance for responding to the Sendai Framework requests", 2017

the showcases that are described in their final form in this report. A first version of the amended framework has been published in the Disaster Science Report 2030, whereas the one that is reported herebelow (Figure 1.3) constitutes a further evolution. In the latter, important achievement of the last year of Lode has been integrated, that is using post disaster damage data to improve the capacity of civil protection authorities to prepare and provide a more appropriate and focused response during an emergency. The uses of post disaster damage data had been insofar considered mainly for recovery, reconstruction and prevention policies, whereas they had not been fully considered as a relevant input also for emergency and crisis management. The presence of two civil protection authorities and one national agency for meteorological monitoring and alerting (FMI) permitted to envisage and to provide an application of such uses.

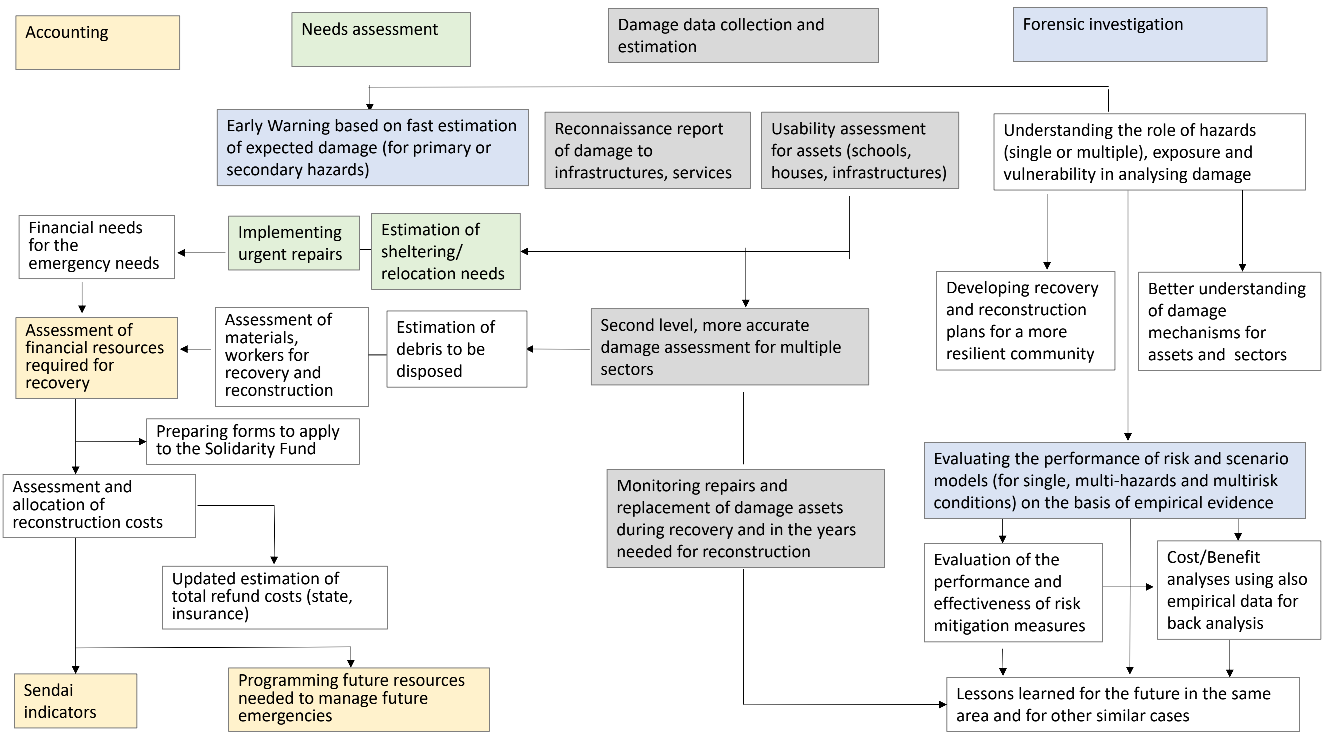

Figure 1.3. Uses of post disaster damage data and their interconnection (amended from Walia and Menoni et al 2020)

In the following the different uses as described in the figure 1.3 below are described in detail.

In the grey boxes, damage data collection and estimation are represented. The latter consist in practical results of usability assessment for assets, such as schools and residential buildings especially in the aftermath of very destructive events that will provoke extended structural damage. The result of such assessment is an “engineering” description of the damage that will provide as an output a judgement regarding the usability condition of that asset or building. On the other hand, in some cases the damage assessment will be summarized in a report to be used for asking the declaration of the state of emergency or to support the request of funding to the EU (in the case of the Solidarity fund) or nationally. In the latter case damage will be mainly represented as financial losses, that are the costs of repair and intervention needed to recover.

According to the framework, the damage assessment should not be carried out only once, that is right after the impact and during the emergency, but should be repeated at different stages of the recovery with increasing levels of accuracy and precision, as the requirement for conducting such assessment changes, as requests for compensations following repairs that have been already conducted or requesting funding or reimbursement to insurance to which entities (private and public) are eligible requires a more advanced and complete damage and loss estimation. In different showcases where we had direct access to the damage data managed by the authorities (in particular in the Kefalonia, Umbria and Madeira cases), subsequent files with evaluated damage and losses were obtained for a variety of sectors, showing in practice that such an evolution in the damage data collection is a reality in many countries and is somehow inevitable due to a number of conditions. First and more obviously because right after the impact only the most critical damage is considered and prioritized according to the fact it impedes crisis management, access to affected area and first recovery; in the early recovery, needs must be assessed more carefully, also to support recovery plans as is the case for Italy. In the latter case the first rough estimation, based on price lists available at provincial levels, is substituted by first invoices already paid for interventions that have been already made and for repairs that could not be delayed. At later stages it is also the case that more organisations and more owners will be able to provide proofs of the damage their assets and workplaces have suffered, also certified by experts and specialized surveyors (sent by insurance companies or hired by owners to obtain some compensation from the state). There is also another important issue that has been already pointed out several times (cita Menoni et al., 2017; Menoni et al 2016): not all damage will appear immediately after the event, some will become manifest at later stages, for example in the case of floods, mold may appear months after, of some equipment may get ruined by humidity. The so called indirect damage, such as for example business interruption, may be practically collected only after some time has passed since the impact. The cyclicity needed in post disaster damage data collection has been recognized in the past as a key point that cannot be avoided, especially because compensation mechanisms based just on initial estimates may largely overestimate or underestimate real needs, real losses. At the same time, the cyclic assessment also contributes to monitoring not only new damage that may appear but also provide an important information on damage that has been already repaired, in this case offering the opportunity for a continuous monitoring of how the money is spent. This is particularly relevant in the case of state compensation, as the latter will not come, as insurance, all at once, but will be most probably determined through subsequent administrative and political acts. In this respect the constant update of damage data is also necessary for further requests or updated requests that will be fulfilled throughout time and considering the financial availability of states.

Continuing in the right side of the framework in Figure 1.3, the forensic investigation is considered. With respect to what was proposed in the Idea project, significant step forward has been made. In synthesis, the forensic investigation is about identifying the key causes of damages to be associated with hazard, exposure and vulnerability specific aspects. Since the first development in the Idea project, a number of applications were made, before the Lode project (Wantim et al., 2018), (Mendoza and Schwarze, 2019) and during the Lode project (Faiella, 2020; Dominguez et al., 2021). Both the concept and the methodology have evolved as will be described in chapter 4. Once the different components that have contributed to the damage have been elicited, they can be used to addressed a better performing early warning system to maximize the effectiveness of alerts in reducing at least some levels of damage as can be seen in the blue box under the "Needs assessment" column. This is in fact the usage that was proposed by civil protection and monitoring institutes and which is fully embedded in the Tapani storm showcase.

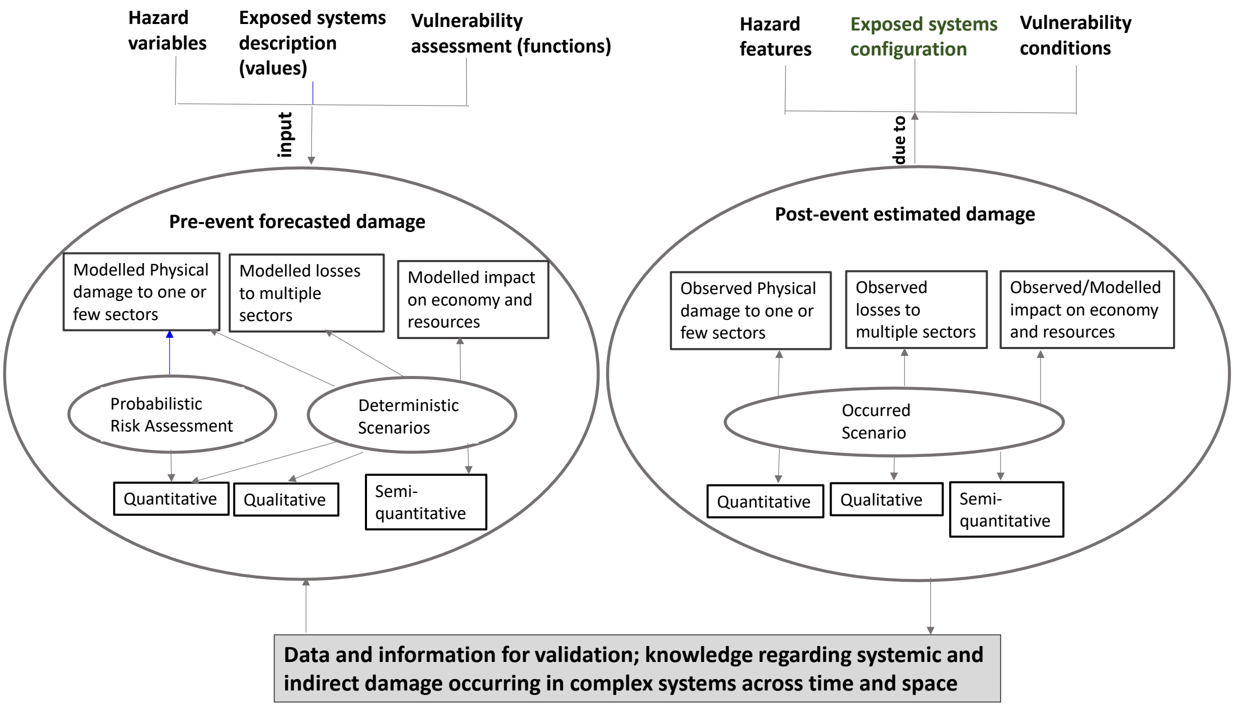

Figure 1.4. Pre-and post-disaster damage assessment (source: Menoni et al 2017)

Analysis of damage has been always key and fundamental for identifying vulnerability factors that could be considered as causes or co-causes of buildings failure for example in the case of earthquakes. Given that hazard, vulnerability, exposure are the same factors that are analysed to forecast (in the case of pre-) damages and reconstruct (ex post) damage causes and mechanisms leads to the decision to put the improvement of risk assessment models as a result, product of forensic investigation (see Figure 1.4.). The lessons learnt from the disasters should be actually embedded in risk assessment to improve the reliability of risk assessments and scenarios to make them more realistic and supported by empirical data and evidence. This is what has been proposed in a number of showcases in this report, for example in the Kefalonia case, where the damage assessment carried out after the 2014 earthquake has been compared to the forecasted damage scenario due to the same seismic input as well as to the worst case seismic shake (VRF).

As shown in the framework, forensic investigation may be carried out on both single and multi-hazard events. In the case of the latter, understanding the type of interconnection between different hazards and/or the combination of hazards and vulnerabilities in complex environments leading to multi-risk conditions is part of the process required to disentangle the damage causes, and refer them to a chain of interconnected hazards, direct and second order impacts. An application is shown in chapter 4 on two Italian showcases: the Central Italy earthquake and snowstorm in 2017 and the flood in Milan in 2014. It should be noted that integrating multi-hazard and multiple-failures investigation is important also for early warning systems especially for events that are triggering one another or that are positively correlated. In the latter cases it may be that issuing an alert for the primary hazard is not possible or loaded with too large uncertainties to be reliable, but on the contrary secondary hazards are much easier to forecast.

Finally, the forensic investigation is an important tools to determine the quality and effectiveness of risk mitigation measures that were or not in place before the impact. In the case of no measure, the damage can be ascribed to the absence of mitigation, in the case of existing measures, their actual capacity to contain the hazard, reduce exposure and vulnerability can be verified. The lessons learnt can be embedded in a number of risk mitigation policies and strategies, for the recovery and reconstruction of the same affected areas and also for similar cases as for the risk and the type of regional and local settings involved.

Going to the Needs assessment, the green column, apart from the use of damage data for early warning already shortly described above, a careful assessment of damage data is the necessary basis for evaluating and prioritizing needs, intended as immediate necessary repairs, relocation, evacuation. The arrows shows the direct link with the accounting use of damage data, at first to support the immediate intervention for temporary and fast repairs (for example of critical infrastructures) and for assisting the affected population. Such accounting as already mentioned supports the requests of funding to governments and also the request, when appropriate, of the Solidarity Fund. A more accurate damage assessment is needed to estimate further in the recovery, the needs in term of debris and waste treatment, that has become a real issue in the aftermath of destructive events, following the requirements of the xx Directive that has been applied also to the temporary storage of materials, successive reuse and final disposal in the 2016-2017 earthquake. It must be noted that more in depth damage assessment will highlight also the need to demolish buildings that do not hold any special value (cultural value for example) and for which repair costs are much above or equal to reconstruction costs. This will create in turn new needs in terms of disposal. The management of debris has been and still is a real issue in the recovery following the 2016-2017 earthquake as resulting from consultations we had not only with the Umbria Region (that has been less affected than others by the seismic swarm) but also of the Marche Region where the majority of severe damages was suffered.

As shown in the framework, several aspects are at the interconnection between needs assessment and accounting as replacement, repair and reconstruction costs will require a continuous update based on more advanced and more precise damage assessments on the one hand and also on political decisions regarding the strategies to undertake for the future of the affected communities. A precise accounting mechanism has been certainly become more consistent and compelling following the financial crisis in 2008-2013 as governments were required to shrink their expenditure and also to provide a much more transparent explanation and justification of their expenses. In this regard there is not doubt that in some countries, for example Italy, Greece, Portugal and Spain a very significant effort has been made in the direction of transparency and accountability which is mirrored by the available data on repair, recovery and reconstruction costs that could be used in the showcases of this report.

Accounting is then needed not only for evaluating the expenses that are undertaken for an event that has occurred but hold also a significance for further usages. On the one hand, as already demonstrated in previous exercises, in particular for the Service that was developed for the Catalunya Civil Protection, the damage data collection method proposed and applied by the Lode project at the asset level whenever possible, does provide relevant input to the assessment of the indicators of the Sendai targets and indicators. In fact, if a damage data collection mechanism and process as the one delineated in the Lode project is followed, the data necessary for evaluating the countries and regions' performance with respect to the Sendai indicators is possible and provide rather reliable estimates of what has occurred in each suffered event with respect to damage and losses to the multiple sectors as required to provide the evaluation for critical infrastructures, agriculture, residential dwellings, etc.

On the other hand, accounting is useful also for programming future needs: a well organized and structured system for post disaster damage data collection provides at the end of each year an overview of what has been spent for different emergencies in a country triggered by the variety of hazards that threaten it.

1.2. Structure of the deliverable

In this deliverable the results of different applications in the showcases of the Lode project as presented in Deliverable 4.1 are detailed. Since the beginning it was thought that each showcase will serve specific purposes in terms of uses of the collected damage and loss data. The uses depend partly on the type of data and partly and most importantly on the interest of the proposing partner. Specific uses were in particular identified by organisations responsible for risk management in their own country, for example Oasp in Greece that is in charge of seismic risk assessment and management was keen to use its database of vulnerability assessment that is implemented an enlarged each year; FMI in Finland was already working on the implementation of a national database and therefore willing to involve power networks and service providers to make them aware of the benefits of using their data on outages and emergency cuts; the Civil Protection of Catalunya with its technological service developing tools for crisis management was keen to develop an application that could be useful also for their own unit in the form of a dashboard showing different types of damage in the same screenshot to guide civil protection intervention. The Civil Protection of the Umbria Region was interested in better understanding the combined impacts of multiple hazards in their jurisdiction that is exposed to multiple severe threats. Multi-hazard and multi-risk conditions are a significant concern for Italian regions, the Lombardia Civil Protection that is acting as part of the larger network of stakeholders created by the Lode project is particularly keen to understand the impact of interconnected threats and multi-level systemic vulnerabilities on critical infrastructures.

The first three showcases are devoted to the illustration of different types of application of the forensic investigation concept and final use of the results, starting with the Tapani storm in Finland (2) to the development of the dashboard and demonstration on the Francolì flood in Spain (3) to the two cases, and the two Italian cases of Central Italy and Milan for multi-hazard and multi-risk conditions (4).

A second group of chapters is devoted to the illustration of how post disaster damage data can be used for improving risk assessment methods, in particular chapter 5 on the Kefalonia earthquake and 6 on the Tara Mountain forest fires in Serbia.

Chapter 7 and 8 provide relevant knowledge on damage mechanisms in two different sectors specifically, the former on the business sector in the chapter devoted to the Lorca case in Spain (7) for which very detailed data on losses suffered by different economic activities were collected, and the latter on the road system grounding on an in dept analysis of the damage reported in different municipalities following the flash flood in 2015.

Chapter 9 provides an interesting accounting proposal of restructuring available data on the PACA flood case in France 2015 to develop an assessment of the resilience of the territorial system also in terms of the quality and effectiveness of risk mitigation measures.

Chapter 10 is devoted to the application of Bayesian networks as an example of advanced machine learning techniques that are increasingly considered as useful methods able to provide predictive hazard and impact assessment capabilities based on real-world training datasets. The data from the Secchia river flood in Italy in 2014 have been used for this purpose.

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2. THE TAPANI STORM IN FINLAND, 2011 SHOWCASE: USING DAMAGE DATA TO ENHANCE EARLY WARNING AND EMERGENCY MANAGEMENT

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2.1. General overview of the impacts due to Tapani storm and problems in response

Most of losses and damages took place in southern and western parts of Finland, though, some damages occurred also in Central and Eastern Finland. Most disruptions and damages occurred in the Regions of South-Western Finland and Satakunta, therefore, focus of description is in these two regions. The damages due to winds occurred between evening of 25th and 27th January leading to disturbances in the critical functions of society and economic losses.

The affected critical functions and sectors were the following (Horelli, 2012):

- Electricity distribution: more than 500 000 customers experienced breaks lasting from few hours up to two weeks.
- Water supply: disruptions in water supply to households and in water purification plants that lead to release of sewage water in to streams and the Baltic Sea
- Health care and social services: problems in patient information systems and malfunctioning in call system of transport for patients. Fortunately, only two deaths occurred both related to clearing of trees by private citizens.
- Transport: disruptions in road and rail traffic as well as in ferry connections to habited islands in the Baltic Sea
- Agriculture: some of the farms with animals had no back-up power production or experienced problems in functioning of back-up systems
- Rescue services: difficulties in communication due to telecommunication network failures, e.g. in Southwestern Finland 50% of the Finnish authorities' telecommunication network was down

Most of the recommendations given in the evaluation report by the Regional State Administrative Agency were about emergency response activities and action to increase of resilience (Horelli, 2012). The development of a weather impact database would further support at least the following aims and actions:

For general development of response and resilience a systematic collection of info on impacts provides basis for monitoring, analyses and development of new impact forecasts. Improved of weather and impacts forecasts and warnings increases the efficiency of emergency response as well as recovery. In the long-term also economic efficiency of response can be increased by improved resource allocation.

2.1.1. Broader significance of the Tapani storm

Owing to the size of its impact, as well as its timing, the Tapani storm initiated a societal pressure for action to better prevent such large scale and long-lasting disturbances to critical functions of society. During the unfolding societal and political discourse, the use of damage and damage risk data played a significant role.

In the wake of Tapani storm, Finnish Emergency Services Academy started to train their students for similar events that would have severe impacts, not only regarding the amount of emergency tasks but also the cascading effects that could severely impact even telecommunication of authorities. If similar storm should hit Finland again, Finnish rescue services would be better prepared than during Tapani storm.

The Tapani storm set a change in the Electricity Supply Act in motion. Preceding storms had already aroused notable amounts of complaints about power cuts, but the massive number of power cuts and the prolonged duration of a significant part of these made the discontent rise to a level that Members of Parliament started to react. In the period 2013 – 2016 (to be checked) on two occasions significant revisions have been made to legislation. A core result is the tightened maximum duration target for reconnection in conjunction with a penalty system for the hours beyond the maximum uncompensated duration of the disconnection. Therefore, electricity distribution companies have started to assess the needs to reinstall the largely above ground low voltage distribution network and to some extent the lower mid-voltage regional distribution network. Since 2016 many companies have adopted plans and started to implement switching to ground cabling across many rural areas. Even though work will continue until 2030 the ground cabling projects should already start to decrease the numbers of storm induced disconnected customers. Ironically, the ground cabling, which is indeed an effective risk reducing measure, caused new Parliamentary debates due to the ensuing substantial rises in distribution charges to customers. In Nurmi et al. (2019) is shown that the ground cabling strategy is overall effective, but not cost-efficient as the share of overhead lines turned to ground cables is overstretched. Especially, electricity distribution companies operating in rural areas have been developing other, less costly measures to reduce disruptions and their lengths, e.g. improving maintenance and moving power lines to easily accessible locations.

2.2. Collecting damage data during the emergency

2.2.1. Data on Tapani storm

The data used in this report are collected during different stages of the unfolding event through different observation and data sharing channels. An important distinction is between information produced and collected: (1) during the unfolding of the extreme event (i.e. from approx. one day prior to the storm until a few days afterwards), (2) in the aftermath of the extreme event, i.e. in the first few weeks after the storm when the direct costs of damage, rescue and clearance have become clear, and (3) in a comprehensive ex-post evaluation often conducted several months or even a year later. This is summarized in Figure 2.1.

In the first phase of information generation, it is strongly associated with weather forecasts and the issuing of warnings (which may contain indications of possible impacts), as well as with observations and announcements of damage (and associated emergency risks). The prime aim is to mobilise affected actors well prepared and rescue and clearance services informed about likely and confirmed cases and their urgency. In the next phase it should be possible to create an overview of all the direct damage incurred. This should enable rescue and clearance services to make an assessment of effectiveness of their actions and the adequacy of their choices. It can also inform insurance companies, public authorities, and – in this case – electricity companies on damage detected and the consequent amount of claims or requests for assistance. Also the second phase of information generation and sharing is event specific. The third phase is more oriented towards learning and thorough ex-post analysis by accumulating information for subsequent events into common data systems. This phase allows to assess also indirect effects as well as how primary costs are transferred to other parties and areas. Also, the judgement of artificial trends and outliers in data can be better done in this phase. The key purpose of the third phase is learning to improve preparedness and prevention.

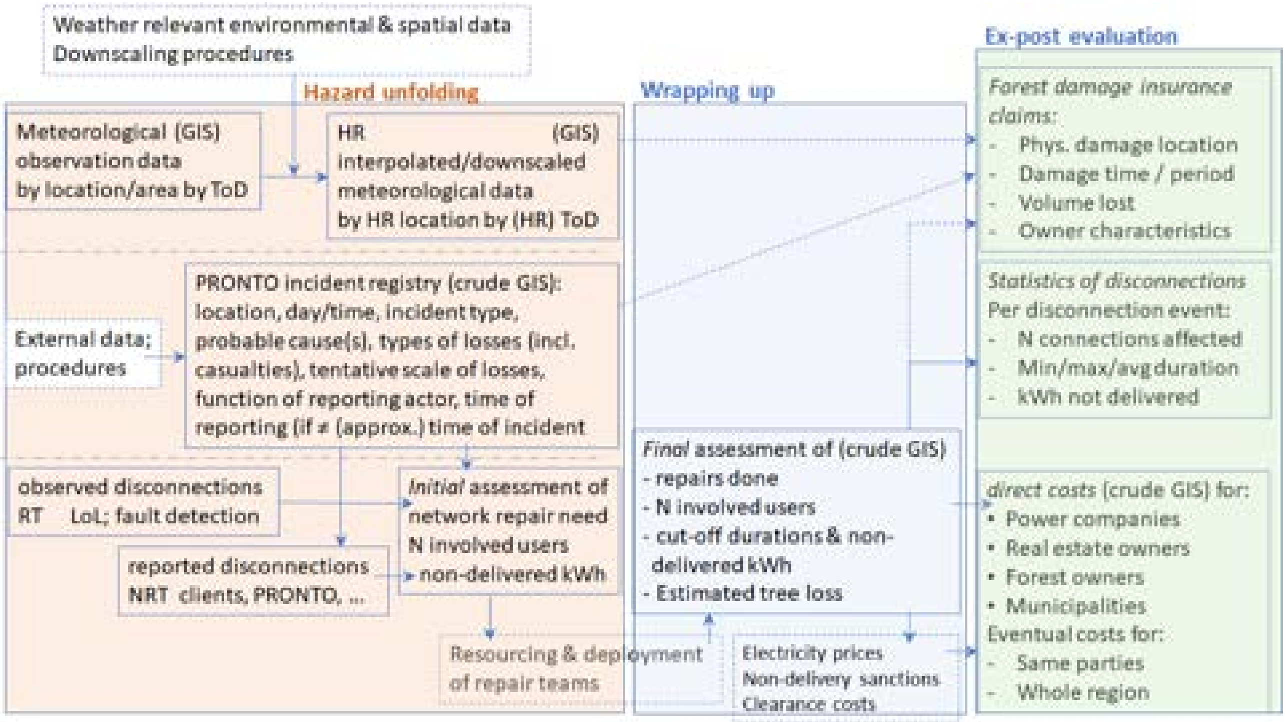

Figure 2.1 Three phases of impact information collection

Tapani storm case illustrates that the registration of physical impacts can be done quickly and fairly soon a quite complete physical hazard and damage picture can be produced. In contrast, the assessment of the costs and consequences takes more time and may depend on non-public sources and estimated parameters (e.g. prices per damaged unit). Furthermore, the auxiliary information necessary to produce cost estimates depend on sources outside the information chain generated in the first phase.

2.3. Generating and using the data while the incident unfolds

2.3.1. Use of weather data in connection to rescue missions: Case Tapani storm

Authorities as well as private sector (e.g. energy companies) use early warnings and outlooks to increase their level of preparedness. These services were described more in detail in Chapter 2.1. We know that timely observations and impact information together with numerical weather models and information about environmental conditions and local vulnerabilities are the key factors for reasonable and accurate forecasts and warnings. The advance in numerical weather prediction during the last decades has been significant and weather forecasting has become more accurate and reliable. However, the role of manual short-term forecasting and warning services that are built on timely weather observations and impact information must not be underemphasized. Even today numerical weather forecasts have uncertainties and errors that can lead into false conclusions regarding severe weather situations. Forecasters personal meteorological knowledge and experience should challenge the numerical models especially in very near-term prediction where real-time observations and information on impacts should have an impact on the decision-making processes.

While the hazard unfolds, forecasters at FMI have access to some good quality real-time impact data sources in addition to weather observations. The most important data on impacts are PRONTO and electricity outage data. PRONTO data consists of weather-related emergency calls that are logged into Finnish Rescue Department's information system and database. This time and location (coordinates) based information is shared also with FMI. The forecasters can visualize the emergency task data in their workstations almost in real-time. Comparisons between meteorological data, including forecasts, and the actual impacts is easy and helps meteorologists in their work.

The real-time electricity outage information is available on a public webpage provided by the Finnish Energy. Currently most of the Finnish electricity companies provide real-time outage information, which is gathered into one webpage operated by the Finnish Energy. The web-page depicts the power outage information both in numerical form and on a map. The map highlights the areas with power outages in municipality level. The current total number of households without electricity both in municipality and national level is available. The webpage also provides a graph that shows a time series of the number of households without electricity. Longer history of this data is however beyond our reach during LODE project. FMI has access to historical electricity outage dataset, which unfortunately is much coarser in horizontal resolution due to restrictions in use of data.

These sources of impact information enable forecasters to follow the weather situation efficiently and to keep "one step ahead" of the hazardous weather situation. This creates situational awareness and leads to better weather and warning services. The sections 4.2 and 4.3 describe the characteristics of both PRONTO and electricity outage data in the context of Tapani storm, in order to reveal the advantage and usability of both datasets.

2.3.2. Emergency data (PRONTO)

The PRONTO data comprises weather-related emergency tasks. However, each task may consist of one or several emergency calls. In other words, several people might make an emergency call related to a same incident, for example a fallen tree that has blocked a road or damaged powerlines. The Emergency Center receives the calls and a task will be created for Finnish Emergency Department. An emergency task means that a rescue unit or several units are sent to take care of the emergency. The tasks vary largely. The Emergency Center flags each emergency call to a certain category (or type) and reason. "Damage prevention" is the most common category for weather related issues, under which there are several categories for reasons, for example "wind or storm" or "flood". For this project, only wind and flood related emergency tasks were included, of which only 33 tasks of ca. 4000 concerned flooding.

The problems behind the tasks vary with respect to significance. Sometimes there is only a singular problem, but sometimes a more complex set of issues. This is an important fact to take into consideration when using the PRONTO statistics. It can be impossible to perceive the true level of significance of each task from the statistics. Not the least because significance and urgency of tasks depend on several factors, of which already incurred damage is only one element. This is of course very problematic when assessing the relations between emergency tasks and financial costs including avoided costs. The detailed PRONTO data does include a free format description of each emergency task, providing some information of the significance. However, the level of information and accuracy in the descriptions are variable and, therefore, it is very difficult to utilise this information. In Table 2.1 is shown a format of PRONTO data.

Province	Municipality	Date	Time	Address	Latitude	Longitude	Category	Reason	Desciption
text	*text*	*dd.mm.yyyy*	*hh:mm:ss*	*text*	*dd.dddd*	*dd.dddd*	*text*	*text*	*text*

Table 2.1 An example of the PRONTO data arrangement and format.

Tapani storm caused approximately 4000 emergency tasks. The number is a bit ambiguous, because there was another storm ('Hannu') affecting Finland the following day on 27th December. Total number of emergency tasks for both storms was nearly 5900. The impact of the second storm was strongest over the Central and Eastern parts of Finland but affected partly also the same areas as Tapani storm. Usually in strong storms, damages are still being reported even 2-3 days after the actual event. This is because some damages are not noticed immediately. Especially in rural areas with lower population density, the time between the actual damage and noticing the damage is larger than in more densely populated areas.

Two storms in the end of December happened within a 36-hour time window, so the origin of part of the emergency tasks remain somewhat unclear.

Compared to historical PRONTO data, Tapani storm stands out as a very significant storm. There are clearly two prominent peaks: 'Tapani' and 'Hannu' storms in the end on year 2011, and 'Janika' storm almost exactly 10 years earlier in 2001. Janika storm affected the whole southern and central parts of the country, whereas Tapani affected mostly southwestern Finland. Janika caused forest damages of 5,7 million cubic meters, which is very significant. For the storms Tapani and Hannu, Finnish Forest Centre estimated the forest damages to be about 3,5 million cubic meters in total. Taking account the areal extent of the storms, Tapani indeed was very violent, approximately of the same magnitude as Janika 10 years earlier.

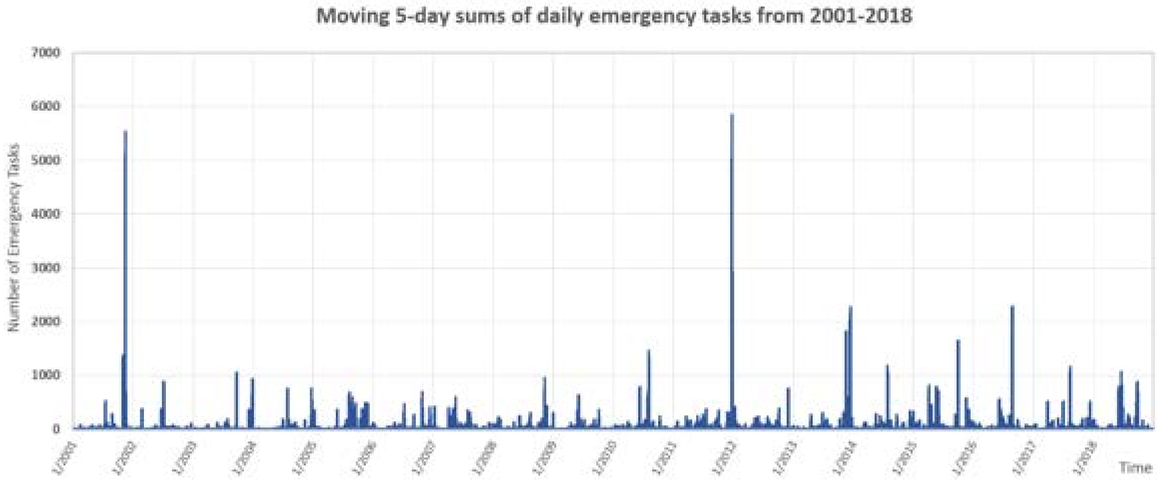

Figure 2.2 Moving 5-day sum of daily emergency tasks from period 2001-2018 in Finland. The data is for the whole country. MANCA RIFERIMENTO NEL TESTO

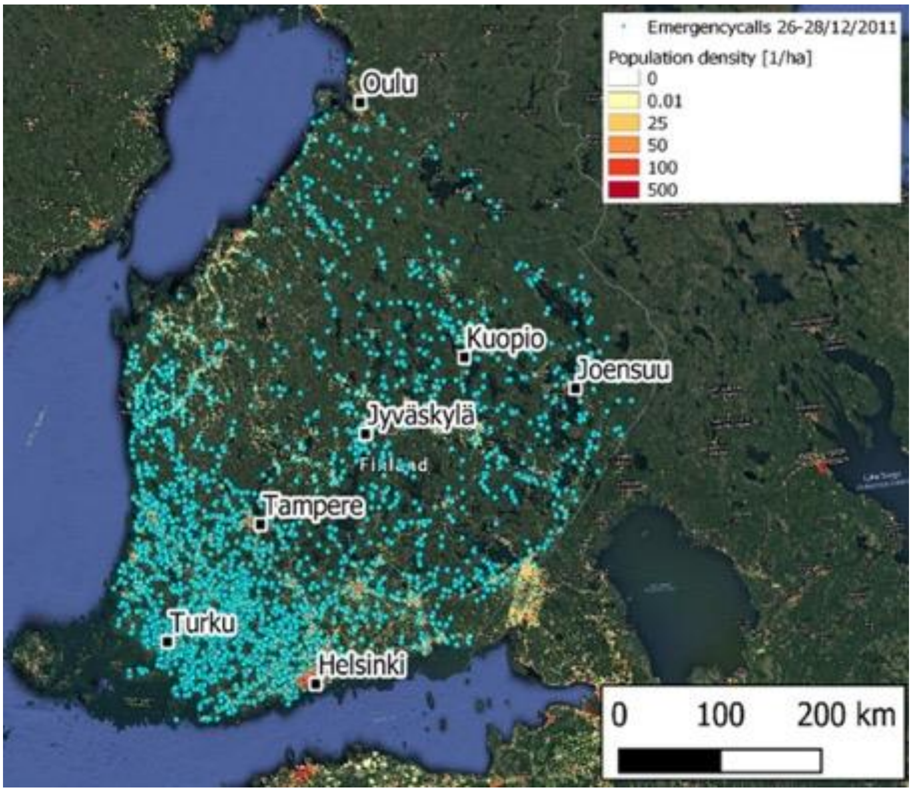

Figure 2.3 Emergency tasks during 26-28th December 2011. The background map shows also population density, which correlates well with the emergency tasks.

In Figure 2.3, blue dots illustrate individual weather-related emergency calls during 26-28th December 2011. Population density is illustrated on the underlying map. Because of the default nature and origin of PRONTO data, it is strongly and positively biased with population density. If we would plot all the emergency tasks from the last two decades on similar map, we would see the dots highlighting all the major cities and other population centers and also the main network of roads. Southwestern Finland is a more densely populated area compared to most other Finnish regions (except South-Coast, i.e. Uusimaa region). If a similar event would take place in sparsely populated northern Finland, the number of emergency calls would be significantly lower.

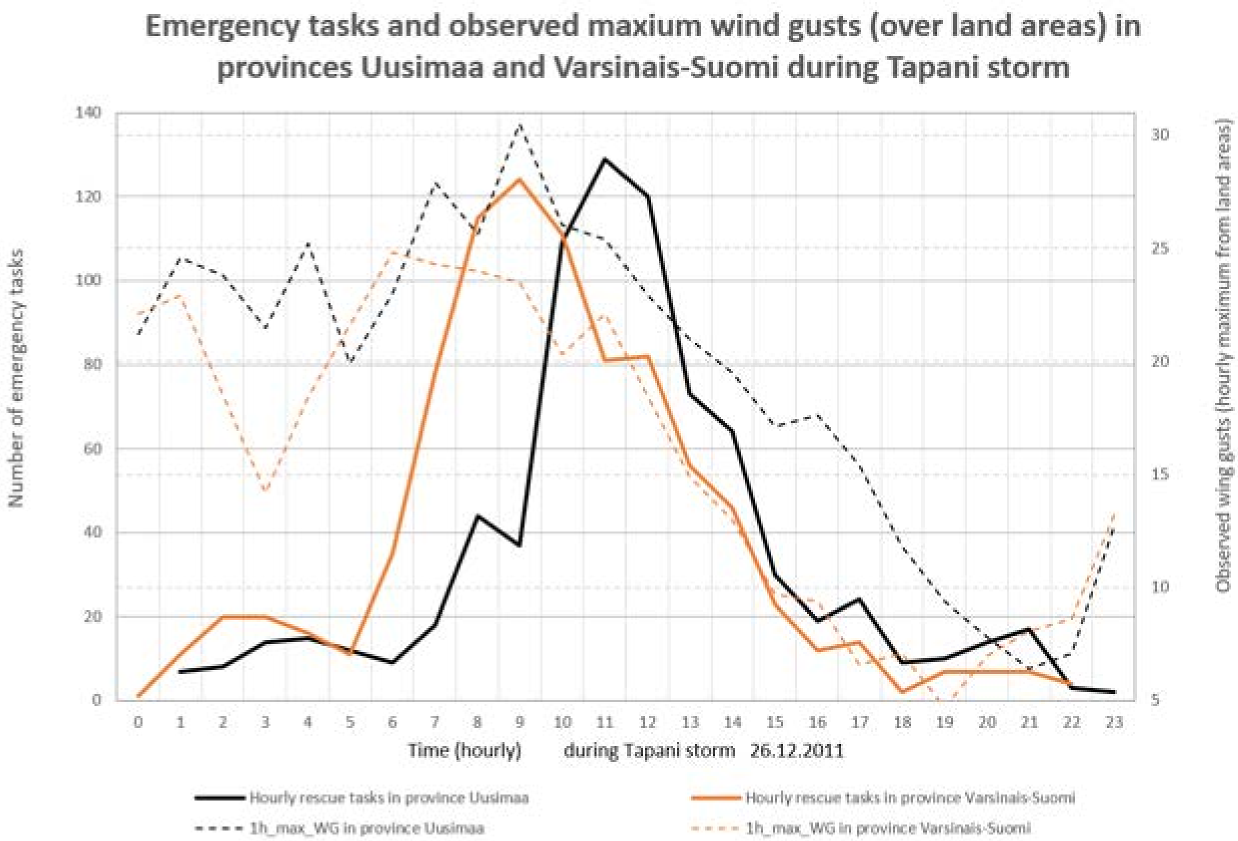

Figure 2.4 Emergency tasks and maximum wind gusts in provinces of Varsinais-Suomi and Uusimaa during 26-28th December 2011.

It cannot be underemphasized how important the PRONTO data is in the real-time monitoring of storm development. In figure 14 is illustrated Tapani storm related wind gust data and emergency tasks from two provinces, Varsinais-Suomi and Uusimaa, that suffered significantly from the storm.

In the Figure 2.4, both data sources are expressed hourly: wind gusts with hourly maximum (from the whole province) and emergency tasks with hourly sum (from the whole province). Marine wind gusts are not included to emphasize the inland conditions. Regarding the peak winds it should be noted that especially the maximum gusts in province Varsinais-Suomi are underestimated in the graph. This is due to a relatively poor coverage of inland wind gust measurements because of disruptions in observations during Tapani storm due to power outages. Impacts however confirm that gusts have been at least 25-30 m/s over large areas in province Varsinais-Suomi.

Due to the movement of the low-pressure system, the gusts peaked 2-3h earlier in province Varsinais-Suomi than in Uusimaa. The temporal difference is nicely seen especially from the time sift of peaks in emergency tasks. The graph shows also that the peaks of emergency tasks tend to lag behind the wind gust peaks. This is expected because the impacts keep accumulating until the strong winds are totally ceased, and on the other hand, because the amount of impacts correlates (especially in densely populated areas) with the number of emergency tasks. In the end of the day, the total number of emergency tasks in provinces varsinais-Suomi and Uusimaa was 1670.

The occurrence of wind damages normally increases when gusts exceed 20 m/s. In Tapani, wind gusts over inland reached 20 m/s already at night, but the occurrence of emergency tasks did not increase significantly until the morning. This is partly due to the timing of the storm and maximum wind gusts, but also due to the common behavior of people to report less damages during nighttime. People tend to sleep at night and be awake during the day. In general, this results in positively biased emergency call occurrence with daytime hours.

Regarding the relation between the rate of emergency tasks and maximum wind gusts, it can be concluded that when gusts were in the range of 25-30 m/s, the rate of emergency tasks was is in the range of 110-130 tasks/h. This is a simple but potentially very useful piece of information, not only for the situation follow-up but also for the future forecasting. This topic is discussed more in section 5.4.

Altogether, PRONTO data provides very timely and efficient good quality information. The data has very good temporal and horizontal resolution and is updated automatically. It is well-controlled and temporally homogenous. However, it in some extent lacks information about the level of significance regarding each task. PRONTO data has also a strong positive bias with population density.

2.4. From crisis data to damage data structure and evaluation

2.4.1 Wrapping-up emergency and outage information after the event

The event information stored into the PRONTO incident registration system is later processed into statistical information. The statistics also include information on the number of actions taken for rescue, clearance and assistance, response time etc. Similarly, the electricity disruption statistics are well recorded. However, there are no nationally compiled statistics on e.g. real estate damage and public infrastructure damage. To some extent damage to forests and commercial crops are estimated, by the use of national inventory data. Yet, these data sources may not be complete, and on the other hand contain other nature related damages as well, e.g. losses due insect outbreaks.

Individual power distribution companies in Finland are collecting the electricity interruption data separately, each on their own distribution areas. This data is gathered nationally from all individual companies by the Finnish Energy, a company producing the annual, public power outage statistics in Finland. The national data can be requested for research purposes from the Finnish Energy but data are aggregated in five areas, containing a minimum of six power distribution companies on each area. This procedure is to ensure the anonymity and the equal competitive situation for individual companies. The data consist of various parameters, i.e. the start and end times of the interruption, cause of the interruption, number of households without electricity and lost kilowatt hours during the interruption.

The electricity interruption dataset covers the years 2004 to 2018, thus, it is a rather long historical dataset. In addition, the real-time electricity interruption data on a municipality level is available at the Finnish Energy, however, the opening cost is high and there is a monthly maintenance fee. Similar type of data can be in some cases requested also from individual power distribution companies with higher spatial accuracy.

Area	**Cause**	**Location**	**Fault type**	**Start time**	**End time**	**Duration**	**Households Without Electricity**
1-5	Text	Location of the fault (transformer)	Code	Time	Time	Duration of the fault	Number of households without electricity

Table 2.2 Example of the power outage data format. In addition, other parameters are available in the original dataset. The data is available in CSV format. MANCA RIFERIMENTO NEL TESTO

2.4.1.1. Strengths and weaknesses of the power outage dataset

The dataset covers comparably long-time frame (14 years), which makes it useful for variety of research and product development purposes. The data includes numerous parameters, related to power outages; duration of the fault, household amounts without electricity, total amount of faults and the number of damaged transformers. The data includes also the cause estimation of the fault, done by the electrical engineers repairing the faults in the field. This is both, a strength and a weakness of the data. As the upside, this makes it possible to connect the faults with the natural phenomena e.g. with storms or floods, because the electricians are instructed to note down the most probable cause of the fault.

However, as often in the case with impact data, there can be some subjective components and mistakes in the interpretation of the cause of the outage. For instance, it is a common mistake in the data that the electricians working on the field confuse the 'Wind and Storm' cause (L1), with 'Thunder' (L3).
The dataset has been divided geographically in five areas presented in Figure 2.5, (Tervo et al. 2020, preprint, Láng et al., in preparation). As mentioned before, on each area there operates at least six power distribution companies. The areas are quite large which can make

the use of the power outage data non-usable for high-resolution studies or risk analysis. Therefore, we estimate the usability of the power outage dataset to be medium level. The length of the dataset is long, however, in some new approaches like in machine learning, the spatial resolution might be too coarse.

Figure 2.5 Aggregation of the electricity fault data in geographical areas (1-5) (Láng et al., in preparation).

The quality of the data is in general good. Still, some parameters of the dataset need to be filtered and double checked to be usable. For instance, the powerless household amounts had to be carefully filtered and still, there might be some of the households counted several times. In the data, one line refers to one fault. There is an automatic back switching system of the electricity, which is usually preventing very long power cuts, especially in situations when the line is not physically broken. When a fault occurs in the power grid system, the system switches the power off and back on after a short time. In our original, unfiltered dataset, also these lines of back switching are included. This procedure causes additional fault lines in the data and can cause doubling of household number, even though the duration of the power cut would be just 0,1 seconds long and not causing any problems for the transformer or the households. Therefore, the very short cuts and the double household records are filtered out of the data.

As described in section 2, Storm Tapani had the most severe wind gusts in South-Western, Southern and Western parts of Finland. Also, the highest population density areas in Finland are located in these same regions (Figure 2.3), so it was expected to cause massive damages for the electricity grids of these areas as well. Figure 2.6a shows the number of households without electricity and 2.6b the total duration of the interruptions caused by Tapani Storm in areas 1-4 (see Figure 2.5). The biggest impacts were recorded in area 1 (South-Western

Finland) with over 500 000 households experiencing power cuts during the Boxing day of 2011. Around 100 000 households were without electricity also on both areas 2 and 4 (South-Eastern and Western Finland). The durations of the power cuts varied from hours to weeks, reaching in total more than 200 000 hours lost energy which means a huge economical loss for power grid companies. In addition, society experienced massive economical losses (tens of millions of Euros), Tapani caused also several smaller cascading effects; telecommunication problems and evacuation of households (even elderly homes) days or weeks without heating in the middle of the winter.

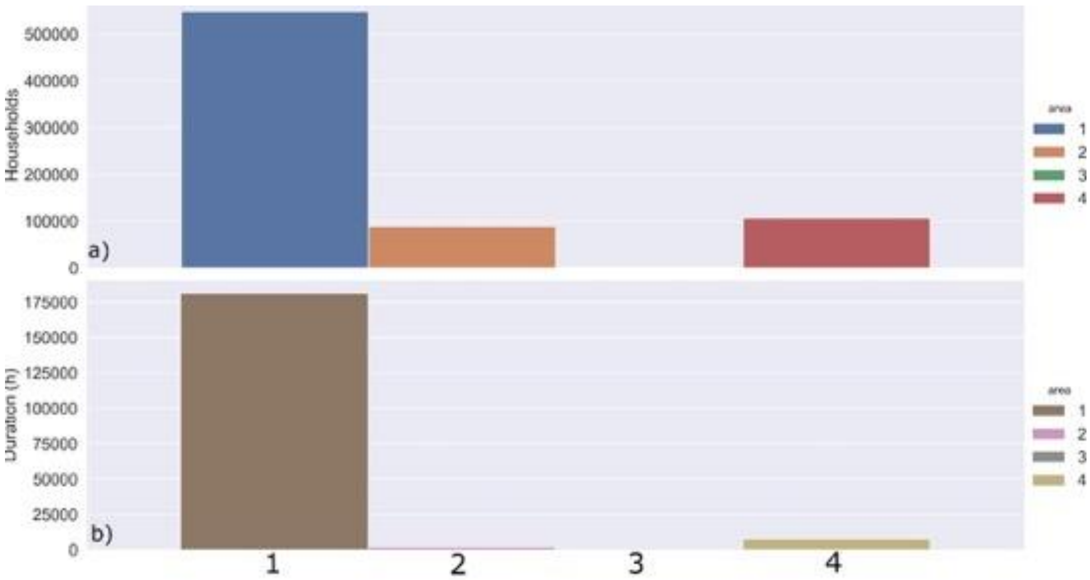

Figure 2.6a Households without electricity during Tapani Storm and 2.6b the total powercut durations caused by Tapani. The areas refer to the geographical areas presented in Figure 2.5 (Láng et al., in preparation).

2.4.2 From physical damage information to economic loss information

Whereas physical losses are observed, albeit incompletely, the economic interpretation of these losses is less straightforward and is not a standard procedure in hazard damage observation in Finland. To some extent economic loss can be inferred from insurance claims. Only for the electricity distribution system the costs can be estimated in a fairly straightforward manner thanks to systematic registration and compilation during and after the extreme event.

2.4.2.1. Dispersed and incomplete data regarding tree fall

Quantitative reports of economic losses of storm induced tree fall are not generally available in Finland (or elsewhere) for several reasons, such as dispersed ownership of forest, belated identification of damage and causal attribution problems, large variations in cost per clearance event, large variations in the wood price (per m^3) and the proper reference price (see also Albrecht et al 2012; Dubrovskis et al 2018). Authorities or experts may provide a crude estimate of tree loss after a storm, inter alia inferred from information in PRONTO and expert evaluation by the Finnish Forest Centre. Furthermore, the disadvantage of tree fall and the consequent lower m^3 price for all wood selling forest owners (Dubrovskis op cit) is matched by a benefit of lower purchase price for the forest processing industry. As for many impact assessments the notion of loss depends on the scope of the assessment.
An alternative source in Finland is the national forest inventory. Since forest damage insurances have become more common in Finland during the past decade, the relevant annual claim data of involved insurance companies would probably be the best basis for obtaining an estimate of the economic loss for forest owners, even though complete attribution of losses by storm may be difficult. Yet, such data sets are normally not available for third parties. An alternative would be forest inventory statistics from which prematurely removed biomass could be inferred, but attribution to storms would remain difficult. Obviously, another option is to use satellite imaging, but proper interpretation still requires additional information. It can be mentioned that from the PRONTO system can be retrieved information about clearance activity regarding fallen trees, but this item represents only a fraction of the overall costs. Finally, the Finnish Forest Centre has been developing their system to collect information from forest owners on wind and other abiotic as well as biotic damage that is expected to improve both accuracy and timeliness of information.

We may conclude that improved cooperation between the PRONTO system and insurance data sets, and better access to the latter ones could greatly improve the understanding of cost and cost variations in relation to weather characteristics, forest management, and ambient environment.

2.4.2.2. The cost of natural hazard induced outages

In case of storm induced outages in Finland it is mostly due to tree fall. In addition, accumulated snow on overhead lines in conjunction with strong winds can cause failures (in a part of the cases also without strong wind if snow and/or ice accumulation is abundant). Electricity supply failures due to lightning occur but they are much less than due to wind or snow. Outages, due to extreme weather or otherwise, are predominantly a significant problem in the countryside. The *average* disconnect time of low-voltage customers in (semi)urban areas is about 30 minutes / year. The same type of customers in the countryside experience *on average* about ten and half hours disconnection, of which over four hours due storms and over four and half hours due to snow and ice loads (partly in connection with strong winds) (Energiateollisuus 2020). In case of electricity outages the following costs occur:

1. loss of revenue for the electricity company[3] due to non-delivered electricity
2. cost for the electricity company due to mandatory compensation to customers with disconnects lasting more than 6 hours
3. cost for the electricity company owing to clearance and repair of the distribution network
4. monetized losses of customers due to the outage (lost production, lost stocks, lost assets)
5. decrease of welfare/welbeing of household members during and after the outage
    - of which a part may be monetized if it leads to medical care
    - a willingness-to-pay (to avoid such decrease or to be compensated in case of a decrease) can be inferred by means of stated-preference studies
6. If the outage is large and consequently demand reduces notably at national level wholesale electricity prices can be affected, provided supply capacity remained unaffected
    - again this means a loss of electricity generators, but a benefit for buyers of electricity (be it consumers or traders)

However, to assess the total cost of an outage not all items should be aggregated. For a start one could assess the total cost at the supply side (sum of items 1, 2, and 3). Alternatively, one can assess the cost at the demand side, of which only item 4 is monetized (+ medical cost under item 5). Yet, if one wishes to know the overall welfare effect it is the estimation performed under item 5, which is supposed to account for expected monetary cost as well. From studies about the value of loss of load (VoLL) we do know that the average use value of electricity is many times its price (London Economics 2013; Carlsson F, and Martinsson P. 2008). For commercial use of electricity this can be easily inferred, but for households a measure should be estimated. In this respect it should be noted that for compensation and avoidance of unpleasant events the survey or interview-based ratings of willingness-to-accept (WTA)[4] and willingness-to-pay (WTP)[2] may show notable disparities (Nurmi et al 2019).

[3] . For the sake of simplicity, we do not distinguish between distribution companies and electricity generators.
[4] WTA corresponds with the amount of (monetary) compensation a person at least requires to accept a situation. WTP corresponds with the amount of (monetary) compensation a person is at maximum willing to pay to avoid a situation.

2.5 Valorizing information by combining weather, emergency and/or sector disruption data

Manually, a lot can be achieved already in terms of reasonable weather warnings and impact estimates, when good quality impact data is at hand both in real time and from the past. Accumulation of experience from the past cases has helped to produce good manual impact estimates, especially regarding strong events. However, it might be difficult to maintain the quality of impact forecasts in terms of objectivity and validity from case to case and person to person.

As showed in the previous chapters, a lot of valuable information can be attained by comparing for example the wind gust observations and PRONTO impact data, both in real time and development-wise. The observed relations between the rate of emergency tasks and related maximum gusts can be used as a reference for similar situations in the future. As the different impact and environmental data sources are gradually increasing in number and in temporal extent, it eventually enables more sophisticated and comprehensive impact assessments and also enhances development regarding impact forecasting, vulnerability and risk mappings and contingency planning that help the society to prepare for different kinds of weather hazards.

This is possible only if all the data sources can be brought into a same database or can somehow be interconnected. Such database or data system could bring the much-needed objectivity, validity, and stability for the impact assessments. Other advantages from such system could be tailored and partly automated tools or services for a variety of customers in the different sectors of society. There are, however, many possible problems concerning the usability of different historical datasets. Different data sources need to be normalized. In other words, they need to be modified to make them somehow comparable with each other. This is not necessarily an easy task to do. There might be issues with temporal continuity and extent, homogeneity, biases, and timeliness regarding the data sources. Some sources might lack of unambiguity, or discrimination regarding different weather impacts. Some sources might not even be in data form but written on a paper instead. Normalization might also require some level of aggregation of the raw data. Some aggregations or supporting classifications can be very useful even if not mandatory. For many useful purposes, for example a province or municipality level aggregation is a compact and efficient way to present and condense information.

In the future, impact databases will be efficient tools to estimate weather related impacts. However, even if included data sources would be ideal, uncertainties regarding weather prediction models will always remain. For at least this reason there is always a large risk in fully automated products. This is an important issue to take into consideration when examining all the possibilities that the impact database can offer.

2.5.1 Potential use and benefits of impact database

Depending on the number and characteristics of the different data sources, impact database can provide very large variety of end-user solutions. Here are some very simple but practical examples. In a case of storm, for FMI Safety Weather Services the approach at first is to assess the probability and magnitude of the storm concerning meteorological information. This is the first source of uncertainty in the whole process. However, when there is an agreement for the range of wind speeds, the process of assessing the consequent impacts can begin.

Example 1:

In its simplest level, impact database provides historical information on similar storms in the past. To access this information, the user should execute a database search that is based on the known characteristics and environmental conditions of the approaching storm. The level of detail in the search depends of course on the data sources available in the database. Let us assume that the database includes at least the following parameters: wind gust and soil frost observations, PRONTO emergency tasks and electricity outages. Already this minimal set of information sources could provide very useful information to estimate impacts.

Let us assume that the imaginary storm is expected to hit the provinces Uusimaa and Varsinais-Suomi with gusts ranging from 25 to 30 m/s and lasting about 5 hours. Let us also assume that expected time is November and soil frost is negligible. With the given information, a database user could execute a search according to the expected weather forecast and environmental conditions. The search would then return a list of dates (storm cases) and associated impacts (emergency tasks and number of households without electricity) matching the original search criteria. Obviously, one case matching this imaginary storm would be the Tapani storm.

The more cases the search returns, the more credibility is gained for the impact estimate. If the number of cases is too small, then the criteria could be loosened to get more cases in return. Then a larger number of cases could be used to calculate median and also upper and lower limits of the expected impacts.

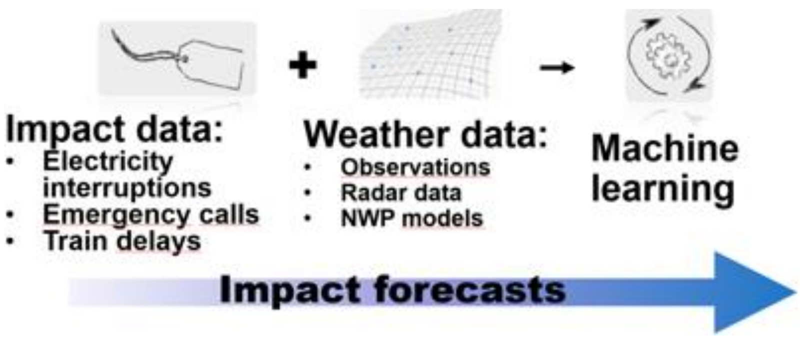

Figure 2.7 General concept of the usage of impact data and weather data in machine learning and developing impact forecasts.

Example 2:

Impact database can be also used to benefit researchers and impact tool or software developers. For researchers and impact modelers, the access to a good quality of impact data can be challenging. Often the researchers need to contact different sectors to request for impact data which can be time consuming. It can be also very ineffective if several researchers, sometimes even from the same organization, are spending time searching and requesting for the same impact datasets. To speed up the data collection process, well-organized and easily accessible impact database can be a highly valuable tool. In this example we also explain, how the impact database can be used to develop decision support tools for different sectors. For example, machine learning can be used to combine weather related data with impact data of different sectors and to find new dependencies between parameters. Machine learning can be further used as a base for algorithms to predict different societal impacts of natural hazards (Figure 2.7). Figure 2.8 shows an example tool and a possible use case for the power outage data. The tool was developed for power companies to improve their preparedness for convective storms. The strong winds and the lightning related to convective storms can cause significant damage to the power grids. Convective storms are typically very small-scale storms with very rapid development cycle and are often difficult to forecast precisely with numerical weather models. Therefore, tools like this might reduce the respond time of power grid companies and help them to anticipate the location of potential faults. The tool is already piloted by few power companies especially some hours before or during the hazardous weather event. This tool is an example of a decision support tool of FMI that has been developed in cooperation with the power company to improve company's employer's situational awareness and preparedness. The tool was developed by utilizing machine learning techniques (Tervo et al., 2018 and Tervo et al., 2020) and training the algorithm with both, weather and impact (power outage) data (Figure 2.7). The benefits of the tool are to provide the power grid company's workers better preparedness for power outages caused by thunderstorms or extratropical cyclones and, thus, for the company to save money by preparing with the right amount of repairing teams and to reduce the fault fixing times. The tool can also be used to inform power grid companies' customers about dangerous situations.

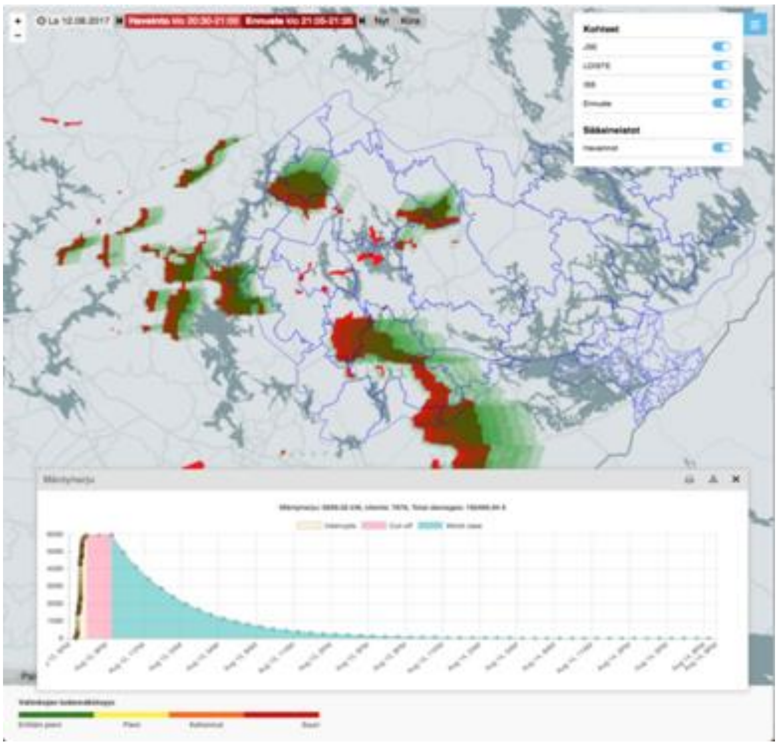

Figure 2.8 Example product to forecast power outages and their economic impacts for power grid companies. The graph of the figure shows the time estimation and the economic impact estimation of the thunder storm cell. The map shows the predicted location of the thunder storm cells (red color shows the current location and severity of the cell and green color shows the estimated moving direction of the cell), the temporal resolution of the tool is 5 minutes.

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3. THE FRANCOLÌ FLOOD IN SPAIN, 2019 SHOWCASE: USING DAMAGE DATA TO ENHANCE EMERGENCY MANAGEMENT AND CONNECTION TO EARLY RECOVERY

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The Cecat is the Operations Coordination Centre of Catalunya and is the unit involved in the Lode project. The idea has been therefore to improve current damage data monitoring and decision making tools to address not only post disaster recovery but also immediate needs during the emergency so as to support and guide civil protection coordination of resources and means once an incident has occurred. In order to do this a dashboard has been developed using ESRI functionalities.

The data from the xx were used to develop and test different dashboard layouts until the most appropriate one has been chosen based on the needs and requirements of the officials working in the unit. This work has been performed by expert IT developers who are part of the unit and defined through different meetings among concerned units, including those who will be guided in the field during an emergency. It is important to point out that without the Lode project this application would have never been accomplished, even though it does serve a real need for the Authority.

The following steps have been performed:

- Data from the 2019 Francolí floods have been collected
- Different dashboard layouts for performance with available data and collaborative settings have been tested and the most efficient has been selected
- Real-time data services for future events have been searched in order to be able record real-time data to be used for further subsequent analysis (forensics, risk analysis, etc…) according to the Lode project methodology.

The following screenshot represent the type of results that have been obtained and the type of information that can be provided to the operators. One added value is certainly the possibility to visualize in the same screenshot different data and information of relevance.

Even though the data are those taken from the Francolí showcase, some have been modified for the sake of the demonstration (i.e. the number of victims that is far higher than the real one).

In Figure 3.1. the following information are reported, starting from the upper left side: first the number of calls to the emergency number (453) then the number of affected roads (13) and the number of power outages (282). Going to the right side, first the number of victims is reported. Below a graphic information reporting the total precipitation in each municipality in the event. The central map permits to locate where the power cuts have been reported as well as road unserviceability.

Figure 3.1. Information represented in the developed dashboard

In Figure 3.2. Information is shown in another scale (considering for example all the municiaplities that issued an alert for the event) or in another form, for example in the left upper part the relative amount of precipitation recorded in each municipality. This information is certainly useful to give an immediate idea of where the largest problems may be found but is an extremely useful information later for analytical purposes, in particular for evaluating and improving risk assessment models, as an exact and local scale value of precipitation is provided.

Figure 3.2. Additional information shown in the dashboard

In Figure 3.3. larger scale information is provided with the mapping visualization of the areas that were affected by the highest levels of precipitation, the total number of Km of roads affected (with is an important complementary information to the number of roads), as well as the number of customers deprived of communication services (15.766). This latter number is pretty high, but it must be considered that each person almost owes a cellular phone and this explains the large number. In the upper right part information on the affected population is reported (number of deaths, very severe, severe and light injuries).

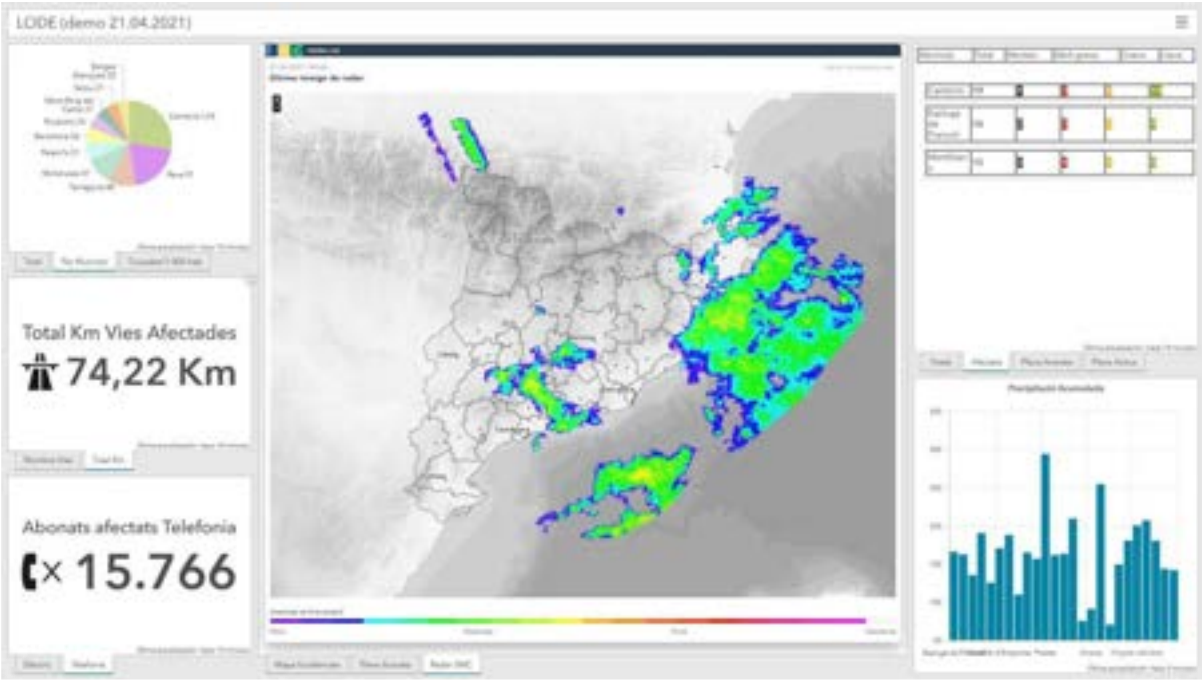

Figure 3.3 Larger scale information

In order to appreciate the value of the developed application, it must be noted that the conceptual approach of the Lode project has been useful to identify the key information to be considered and geolocated. Also, it is a way to capitalize on the large amount of data that usually pours to the emergency control centre at the time of an incident and that is usually lost afterwards and rarely used for further analysis both of the effectiveness of the emergency management procedures and plans and of the vulnerabilities the incident has actually highlighted also as far as the affected region is concerned.

The further development that is envisaged is to link the dashboard to the Lode project information system so as to guarantee that the data collected in the dashboard become the "time '0'" information that can be later updated or specified during the recovery and the repair phase.

4. USING POST DISASTER DAMAGE DATA FOR FORENSIC INVESTIGATION OF DISASTERS- APPLICATIONS TO THE CENTRAL ITALY AND MILAN SHOWCASES

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4.1. Forensic investigation of disasters in the Lode project

Following the results of the Idea project, it can be held that three main types of post-disaster investigation are at the origin of the forensic investigation of disasters as conceived in the Lode project, as follows: forensic in the more traditional sense of managed in tort courts; investigations as traditionally carried out after severe accidents in industry; and a more recent field opened by a number of independent initiatives having all in common the idea of eliciting the causes of damage that has occurred after a natural extreme. Such initiatives comprise the Forin project launched in 2010 by IRDR, the Perc method developed by Zurich and the so called "return of experience" dossiers prepared in France after some disasters by public administrations.

Those different interpretations are all relevant for the type of approach that is proposed here and merge into the framework that is depicted in section 2. Such investigation typologies will be discussed adopting different lenses, namely considering: the objectives of the investigation, the type of causality that is implied, consequently the type of data and evidence to support the search of causal links between triggering factors and damages, and finally the type of learning that can be achieved as a result of the investigation.

4.1.1. Forensic investigation to serve tort law cases

In the USA litigation suits on damage due to natural hazards, mainly erosion, floods, landslides etc., has already a long enough history to foster the production of literature aimed at educating and training those who will act as experts, mainly engineers and geologists (Slosson and Shuirman, 1992), in a court. Also in Europe though such cases have become more frequent in the last decades, especially regarding cases of damages due to presupposed negligence of public authorities in providing structural defenses or in maintaining existing protections and riverbed. However most of those cases used to refer to localized facts, regarding very specific damage suffered by owners who wanted to get compensated after an extreme event in cases where they considered public administrations have omitted to guarantee safety as would have been required by them.

In the more recent years, though, we have witnessed an escalation in the type of cases that are debated in courts, that as held by Lauta (2016) signal a change in perspective on the so called "natural hazards". In fact, a conceptual shift has occurred from considering disasters as unavoidable facts due to uncontrollable forces towards the recognition of the intimate social nature of the extreme consequences natural forces may provoke on vulnerable exposed assets and communities. Lauta indicates in the term "vulnerability" the major novelty mirroring a general shift of interest from hazards towards vulnerability and resilience. If the creation of vulnerability is the major component of disasters, responsibilities for its development and piling up overtime can be sought, at least in principle. Bretton et al. (2015) present a number of cases that are very relevant as for this escalation: the Katrina case for the flooding of New Orleans in 2005 and the overly complex case of the l'Aquila trial after the earthquake in 2009 that affected the capital city of the Abruzzo Region in Central Italy. Both cases manifest a tendency that is apparently on the increase (see Farber, 2009) in the era of climate change to search for liabilities in entire bodies of government, including organisations of scientists serving as experts and consultants, and for damages that are not limited to the physical destruction of individual items but for victims and widespread damage triggered by large events, but considered as the main consequence of negligence regarding protection and in the creation of vulnerability. What is of interest here is not the discussion regarding whether or not such cases are forming the basis for a much wider implication of government, organizations with responsibilities in risk prevention and mitigation (including some relevant service providers as energy and water companies), but rather the understanding of how such cases can help in enhancing our knowledge and our responsibility as scientists in learning lessons on disasters as a complex mixture of different components besides hazard, that are exposure, vulnerability etc.

As for the causality, it is important to understand that the recourse to scientific expertise is serving not so much the purpose of finding out the "true" reasons for damage but rather the argument of the part for which the expertise is asked for. This does not mean necessarily that the truth is manipulated, but rather that it is presented or cut in parts and then the parts relevant useful for the case are selected and investigated more in depth. In this regard the case of Katrina is extremely enlightening: from the technical explanation of the flooding as due to poor maintenance of levees (that would have implied mainly the responsibility of the US Army Corps of Engineers), in consequent appeals, the causality model shifted towards larger environmental mismanagement aspects involved in the poor design of the water channel that had been constructed some years earlier and that funneled water into the city without any possibility to avoid it. As such large disasters are complex in their unfolding, it may well be that all causes that have been debated in court have a share in the overall disastrous outcome. However the main goal in a court is to find out clear cut responsibilities and make them pay for negligence, misconducts, mismanagement, etc. In a nutshell it can be said that in a tort suit the main objective of the forensic investigation is to find out liabilities in a convincing way so as to be able to punish misconduct and/or compensate victims for the damage they suffered, be it physical harm to people or damage to their properties and goods.

Data that are collected and analyzed in tort cases are aimed at providing evidence supporting the case of the counterparts in the litigation, their use serves a specific purpose and a specific interpretation of the event, of its development and its causes, and not so much to learn lessons in a “neutral” sense. An important antecedent and reference for “natural” disasters can be found in cases after severe technological accidents, that are actually the second type of forensic investigation that will be considered in this paper. In the latter, there has been a tendency to overcome the strict search for responsibilities pattern towards the recognition that large severe, the so called top accidents are rarely the result of on single error but rather the final outcome of chain of failures occurring in complex socio-technical systems, where management mistakes are as (or even more) relevant than the individual factor that triggered the accident. As a consequence of such recognition, a field of investigation has developed in the aviation industry and in similarly complex technological systems (chemical plants for example) that aims at eliciting the various elements of the chain of failures, often implied by the human-machine interface, but not limited to the action of the operators. The shift towards enquiries that are aimed at learning lessons from mistakes and failures to improve the performance of the organization requires that the goal will not be the punishment of single conducts (unless proved to be clear negligence and/or misconduct), but rather the enhancement of the performance of the whole organization, considered in its environment as well as for other organizations in the same field that have not suffered any accident but clearly benefit from the discovery of latent vulnerabilities and weaknesses in their own systems they may have not been aware of until that specific accident has occurred. The different forms of “forensic investigation” of natural disasters that will be discussed later respond to this call for more open, public inquiries of disasters aimed at learning lessons valid for all those organizations, public and private that hold some responsibility in natural hazards management.

4.1.2. Accidents investigation

The investigation of accidents has a long history, firmly rooted in the aviation industry but not only and may count on a significant apparatus for the identification and the analysis of causal links. In the analysis of the causes of an accident, one has to identify the key factors triggering the sequence of failures that led to the so called “top event”, their interplay in the specific case given environmental, organizational and even cultural settings. Crucial links among factors must be found within a given spatial and temporal nexus, therefore carrying out the back analysis until what Turner (1978) intelligently named the “incubator” of the disaster is found. There are several tools that can be used to trace back the causes overtime, such as the fault and the event tree that are widely used. In order to use the latter, data that are searched for must be detailed, reliable, precise, consist of a mix of information regarding the operational environment in which the accident has developed and of quantitative data regarding the various variables that are implied by a specific industrial process, by the stocked substances and some quantitative and semi-quantitative information regarding the toxicity, inflammability, in a word the hazardousness of material stored and managed.

The final outcome of the investigation are lessons that can be learned at various levels (Roux Dufort, 2000) ranging from the dynamics of the event itself, to the existence and performance of in place emergency devices and protection means, to the overall safety policy and strategy of the involved firm. Results of the investigation may trigger changes in management schemes and modalities, in the improvement of monitoring systems, but also at a wider scale in the legislation and safety rules of a specific sector.

4.1.3. Forensic investigation aimed at unveiling causes and drivers of risk

We have decided to group together a number of initiatives that are not strictly connected to each other, namely the initiative by Forin, the Perc methodology proposed by Zurich and the reports prepared on the occasion of some events y public administrations in Europe, especially in France where they are conducted with a good level of detail and at a rather local scale, to account for the overall damage a natural disaster has provoked and the experience in managing it.

The Forin initiative has been proposed by the IRDR in 2010 and then the methodology has been revised and systematized in 2016 (Oliver Smith, 2016, Burton, xx). The main objective is to find out the social, political root causes and drivers, intended as those factors such as poverty, corruption, poor practices and poor enforcement capability that are at the origin of the damage suffered during and after severe disasters.

The Perc methodology consists in a thorough analysis of some damaging events as part of the social corporate responsibility mission of the insurance company Zurich, but has inevitably as one of its main objectives to “develop perspectives on appropriate risk transfer and risk management solutions in flood vulnerable areas, including the pre-requisites for their effective functioning”.

The “Rétour d’expérience” in France have been developed with the idea of collecting and preserving crucial information on extreme events in order to develop knowledge regarding the cost of disasters across different economic and societal sectors. They should serve the important objective of systematizing such reporting so as to feed public debate also at the highest levels of government (Sanson, 1999). Even though the three types of investigation are not fully coincident, we may group them as for their main objective that is enhancing knowledge and understanding of disasters to improve current mitigation capacity.

As for the type of causality, it can be held that the three instances of forensic investigation look for causal links in a or explorative sense, without the compelling need to demonstrate shares of responsibilities (as in the case of the tort cases) nor to limit to compelling evidence of errors and failures as in the case of accident investigation.

The type of data that are looked for is therefore not necessarily complete, exhaustive, fully reliable, detailed and from sources recognized for their quality and trustworthiness. This permits actually a wider use of newspapers and more recently of social media data providing insight into service outages, criticalities faced by search and rescue agencies, etc.

The learning outcome on the other hand is more vast, encompassing all risk factors and considering also social and environmental aspects in a large sense.

Here we wish to advance the proposal of our own methodology to carry out forensic investigation of disasters that we have developed starting from the Idea projects and largely based on the intuition of De Groeve et al. (2013) going through an application in the field of volcanology to reconstruct the consequences of the 1999 Mount Cameroon eruption with the aim of describing and possibly explaining how exposure, vulnerability and resilience (or lack of) have shaped the damage in the short, medium and long run (Wantim et al., 2018) to the current application in the context of the Lode project. In the latter, the aim is to reconstruct the event in its complexity including the identification of main risk factors, of their links and intersections to produce second and higher order damage and the contextual elements that have or have not acted on the risk factors contributing to reduce, mitigate or on the opposite increase the expected impacts and their severity. In the Lode project we have addressed more broadly the use of forensic investigation to analyse multi-hazardous events with cascading effects (see Boni et al., 2020; Menoni and Boni, 2020).

4.2. Intrinsic complexity of disasters due to multi-hazardous events and limitations in current multi-hazard and multi-risk assessment models

In the last years there has been an increasing interest in multi-hazardous events, as both interveners in a disaster scene and scientists have become more aware of the fact that in many occasions extreme events do not occur as single phenomena. Often multiple phenomena occur simultaneously or within a very short time delay in the same area each provoking damage and impact in a given territory. Delimiting the latter is a matter of spatial scale, especially when certain types of hazards, such as those meteorologically driven, are considered. For example, a severe storm may affect entire regions and even states provoking locally a number of different effects, such as localized landslides, floods, intense precipitation, grail, etc. This has been the case in Europe with large devastating storms that can be recalled such as Xynthia in 2010 for France, Tapani (2011) for Northern Countries and especially Finland or in Northern America with a long history of devastating hurricanes such as Andrew (1992) Katrina (2005), Sandy (2012), Harvey (2017). Hurricanes in fact are not only devastating because of extreme winds, but also or even more for a number of enchained effects conducive to extensive floods and na-techs. Considering the Italian case, that is known to the author as a first hand professional experience, reports written by Regional Civil Protection Authorities in the aftermath of severe hydro-meteorological events in the last years are rarely informing about a single large phenomena, rather, increasingly, about multiple occurrences that comprise severe precipitation (rain or snow), hydrogeological phenomena (landslides and /or avalanches), joined with mountain or riverine floods. The complexity of such events is challenging for interveners who are faced with events that unfold in a matter of minutes to hours overwhelming their crisis management capacity and defeats the dominant scientific approach according to which hazards are studied separately by experts with different disciplinary background. Also because of such fragmentation of expertise, multi-hazards are difficult to analyse and especially to model. Despite recent attempts (Mignan et al., 2014), the whole topic is still at a very pioneering stage or tackled qualitatively. Until now most scholars focused on assessing their probability (Mignan et al., 2014; Liu et al., 2016), which is very challenging given the lack of sufficient time histories that is partly due to the fact that such events were not recorded in the past as multiple occurrences.

No matter how difficult it is to assess multi-hazardous events, it is certainly even more so to address multi-risk conditions, including the vulnerability of systems and assets in a multi-hazardous environment. When dealing with areas where industrial settlements or lifelines such as gas conducts, power generating plants are located, the potential for a technological accident that may be triggered by a natural phenomena increases. Since the introduction of the term na-tech in the literature in 1992 (Showalter and Fran Myers, 1992) a large body of information and research has been developed on the topic, providing a more mature understanding of the multiplicity of failures that may affect a region in case of severe incidents (Galderisi et al., 2008; Krausmann et al., 2016). Some failures originate because a vulnerable asset can be also hazardous (like the case of a water treatment plant that may provoke a huge contamination effect as was the case feared in the Tewksbury example in the 20017 Severn flood, UK). In other cases ripple and amplification effects may provoke the halt to vital services or hamper business continuity in key economic activities. As discussed in Menoni et al (2017), the multiple dimensions of damage must be understood and analyzed not limiting to the direct physical impact that is the most evident but not necessarily the most relevant for the recovery of affected communities. Following the proposal of Rose (2004), we preferred to avoid the rather generic term “indirect damage”, recognizing that there may be a chain of effects and consequences that are due to the interconnection and interdependency of components of systems and between systems in a region that has been hit by an extreme event. We were proposing therefore to distinguish between direct physical damage, provoked by the initial stress (or by the chain of multiple stresses in case of multi-hazards), the second order or systemic damage where the functionality of relevant services and businesses is hampered by the dependency of the latter on components of the systems that have been physically harmed, a third and higher order damage in case such lack of functionality triggers a more vast array of consequences on entire sectors of economy and for longer periods of time. By proposing this concept of chain of damages a reference was made to the enlightening work by Van der Veen and Logtmeijer (2004) who were considering the systemic damage as triggered by physical damage to one or more crucial components of systems on which other systems depend rather than directly by the initial stress.

Similarly to the classification of different types of connections among phenomena and incidents, there is the need to categorize the different interdependencies and interrelationships that exist among societal systems, sectors and sub-sectors improving the level of understanding and characterization of the mutual relationships that exist at the component, sub-system and system levels. Improvement of risk models would require a more advanced conceptual framework, making use of “extensive database of information involving different infrastructures, features of disruptive events, and detailed social and economic costs” (Hasan and Foliente, 2015). Such framework requires a better understanding of the interaction between physical factors influencing the damageability of crucial components and parts of different sectors, the disruption in the functionality of the latter and the systemic vulnerability and resilience elements that may amplify or reduce the disruption in the operability of sectors and sub-sectors at different scales (Zio, 2016).

We present a framework for describing consequent damage scenarios triggered by multiple hazards, in combination or independently from one another. As discussed in Menoni et al (2017), the multiple dimensions of damage must be analyzed not only with respect to direct physical impact but also in relation to second and higher order damage (Rose 2004). This is more than just indirect damage as it recognizes that there may be a chain of effects and consequences that are due to the interdependency of components of systems and between systems in a region hit by an extreme event. Menoni et al (2017) proposed distinguishing between direct physical damage, provoked by the initial stress (or by the chain of multiple stresses in case of multi-hazards) and second order or systemic damage where the functionality of relevant services and businesses is hampered by dependency on components of the systems that have been physically harmed (Van der Veen and Logtmeijer, 2005). Additionally a third and higher order cycle of damage occurs when lack of functionality triggers a vast array of consequences on entire sectors of economy and for longer periods of time.

A framework of this type would need to account for how physical damage transforms into lack of serviceability and functioning capacity across systems escalating towards entire societal and economic sectors, following the definition of different types of damage as proposed in Menoni et al. (2017) and illustrating in the fishbone graph in Figure 4.1. The shift from a physical damage to a systemic disruption depends not only on the intrinsic physical features of affected components, but also on organizational aspects and also, as will be discussed later, on the territorial context where the failure occurs.

Figure 4.1 summarizes the framework that is proposed for including in the same scenario assessment the different linkages due to the interaction or co-occurrence of multiple phenomena, the differential sequence of impacts due to the latter and to the ripple effects created by systemic vulnerabilities, response and coping capacity (or lack of) and resilience. The framework is organized so as to show the logic sequence of effects across the time scale that is represented in the shift from one level to the following one. The stressing factors (hazards and physical damage) are always reported on the upper part of the sequence line, whilst the vulnerability and resilience factors are always represented in the lower part.

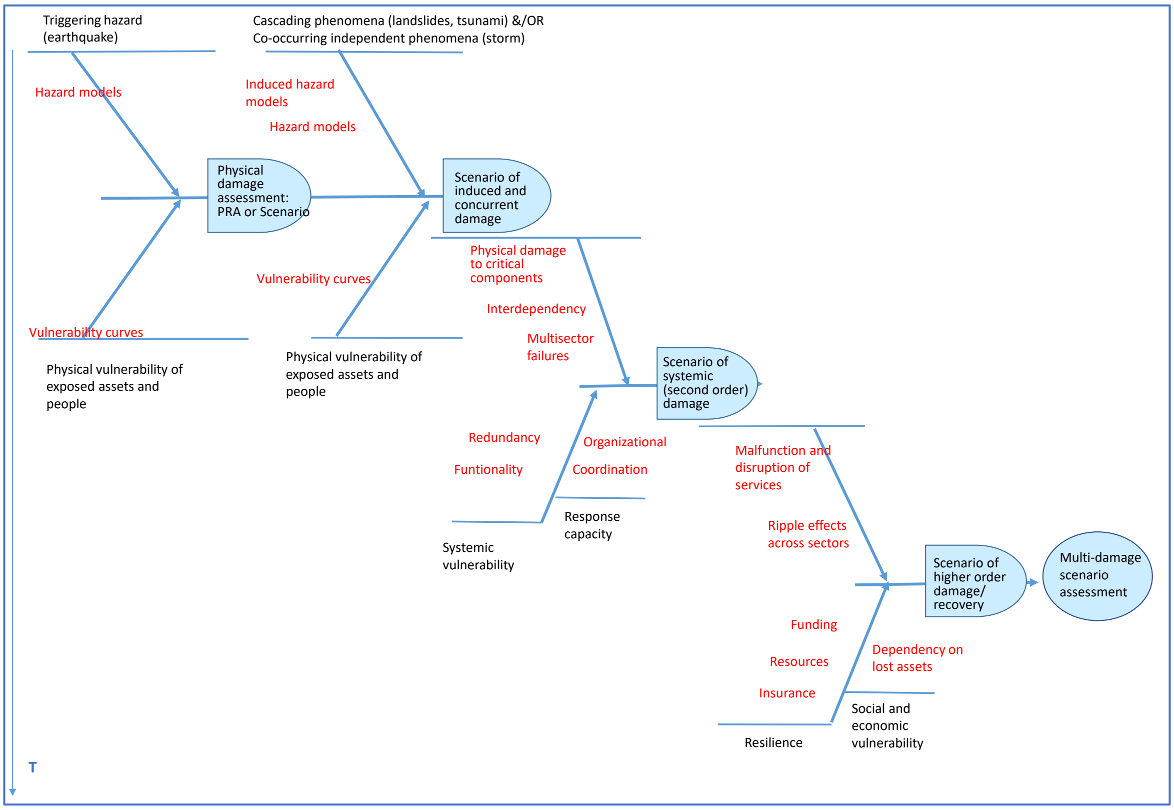

Figure 4.1 Sequence of multiple hazards and consequences

The framework is organized so as to follow the logic sequence of the effects across the time scale represented along shifted levels. The stressing factors, that are the hazards for the first level and the first and following order damage are always reported in the upper part of the sequence line, whilst the vulnerability and resilience factors are always represented in the lower part. The first order damage is the physical impact resulting from the stress produced by an initial hazard occurrence, triggered or co-occuring hazards and the physical vulnerability to the latter of exposed assets and people. Second order damage results from the combination of the first order physical damage and the systemic vulnerability of complex systems that can be counterbalanced by effective coping capacity of responding organisations and community (or instead magnifying the effect of systemic vulnerabilities). Higher order damage can be identified in larger systems and sectors that depend to different degrees on systems such as lifelines, supply chains and services and that are in their turn interconnected to each other (like for example economic activities that pertain to the same production chain).

Two showcases will be analysed using the fishbone representation technique to disentangle the different factors of hazard, exposure, and different vulnerabilities that can be identified as causes of damage and namely: the Central Italy seismic swarm 2016-2017 and the 2014 flood that affected the city of Milan.

4.3. The showcase of the Central Italy seismic swarm 2016-2017: analysing cascading impacts

4.3.1. A multi-hazard event

As for the hazards, the four regions of Umbria, Marche, Abruzzo, and Lazio in Central Italy have been affected in the period comprised between the 24th August to January 2017 and till today by a prolonged seismic swarm with epicenters moving from North to South and back North along a system of active faults in the Apennines following a sequence that was witnessed also in the past (in particular in the XVIII century). Thousands earthquakes have been recorded in the area, even a year after January 2017, however the highest peaks occurred in the period comprised between the 24th August 2016, when the first 5.9 shake hit a mountain area between the Marche and the Lazio Regions with epicenter very close to the town of Amatrice. Other two very strong earthquakes occurred on the 25th , 26th and 30th October 2016, reaching a maximal level of 6.5 on the Richter scale in the last shake of this sequence. A series of 4 events occurred on the 18th of January 2017 January, the strongest of which reached a level of 5.5 on the Richter scale with an epicenter close to the town of Campotosto in the Abruzzo Apennines. Given the mountain setting, numerous landslides were triggered by the series of earthquakes on already instable slopes. Out of the 541 interventions that the Anas company in charge of the road system carried out in the weeks and months after the first shakes, 65% regarded landslides (Boni et al., 2020).

In January 2017, an exceptional and prolonged snowfall occurred starting on the 5th of January and lasting on the 23rd. The snowstorm has been particularly intense in the Abruzzo ad Marche regions with significant accumulation in the mountains. The snowstorm was clearly divided into two main sub-periods, before and after the 15th of January, the second period being characterized by significantly larger amount of accumulated precipitation. Here the focus will be on the Abruzzo Region for which we have more data and more advanced analysis. Considering the recorded snow accumulation, it can be seen from the graph in Figure 4.2 that the largest amount occurred in the days between the 15th and the 23rd of January.

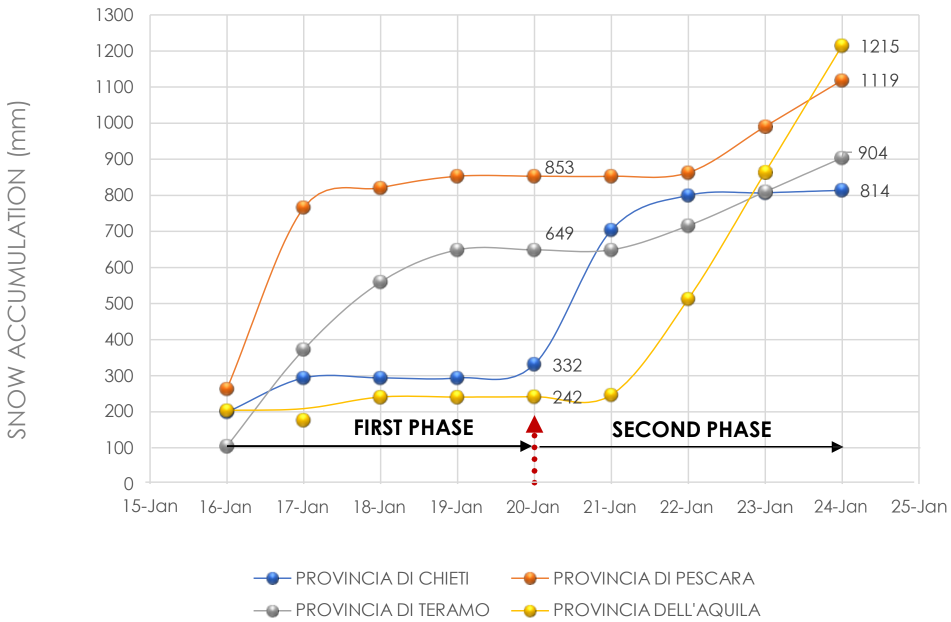

Figure 4.2 Snow accumulation as recorded by Enel and Terna

The snowstorm affected severely the power system: the accumulation of wet snow sleeves damaged power overheads while trees fell on both high voltage and medium to distribution lines. A number of transformation rooms in substations were disconnected as a result of disturbances along the lines resulting in a large number of outages across the four provinces of Abruzzo as can be seen in figure 5.

Last but not least, the 18th January earthquake provoked a series of avalanches, in the sadly known case of Rigopiano, where 29 people died trapped in a hotel, and in Campotosto, where a person died as a consequence of the avalanche that hit him when he was outside trying to clean the vast amount of snow in front of his house.

In an effort of transparency and accountability to their customers and to the public at large, the two companies on charge respectively of the high voltage lines (Terna) and of medium and distribution lines and service provision (Enel) published on a daily basis on their website information and data regarding the snow precipitation, the outages, the number of customers for which service was progressively restored. The quality and the detail of the provided data was enough to develop some analysis the results of which are briefly described here (Koçoğlu, master thesis 2017).

4.3.2. The effects of the landslides triggered by earthquakes on the road system

The evolution of the seismic crisis in the months between August 2016 and January 2017 caused a continuous evolution of the landsides activations and displacements. After the 24th August event, the triggered landslides were very numerous and spread in the territory, but, in most of the cases, characterized by limited dimensions, with the exception of the well-known case of Pescara del Tronto. The situation though worsened significantly after the October events both in terms of number and dimension (GEER, 2017).

Phhenomena such as rock-falls, debris-falls on the roads, or cracks/failures of the roadways impacted severely the road system interruptiing and/ot reducing its functionality over a large area. These criticalities had to be added to the numerous direct damages caused by the earthquakes (e.g.: to bridges and retaining walls).

Due to the complexity of the problem, the national government decided to design Anas (National Autonomous Roads Corporation) as the unique subject in charge of analyzing, coordinating and managing the damages and the consequent interventions in collaboration with the local administrations and Civil Protection (D.L. n. 205/2016). In order to define a program of prioritized interventions, specific criteria were applied, balancing the relevance of the various roads for the emergency phase (e.g.: to guarantee the access to the temporary sheltering areas or the accessibility to the debris storage areas) and the level importance of each road for territorial accessibility (e.g.: a main road connecting two regions is more important than a local road). The program signed in 2017 is still undergoing and its specific realization can be followed through a devoted website (http://www.anas-sisma2016.it).

To understand the dimension of the problem and the weight of the landslides effects in the total amount of criticalities, it’s possible to download the data from the interactive map published in the website (updated to May 3, 2018, Figure 4.3): overall 541 interventions are reported, 65% of which regard landslides.

The functional second order damage, in terms of interruptions or limited accessibility before and during the interventions, varied depending on the type and relevance of roads. As an example, intervening on a series of rockfall threatening a road required several subsequent interventions to retrofit large portions of slopes required to close and reopen the same road tract more than once to permit the access and the works in safe conditions.

In the following two examples of functional second order damage will be discussed in more detail.

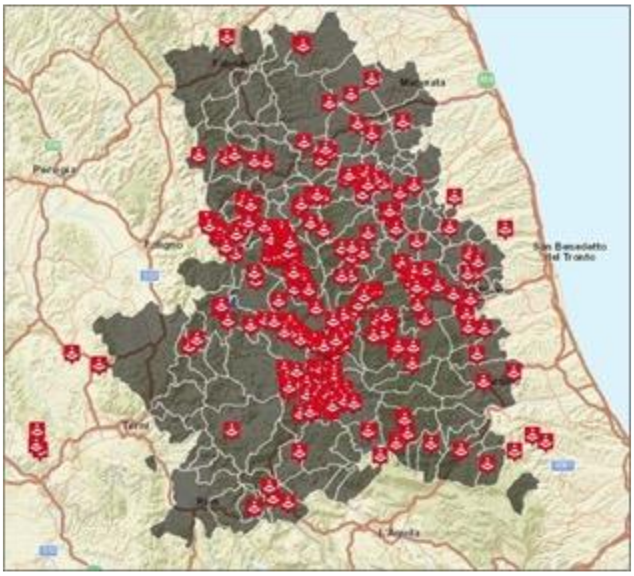

Figure 4.3 Anas interventions at different work progress updated to May 3, 2018 (http://www.anas-sisma2016.it)

The first case regards the provincial road number 209 (Valnerina), an important connection between Umbria and Marche regions, that, during the 2016 seismic crisis was affected by a large number of landslides, in most of the cases rockfalls. Figure 4.4 shows the impressive rockfall provoked by the 30th October 2016 earthquake near Visso (km 65.8) that fall down in the narrow valley where the sp 209 road runs parallel to the Nera River. The road and the river were buried by a large amount of deposits and the riverbed diverted, flooding the road following the sequence represented in the scenario diagram in Figure 4.5.

Figure 4.4 The rockfall triggered by the 30 October 2016 earthquake on the sp 209 and Nera river (courtesy of https://www.perugiatoday.it/foto/cronaca/terremoto-norcia-frane-valnerina/aa644aa1.html#&gid=1&pid=1)

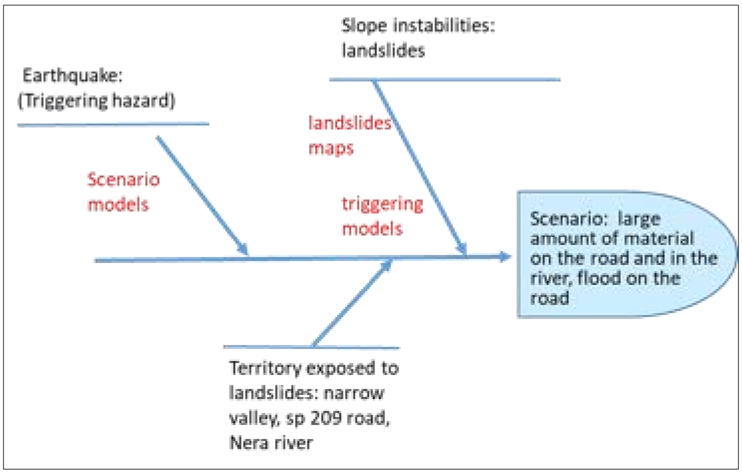

Figure 4.5 Cascading effects concerning the 30 October 2016 earthquake and the SP209 near Visso.

In this case, the road interruption was a concatenation of criticalities: the large rockfall, and the flood. So, a series of complex interventions were planned by Anas: to retrofit the slope, to remove the deposits and the repositioning of the river in the original riverbed, besides the repair of a bridge and of another part of the road near this point damaged by other rockfalls (http://www.anas-sisma2016.it). A temporary re-opening with limitations was possible in October 2017 and the road was completely accessible since the 1st February 2018 (in Figure 4.6 the situation in July 2018, after the interventions).

Figure 4.6 the SP 209 near Visso after the

The described situation put in evidence the many vulnerabilities of the SP 209 road in that site: an intrinsic physical and morphological condition (a narrow valley), the river near the road, the presence of numerous landslides with high possibility to fall down, especially in case of earthquake.

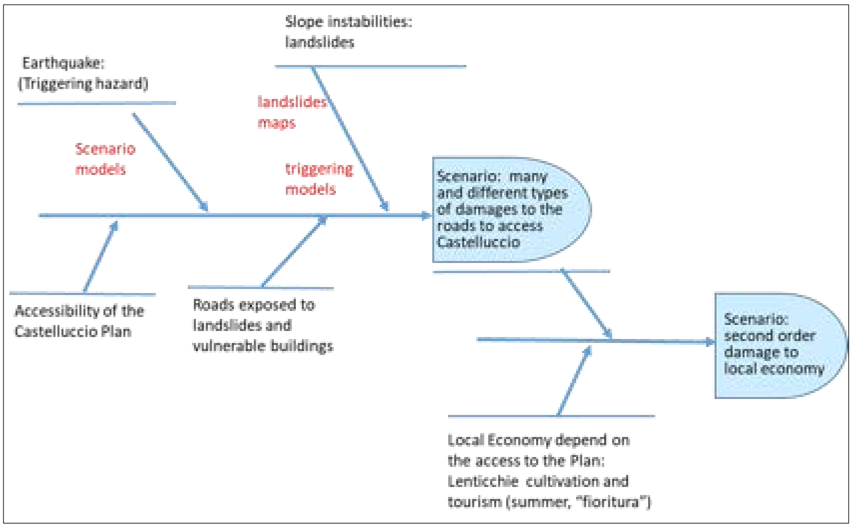

Figure 4.7 Second order damages due to the 30 October 2016 earthquake in Castelluccio di Norcia Plan

The second case refers to the access roads to the Castelluccio di Norcia Plan. All four roads leading to the Castelluccio Plan were affected by the 30th October 2016 shake. Different causes produced damages and/or obstructions: roads structural failure, landslides, and debris of collapsed buildings (http://www.anas-sisma2016.it). After the event, it was quite impossible to access the Plan, with significant repercussions not only in terms of mobility for the inhabitants of the hamlet of Castelluccio, but also for the local economy based on the lentils cultivation (very particular and appreciated variety) and on tourism, especially in summer during the "Plan Flowering", when a carpet of coloured flowers covers the Plan and it seems like a paint. The sequence of second and higher order damage is represented in Figure 4.7. Given the multiple causes of the roads damage, several interventions were programmed and realized, setting as a primary goal to permit at least limited access to allow the lentils production and the presence of tourists during summer. On the 3rd of April 2017 it was made possible for the farmers to reach the Plan for the lentils sowing with the tractors and other agricultural vehicles. Farmers were guided by Army personnel along two pre-defined itineraries, after some interventions to guarantee a minimal level of safety (www.valnerinaoggi.it, 2017). During the summer, instead, some roads were temporarily reopened in the weekends for touristic activities. Such program of interventions followed a systemic approach considering, beyond physical/technical aspects of road recovery also social and economic needs. Such an approach required the coordination among many actors: the local administrations, Anas, the Civil Protection, the population/associations. An unusual and complex way of working together had to be achieved: albeit difficult and imperfect, it permitted to obtain some relevant shared results.

4.3.3. The snowstorm and the power outages in January 2017

In the days between the 5th to the 23rd January 2017, an exceptional prolonged snowfall associated with strong winds affected Central Italy. Two phases can be identified in the series of snow accumulation recording before and after the 16th of January. The second phase was characterized but significantly higher levels of precipitation with peaks recorded in the days 18th and 19th of January. The storm occurred mainly along the Apennines but to some extent also along lower areas up to 300 mt, affecting the same regions already hit by the August and October shakes but more severely Marche and Abruzzo.

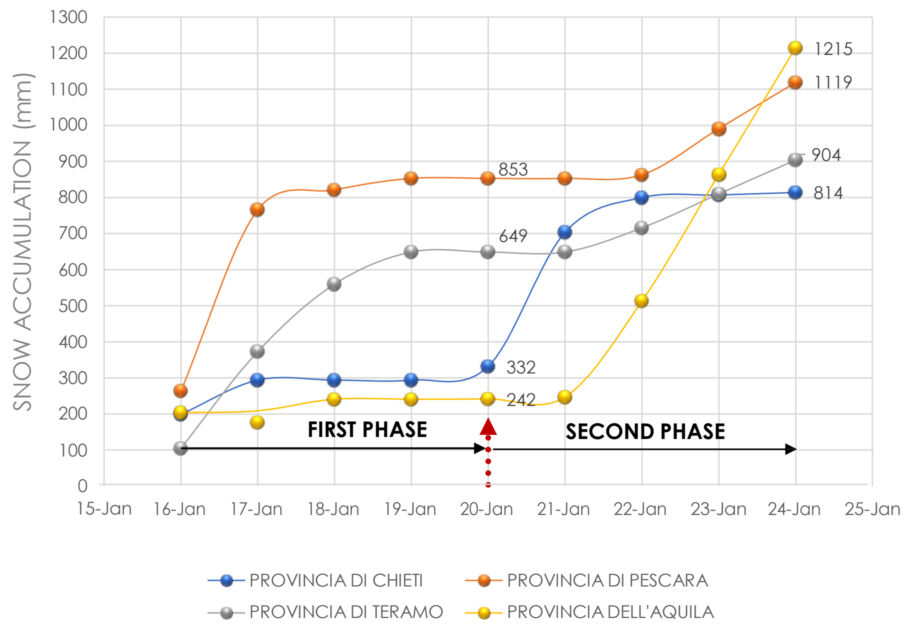

Figure 4.8 Snow accumulation as recorded by Enel and Terna

According to the recording that were made available by Terna and Enel (the companies responsible respectively for the network and for the provision of power) in their official website open to the public, after the 15th of January, two further phases can be distinguished: the first between the 15th January in the afternoon and the 19th January, when both mountain and plain areas as low as 200 mt above sea level were covered by snow; the second phase between the 20 and the 24th January mainly in the mountain areas. In the first period the two provinces of Pescara and Teramo witnessed a continuous increase in the amount of accumulated snow precipitation, whilst the two other provinces of l'Aquila and Chieti recorded a more constant level. In the second period, and differently from the forecasts of those days, the amount of accumulation increased steadily in all provinces. The snow created problems to lifelines, in particular to the road network and to the power system. As for the latter, the accumulation of wet snow sleeves damaged power overheads while trees fell on both high voltage and medium to low lines. A number of transformation rooms in substations were disconnected as a result of disturbances along the lines resulting in a large number of outages across the four provinces of Abruzzo as can be seen in Figure 4.8. The long lasting precipitation worsened the operational conditions of the workers of the Enel and Terna companies in charge of repair and of providing mobile generators to restore energy in multiple places. According to the hearings that were held in the Italian Senate, a number as high as 900 generators were dispatched to different areas, drawing on both companies' resources and on external provisions.

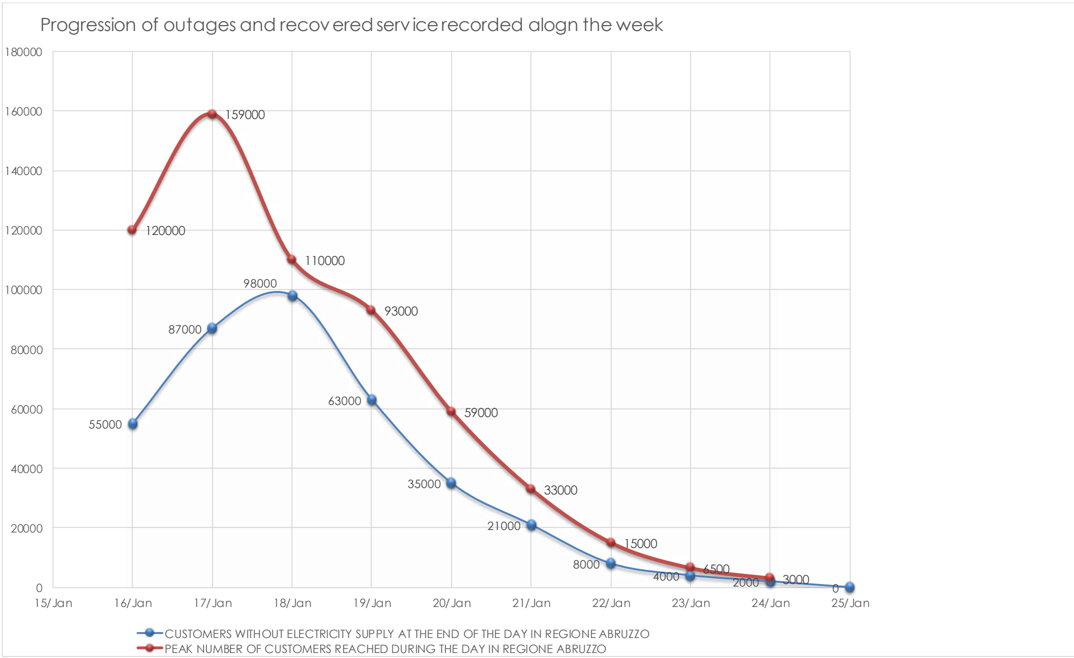

Figure 4.9 Outages and power restoration at each day during the crisis

In Figure 4.9 the effectiveness of the restoration operations can be appreciated as the red lines shows the peak number of customers suffering power outages in each day, whilst the blue line represents the same parameter at the end of each day. The difference between the two lines is the actual number of customers experiencing recovered service. For example, on the 17th of January as many as 159.000 customers suffered a blackout; at the end of the same day this number had diminished to 87.000, meaning that energy had been restored for 72.000. A steady decrease of unserved customers can be appreciated in the graph, even though after a week there were still 15.000 customers deprived of energy.

Figure 4.10 provides information regarding the geographic distribution of the outages along the entire disturbance period. The provinces of l'Aquila and Pescara experienced a less severe blackout in terms of unserved customers; the maximum number of outages were felt in the Chieti province, but diminished rather fast in the next days. The province of Teramo is the one that experienced the second highest peak of outages and for a longer period of time compared to the other provinces. A number of factors may explain this result. Some cannot be verified without a more refined and exact information regarding in which areas the most severe physical damage occurred and also the geographic distribution of customers served by the physically damaged lines and by the disconnected sub-stations. However, some systemic vulnerability factors can be certainly appreciated. As the snowstorm affected severely also the road system, a number of localities became inaccessible to rescue services and to the teams in charge of restoring energy.

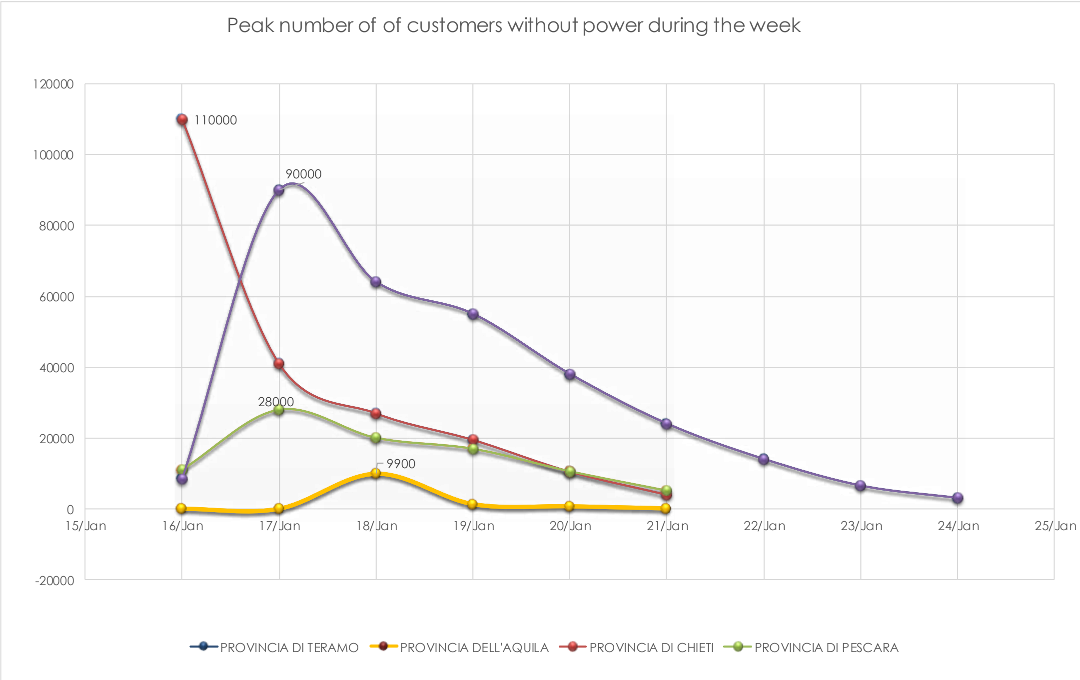

Figure 4.10 Duration of power outages in the four provinces of Abruzzo Region

The map in Figure 4.11 shows the overlapping of the towns that experienced the longest duration of power cuts and the roads that were closed for one day or more in the days between the 20^{th} and the 23^{rd} of January. In fact, it ca be easily seen that those towns are mainly in mountain areas, and were difficult to access those days.

The example illustrated above displays a number of features that characterize a multi-hazard event in a complex setting. The chain of failures and resulting damage scenarios are displayed in the fishbone diagram in Figure 4.12. In fact, two independent events, the snowstorm and the rather strong earthquake co-occurring at the same time created additional challenges to a territory that had been already significantly affected by the seismic swarm of the preceding months. The snow, exceptional both for its duration and intensity in terms of accumulation provoked damage to physical components of the power system. The mountain setting of the area made some places unreachable for the combined effect of the snow on the road system, made of narrow lanes with many curves and high inclination in some parts; small towns and hamlets dispersed over a wide region, partially isolated also in less severe circumstances where a declining old population lives without means and resources such as local generators and snow cats.

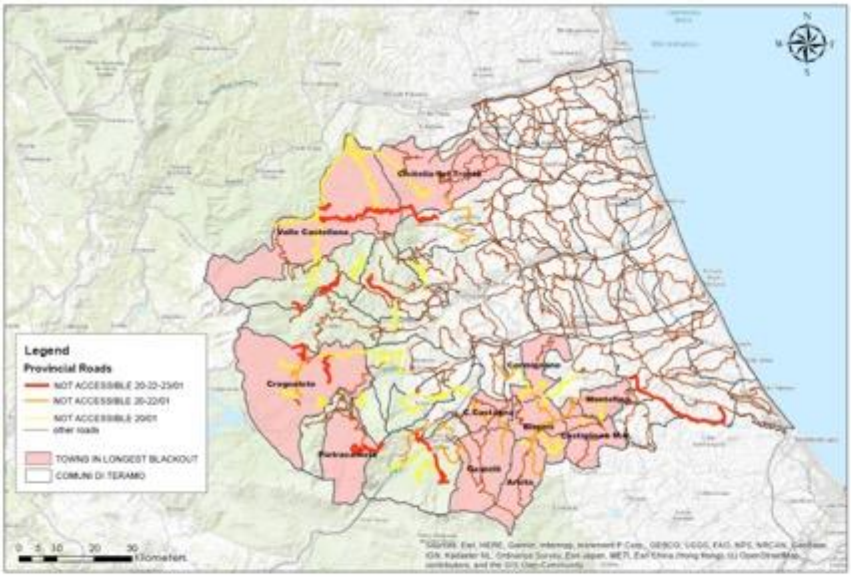

Figure 4.11 Maps overlapping road interruption and the towns experiencing the longest power cuts

Following the fishbone diagram representation, the event has been re-constructed in its main aspects in Figure 4.12.

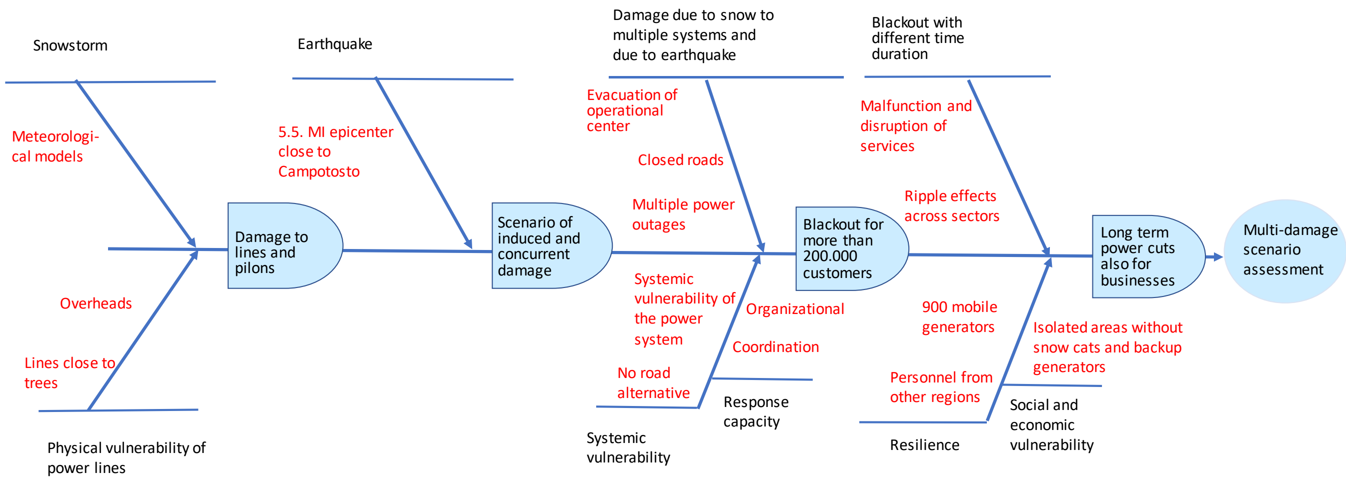

Figure 4.12 Sequence of damages in January 2017 in Central Italy due to the combined effect of the snowstorm and the earthquake

4.4. The 2014 flood in Milan: using post disaster damage data to support forensic investigation of cascading effects and impacts on economic activities

Forensic analysis of damage is essential to understand how different risk factors, including hazard, exposure and vulnerabilities have played differently in individual events to produce the final outcome. Identifying vulnerability factors in particular requires a careful consideration of the intrinsic features of exposed assets and systems that have been revealed by the hazard. In the meantime for considering cascading effects, there is the need to understand how physical damage transforms into lack of serviceability and functioning capacity across systems escalating towards entire societal and economic sectors. The shift from a physical damage to a systemic disruption depends not only on the intrinsic physical features of affected components, but also on systemic vulnerability and organizational aspects as they unfold in a given territorial context (Menoni and Boni, 2020).

In the following the flood event that occurred in November 2014 in the city of Milan is described and analysed, referring in particular to the impacts on critical infrastructures (power and transportation systmes) and on economic activities. The final objective being understanding what vulnerabilities and exposed assets are at stake so as to propose appropriate mitigation measures.

In this regard the case study of the 2014 flood in Milan provided some elements that can be used for better understanding on which factors resilience strategies and adaptation should focus. The reconstruction of the scenario that has actually occurred can be made also using simple techniques as the fishbone graphic representation (see figure xx) that we have alredy used for the Central Italy case. The fishbone is particularly apt to represent consequent levels of damage and the impacts due to different types of vulnerability (physical, systemic). On the other hand the characterization of the economic activities that have been actually flooded permit to understand what type of local level mitigation including internal emergency management arrangements can be proposed to enhance the resilience of the economic sector.

4.4.1. The exposure of Milan to flood risk and the 2014 event

The city of Milan lays in the middle of the Padana plain between the Ticino river to the West and the Adda river to the East. A complex network of tributaries and channels flow through the plain making the city at a rather high risk of flood as highlighted in the emergency provincial plan that we contributed to prepare in the years 2002-2005. The city is saved from frequent events through a complex control system that rather will allow flooding to occur in areas North to Milan. Even though structural measures have been implemented over the years, large retainment basins North to the city are still waiting for full implementation. According to the flood risk management plan, the most hazardous tributaries are the Seveso and the Lambro rivers both in the Eastern part of Milan. Part of the rivers are actually covered manholes whose capacity is also stressed during severe events. A number of extreme events have occurred in the last decades of varying severity. In addition, urban flooding occurs as a consequence of the insufficient capacity of urban water networks to cope with increasingly intense precipitation levels over short periods of time and which provoke localized flooding that is not directly due to river overflows or to manhole limits. The risk management plan distinguishes between different subareas that are governed by different sub-catchments as the ones just mentioned and associated different levels of hazard. The Eastern area of Milan has also been investigated more locally using hydraulic modelling considering also the geometry of existing buildings and infrastructures (Mambretti et al. 2005). Results show a significantly higher risk for areas than the average ones generally considered at the regional scale depending on the actual scenarios with different return periods. An important aspect that has been highlighted in many reports also after the 2014 event, is the fact that given the reduced pumping of water due to industrial activities that moved outside the city in the second half of the last century, the water table level has increased and therefore likely to provoke inundation of underground structures in the city, such as basements, parking places and the metro underground.

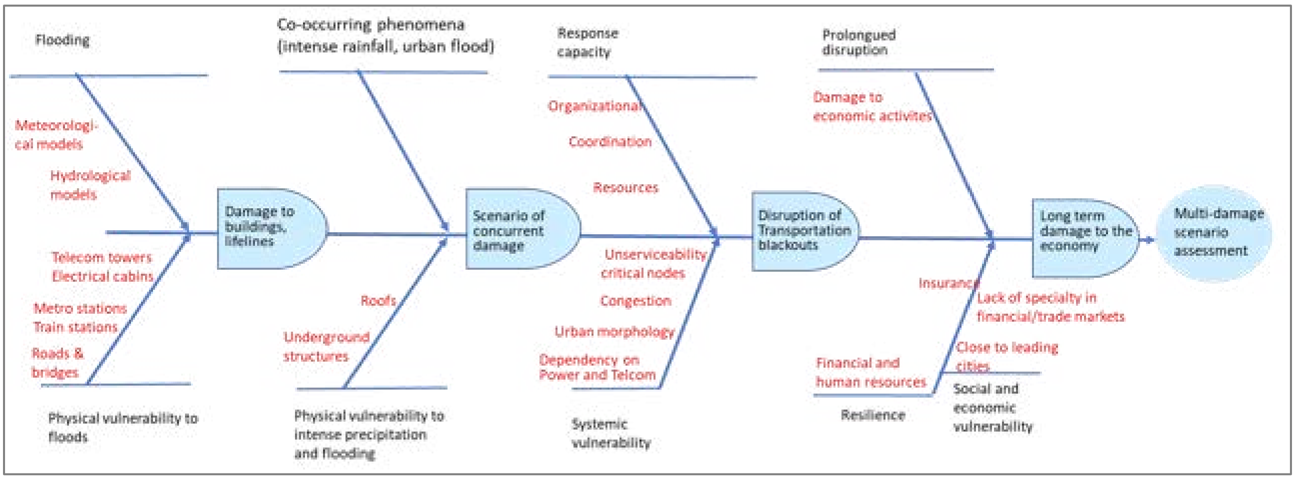

Figure 4.13 Fishbone representation of the sequence of damages due to the flood that affected Milan in November 2014.

Two sources of data have been used, on the one hand the Rasda database, that has been run manually since 1992 and digitally since the year 2000, and the forms required to apply to the European Solidarity Fund. Both tools are certainly a step forward in getting a comprehensive more precise picture of losses incurred by multiple sectors due to a hazardous event occurrence. However, there are still limitations to the type of knowledge and information that can be obtained from such sources. First the losses are reported primarily for compensation purposes, thus neglecting the need to precisely report what features of the hazard have impacted locally producing certain damages (overflowing, failure of the sewerage systems, increase of the water table, water depth in different locations). Second, even though the Rasda system requires to describe the damaged components, often this is not done by officials in charge and only the monetary corresponding repair value is reported. In addition, no information on the damage mechanism is provided at all.

Following the framework in Figure 4.13, as for the hazard, in the days between 12th and 16th November 2014 intense precipitations occurred in the Lombardia Region, North to Milan, on the main catchments that flow throughout the city. The Meteorological Service of the Region provided a comparison between the average precipitation in the 13 years prior to the event with the years 2002 and 2014 when flooding occurred in the Eastern part of the city (Table 4.1).

ARPA Rain Gauges	Average 1990-2013 **mm**	2014 (01.11-17.11) mm	2002 (01.11-30.11) mm
Rivolta d'Adda-CR	117	270	281
Angera-VA	180	608	626
Milano (*Parco Lambro*)	122	350	345
Cantù-CO	169	441	469

Table 4.1 Precipitation levels in rain gauges in the Lombardia Region in the period 1990-2014

In the first rain gauge, located Eat to Milan on the Adda river, 67 mm were recorded on the 12th November, 227 mm in a small town North to Milan in the days comprised between Monday 10 and Wednesday 12, whilst 116 mm were recorded on Saturday 15 in the rain gauge positioned in the Lambro river Park in the North Eastern part of Milan City. On average it rained in those few days between 30% and 43% more than in the overall period between the years 1990 and 2013. The event is comparable to the one that has occurred in 2002, albeit the latter has been even more intense.

4.4.2. Impact of the 2014 November flood on the transport and power system of Milan City

In the quartiers shown in the map in Figure 4.14 the area that has been flooded is shown. At the ground level water depth was at about 10 cm average, but in the area the important transportation node of the Garibaldi station where the metro Green Line and 20 tracks of the railway converge. In the precedent years, the Garibaldi area had been at the heart of a huge project investment to substitute the former shanty area illegally occupied with one of the most vital regeneration project with a new elevated place with offices of banks and companies, and the location of the new building of the Regional Government offices and the refurbishment of another construction hosting the municipal offices of the City.

The economic direct losses reported in the application to the EU Commission Solidarity Fund totaled 3.8 M Euros and 1.9 M respectively to the road and the railway network in the entire Lombardia Region. 1.7 M damage occurred in structural defenses. The electrical company claimed 370 K Euros damage to the power network. An overall amount of 8 M Euros was suffered by all critical infrastructures, including water and telecommunication systems mainly as a consequence of damaged electrical equipment and machinery.

Highways, state roads, metro and railways underground lines and stations were severely affected in the Eastern part of Milan in the days comprised between the 12th and the 16th November, with more intense flooding occurring in the night between the 15th and the 16th. The circulation of the metro line between the two main railways station of Garibaldi and

Centrale was limited to one lane. The state road connecting Milan to Lecco and Sondrio in the Northern part of the Region was disrupted with capacity limited to one out of three lanes for a couple of hours in the morning of the 16^{th} November. The third line of the Metro was closed in both direction on Saturday 15^{th} afternoon until the next morning, then completely reopened by 4 pm. Overall 140 trains were suppressed by the two operating companies of regional trains. Three out of four junctions of the Eastern beltway were closed and one junction of the highway in the direction to Bergamo and Venice. It is interesting to note that a landslide occurring on the Lake Maggiore outside the metropolitan area still provoked some perturbations on the regional train line between Milan and Domodossola at the border with Switzerland, as 15 trains were stopped.

The fishbone framework in figure xx displays the different damages considering their main causes and their evolution overtime. Overall the disruption to transportation and blackouts were contained rather rapidly and did not extend over the week after the triggering intense precipitation event. Differently from what has occurred in the case of the Central Italy, here means for repair and personnel were deployed in a very short time and immediately at work, given that no long distances had to be covered, accessibility albeit hampered was still possible and the affected area constituted a relatively small part of the city. As for longer term impact, it can be said that Milan is among the richest cities in Italy, in a region that is among the first for GDP in Europe. Thus resources and means for recovery have been readily available and most private owners had some of their damage covered by state compensation or private insurance, whereas the EU Solidarity fund covered damage suffered by public services and infrastructures.

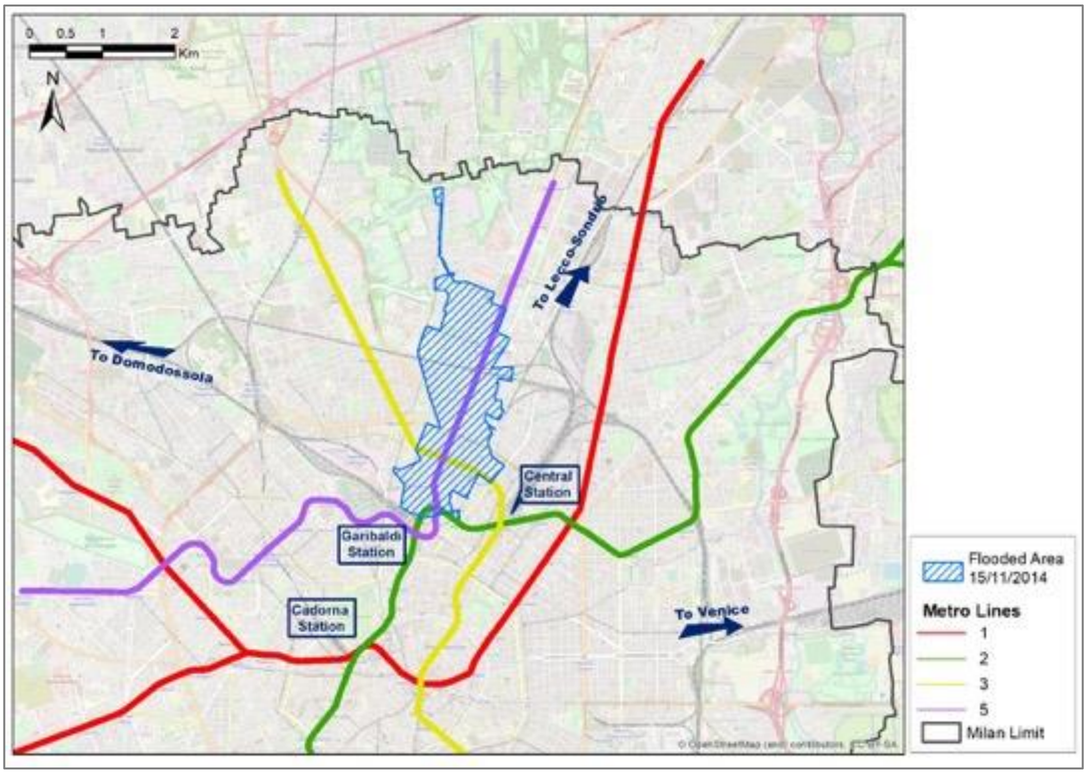

Figure 4.14 Map of the Eastern part of Milan showing the infrastructures damaged by the November 2014 flood (flooded area source: http://www.geoportale.regione.lombardia.it)

4.4.3. Impact on economic activities in the flooded area

Milan is the first city in Italy in terms of occupied people, therefore understanding the risk which firms are exposed to is particularly relevant, as well as understand the direct and indirect consequences of floods. In this context a collaborative activity with Assolombarda, the largest Trade Association in Italy, has permitted to cross the data regarding the flooded area in 2014 and the features of the firms that have requested compensation for damage. The 200 economic activities that are classified in the Assolombarda database and that are exposed to the flood hazard in the City of Milan have been mapped. This way it was possible to obtain the total number of 16.463 workers that are employed in those firms and to classify such workers by type of firm according to the NACE classification. The dimension of the firms has been considered as well. 67 very small businesses with 260 employees persons, 65 small businesses with 1.641 employees, 42 medium size activities with 4.474 employees and 9 large factories with 10.088 employees. The largest number of employees pertaining to the same activity exposed to floods is 3.653.

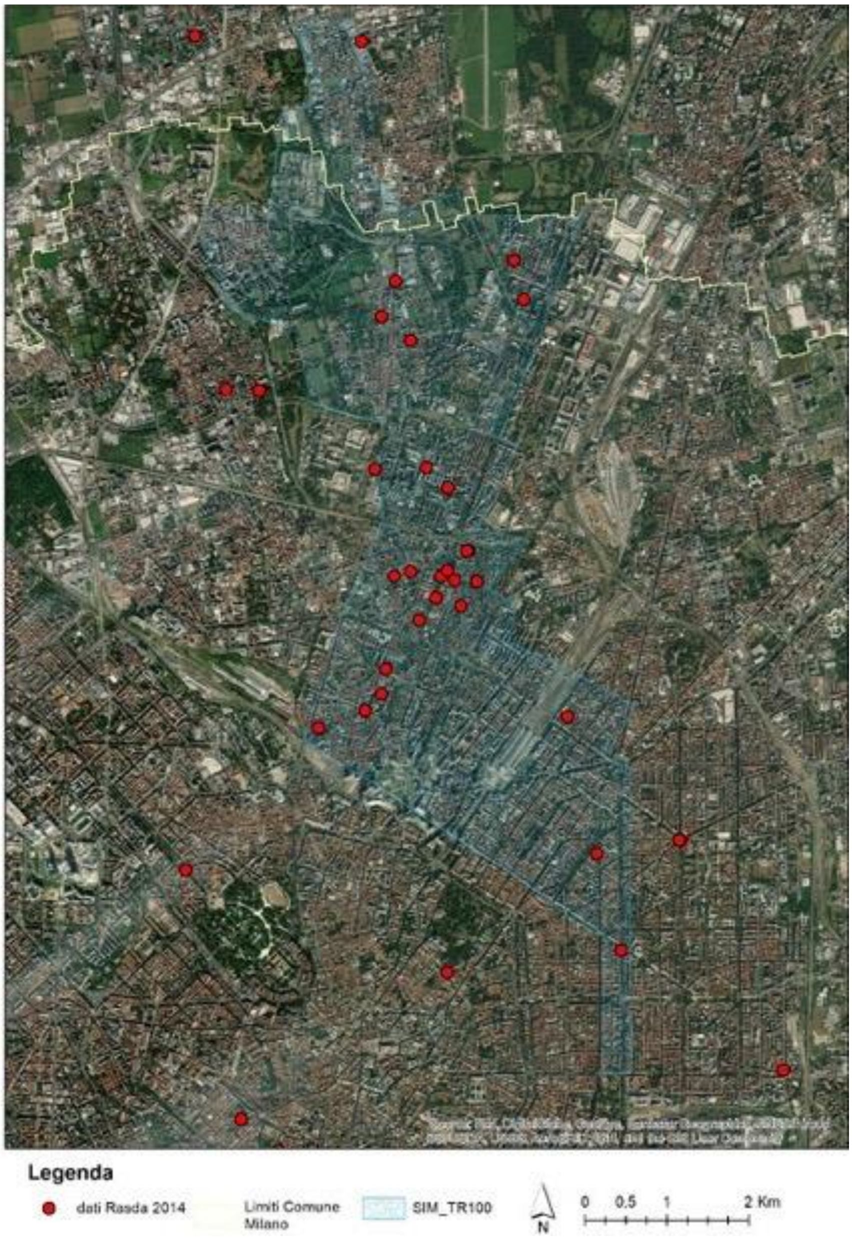

Figure 4.15 Mappa delle aziende alluvionate nel luglio 2014 rispetto allo studio idraulico del Comune di Milano

In Figure 4.15 the economic activities that have been affected during the 2014 flood are represented. Out of the 91 damaged activities, 70 could be geolocated:

- 11 are located outside the city of Milan, in the metropolitan area and are not shown in the map;
- 32 are located in the area exposed to floods with a Return Period of 100 years;

- 27 are outside the 100 RP flood zone, in an area where the probability of floods ranges between 200 and 500 years. However such zones are not included in the hydraulic assessment that was available for the study.

The case of Milan is representative of a type of events that have become more frequent in the last years also as a consequence of climate change provoking more intense precipitation episodes that overwhelm the discharge capacity of the complex network of channels and rivers that cross through the metropolitan area coupled with urban flooding. The interconnected incidents that affected the transportation and power networks stressed the city over a couple of days in the week end, condition which contributed to limit the consequences as traffic is less congested in all lines than during working days. In addition, issues that were experienced in previous floods, in particular in November 2002, such as the flooding of the emergency unit of one of the main city hospital and several localized sewerage overflowing in the Eastern part of Milan affecting the area hosting some universities, were not experienced in 2014 thanks to measures that had been taken in the meantime and that proved effective for a comparable intense phenomenon.

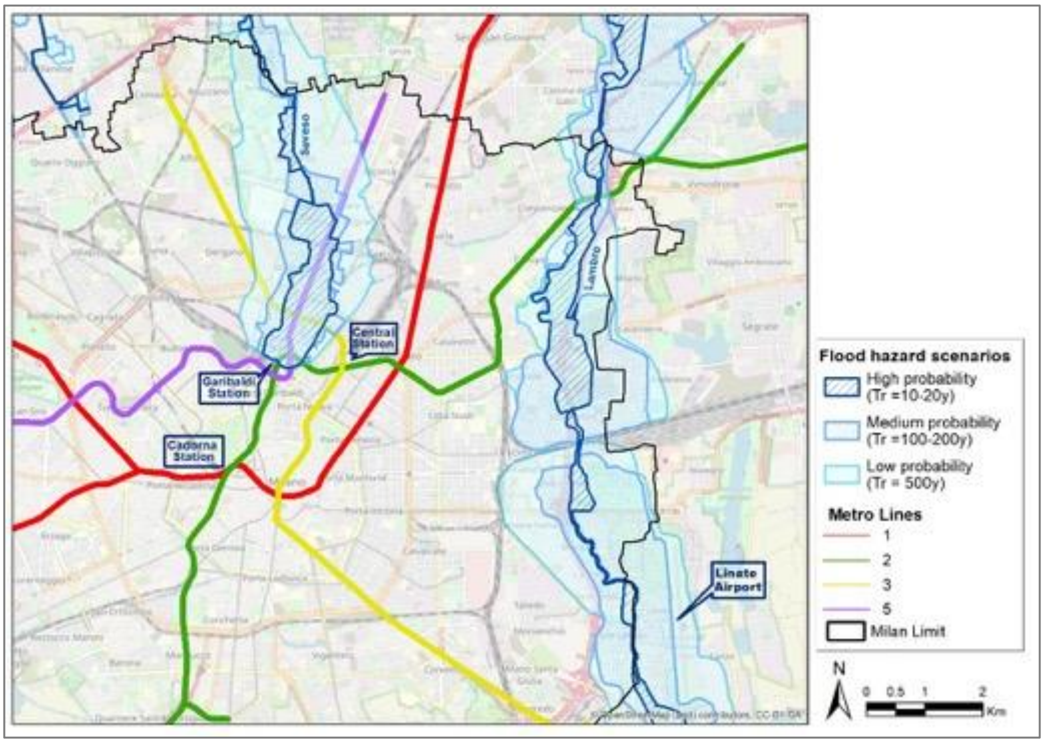

Figure 4.16 Flood hazard scenarios for the Seveso and Lambro rivers (hazard maps 2019 of the Flood Risk Management Plan. Scenarios source: http://www.geoportale.regione.lombardia.it)

The flood risk management hazard map however displays a condition that is still alarming regarding the Eastern part of the City and that accounts for different scenarios other than the one that has actually occurred (see Figure 4.16) and that may be larger in terms of intensity and covered zones. Concentration of assets and dense residential and commercial areas are certainly more prone to suffer higher levels of damage per square meter than more dispersed settlements as those in mountain areas. An interesting aspect that has been noticed about the 2014 event is that events occurring in the metropolitan area or even just close to its margins may produce repercussions in terms of network disturbances. In that specific event the disturbance was moderate, however had the power or the transportation networks been affected in a more critical node or segment, the consequences could have been much worse and amplified across the entire region and perhaps even farther. On the other hand, significant advantages are associated to being in a metropolitan area: the incident could be controlled in a matter of hours thanks to the availability of personnel and spare material for repair that are both available on site.

One important legacy of the 2014 flooding season was that it created a strong incentive to prepare with care safety and security measures for the next to come Expo Fair that opened on the 1st of May 2015. An extensive coordination work was carried out by all concerned administrations across different sectors and spatial scales creating a platform where all sectoral contingency plans could be shared and visualized while having at disposal the real time situation in terms of traffic, potential incidents in different areas of the city, availability of ambulances etc. Longer term mitigation coordinating both structural and non structural mitigation has still to be achieved even though strategies have been proposed in the context of the 100 Resilient City project that Milan was granted in December 2014.

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5. THE KEFALONIA EARTHQUAKE SHOWCASE, GREECE, JULY 2014: USING DAMAGE DATA TO IMPROVE RISK MODELLING

Authors:
Maria Panoutsopoulou, Deni Panagiotopoulou, Thekla Thoma, Ioannis Dourakopoulos, Myrto Gari, Spyros Santrivanopoulos - OASP

5.1. Post-earthquake damage assessment

5.1.1. The purpose of the post-earthquake damage assessment of buildings in the Greek context

When a damaging earthquake hits a populated area, the inspection of the buildings from the competent authorities in the affected area is of high priority, in order to identify safe and unsafe for use buildings. The primary objective of the assessment is to protect human life and save properties.

More specifically the inspections, carried out on the affected buildings after an earthquake, by the engineers, aim at:

− Identifying as soon as possible all buildings that are safe to occupy and use. Thus, to minimize the number of homeless and reduce the loss of economic activities.
− Examining if there is an immediate danger due to building collapse and indicate unsafe areas around the building so to avoid casualties or injuries.
− Proposing safety measures for the protection of the occupants or the public.
− Identifying temporary shelter areas and provide the number of required temporary housing units.
− Providing reliable estimates of the building damages that will allow authorities to take relief measures, formulate disaster mitigation policies and allocate available resources.
− Providing data that will identify frequent causes of damage, so that potential rehabilitation plans may consider such assessments.
− Supporting future scientific studies on building response and vulnerability. These studies may lead to revaluation of existing codes, construction practices, seismic hazard maps and to elaboration of seismic vulnerability models for pre-earthquake assessment.

5.1.1.1. The procedure of the post-earthquake damage assessment of buildings

The coordination of the inspection of damages due to earthquake is a responsibility of the General Directorate of Natural Disaster's Rehabilitation - GDAEFK (GSCP 2020). GDAEFK, after being informed of the consequences of the earthquake implements the operational emergency plan for earthquake. According to this plan, GDAEFK, mobilizes the staff and coordinates inspections in the affected area in order to identify potential hazards, inspects public and private buildings. In particular, the Head of GDAEFK act as follow:

- Informs about the incident and according to the action plan and mobilizes the Territorial Competent Directorate, while setting the other Directorates on alert.
- Organizes the immediate transition, at the affected area, of an adequate number of engineers who belong to the competent Directorate in order to assess the consequences and the severity of the damage.
- Mobilizes the human resources required, from all Directorates, if it is necessary, regarding the extent and size of the damages.
- Suggests the availability of experienced engineers from other Departments of the Ministry of Infrastructure and Transportation, and from the local authorities of the affected area (Decentralized Administration, Regional Administration and Municipality) for the conduct of the post-earthquake inspections.
- Organizes the transition and housing of the staff.
- Organizes the operation of the coordination center at the affected area, in collaboration with local authorities and organizes the transport of equipment.
- Installs telephone lines, in cooperation with the local authorities, to facilitate the requests for building inspections.
- Sets up committees for first degree inspections and re-inspections of buildings and informs about the results the responsible authorities (Police, Municipality, Region).
- Sets up committees to locate dangerous for collapse buildings and contact relevant Protocols.

The main tasks of the procedure are:

- Inspection of all the buildings in the affected area and characterization according to their safety and damages, as well as identification of the buildings that require urgent support to avoid collapse, is performed by the inspection teams.
- Interventions to eliminate possible casualties due to damages (removal of non-structural damages, support of buildings prone to collapsing, disconnection of utilities such as electricity, gas, etc.), are performed by the intervention crews.

The procedure of the inspection of the buildings consists of two degrees (Figure 5.1) of inspections:

A) The first degree is a Rapid Visual Inspection (Figure 5.2) that evaluates the buildings and classifies them according to their usability into two categories:
    - Usable (Safe for use): Buildings without damages or with local damages which do not affect their seismic response (original seismic capacity has not been decreased).
    - Unusable (Unsafe for use): Buildings with reduction of their seismic capacity due to

damages, heavily damaged buildings with hazardous parts or buildings possible to collapse and cannot be used until Re-Inspection is performed.

B) The second degree is a Revised more detailed Inspection (Re-Inspection), that is performed to the buildings characterized unusable during the first degree (Figure 2.7). The buildings are re-inspected and classified according to their usability and damages in three categories (Color Tag Scheme):

   - Usable (Posted in green): Buildings with no visible damages and/or whose original seismic capacity has not been significantly decreased.
   - Temporarily unusable (Posted in yellow): Buildings whose seismic capacity has been decreased and/or they pose a danger condition due to damage of non-structural elements. All necessary safety measures should be taken immediately.
   - Unusable / Dangerous (Posted in red): Buildings with heavy damage. Imminent danger of sudden collapse. Entry is absolutely prohibited. All necessary measures should be taken immediately.

The re-inspection is performed in all stories of the building unless there are areas of the building with no access. The re-inspection as a more detailed assessment may result in changing the characterization of the rapid assessment. The need for re-inspection could also arise in the event of aftershocks that could change the condition of buildings already inspected. After the re-inspection, an appropriate sign is placed at or near all entrances of the building to be clearly visible by anyone who wants to enter, indicating the classification of the building into one of the three categories.

The inspections should be part of an earlier planned operation designed to cover efficiently and reliably large numbers of affected buildings under the usually chaotic emergency conditions created by the earthquake.

The operation of the whole procedure, in order to be successful, must meet the following objectives:

- Be well organized.
- Yield uniformly reliable assessments and damage data.
- Be completed in a short period of time.

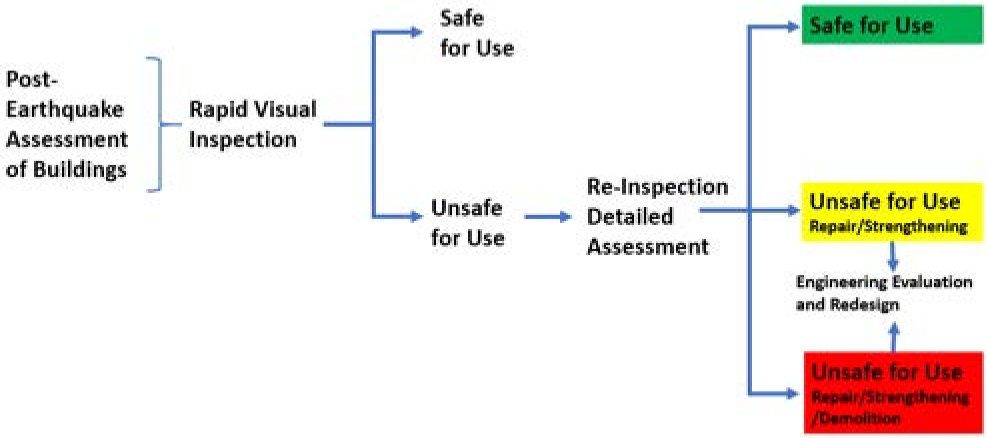
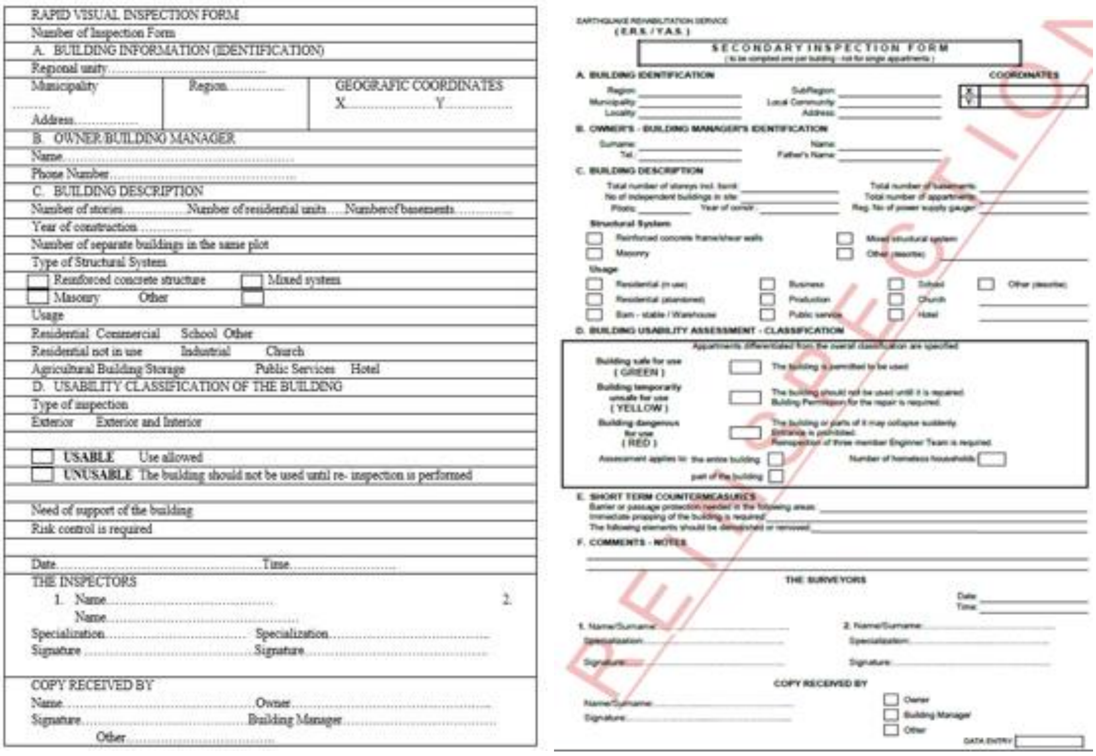


Figure 5.1 Procedure for post-earthquake assessment of buildings safety after a damaging earthquake.



RAPID VISUAL INSPECTION FORM
Number of Inspection Form
A. BUILDING INFORMATION (IDENTIFICATION)
Regional unity……
Municipality …… Address…… | Region…… | GEOGRAFIC COORDINATES X…… Y……
B. OWNER BUILDING MANAGER
Name……
Phone Number……
C. BUILDING DESCRIPTION
Number of stories…… Number of residential units…… Numberof basements……
Year of construction ……
Number of separate buildings in the same plot
Type of Structural System
☐ Reinforced concrete structure ☐ Mixed system
☐ Masonry Other ☐
Usage
Residential Commercial School Other
Residential not in use Industrial Church
Agricultural Building Storage Public Services Hotel
D. USABILITY CLASSIFICATION OF THE BUILDING
Type of inspection
Exterior Exterior and Interior
☐ **USABLE** Use allowed
☐ **UNUSABLE** The building should not be used until re- inspection is performed
Need of support of the building
Risk control is required
Date…… Time……
THE INSPECTORS
1. Name…… 2. Name……
Specialization…… Specialization……
Signature …… Signature……
COPY RECEIVED BY
Name…… Owner……
Signature…… Building Manager……
Other……

SECONDARY INSPECTION FORM
A. BUILDING IDENTIFICATION
B. OWNER'S - BUILDING MANAGER'S IDENTIFICATION
C. BUILDING DESCRIPTION
D. BUILDING USABILITY ASSESSMENT - CLASSIFICATION
E. SHORT TERM COUNTERMEASURES
F. COMMENTS - NOTES
THE SURVEYORS
COPY RECEIVED BY

Figure 5.2 Required Information to the (a) Rapid Visual Inspection Data Form and (b) Secondary Inspection Form (Re-Inspection)

5.1.2. The damage assessment following the Kefalonia earthquake

After the earthquakes of January 26 and February 3 2014, no casualties but damages to buildings and infrastructure were recorded.

<u>Geotechnical Failures</u>

The two main shocks caused widespread liquefaction in the Lixouri and Argostoli ports and in adjacent waterfronts, landslides and rock falls, extensive cracks on the road network and failures of port marines (Figures 5.3, 5.4, 5.5).

Figure 5.3 Ports of Lixouri and Argostoli after the seismic events.

Figure 5.4 Damages on road network (a), landslides and rock falls (b)

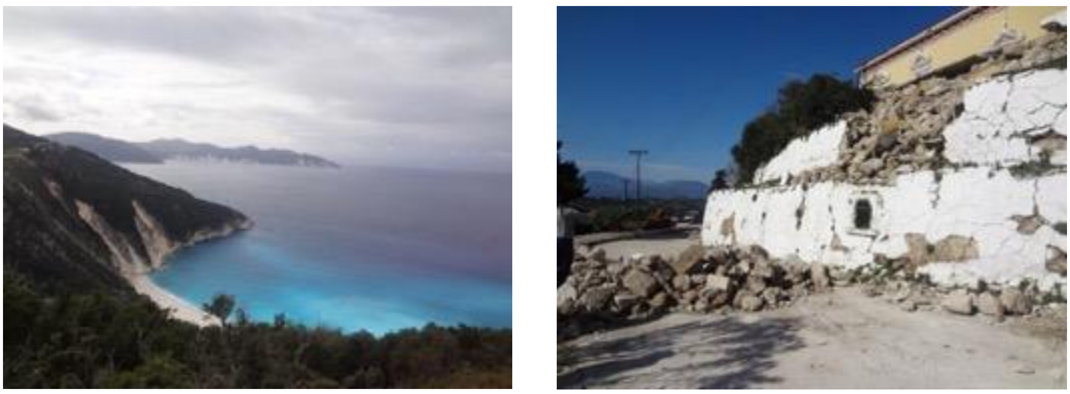


Figure 5.5 Myrtos Bay-Rockslides, raveling (a) and collapses of earth retaining structures (b)

<u>Building Damages</u>

Most of the structural damage was observed during the 2nd seismic event and was primarily concentrated in the Paliki peninsula area, on the western part of the island. In general, the buildings on the island had a good seismic response, considering the high intensity of the earthquake which can be mainly attributed to the strict Greek Seismic Design Codes and the good construction quality (Figure 5.6).

Figure 5.6 Severe damaged structures in Kefalonia

Damages in Potable Water and Wastewater Networks

The earthquake on February 3rd, 2014 caused significant problems in the water supply network. The majority of the damage was concentrated in the town of Lixouri. Large scale repairs and replacements took place until full functionality was achieved (Figure 5.7).

Figure 5.7 Rapid network assessment in Lixouri after the second earthquake. Source: EYDAP 2014

Damages in Culture Heritage

Unlike the residential and public buildings, the Kefalonia churches exhibited extensive structural damage (even partial collapse), and severe nonstructural damage (Figure 5.8). This can be mainly attributed to their construction type and their retrofit history. Most of the churches are very old, tracing back to the 17th century.

Figure 5.8 Church of St. John in Fafatata, Kefalonia (19th century). Repaired after 1953 earthquake. The outer masonry leaf was severely damaged during the 2014 earthquake. Source: OASP

<u>Nonstructural Damages</u>

Damage of nonstructural components was extensive. The impact of this damage was substantial in the function and the economy of the island. Nonstructural damage caused business to stop operating, including banks, restaurants, and stores and shut down the only airport in the island for more than 10 days (Figure 5.9).

Figure 5.9 Nonstructural Damages (Source: OASP)

5.1.3. Post-earthquake inspection of buildings

From 27-01-2014 to 08-02-2014, 2810 buildings were inspected. According to the results of the rapid inspection, 1538 buildings (55%) were marked usable and 1272 buildings (45%) unusable. The rapid visual procedure continued until 3672 buildings were inspected by 10-02-

2014. The number of usable buildings reached 2095 (57%) while 1577 (43%) buildings were marked unusable (Figure 5.10). The re-inspected buildings were classified according to their usage and the structural type (Figure 5.11).

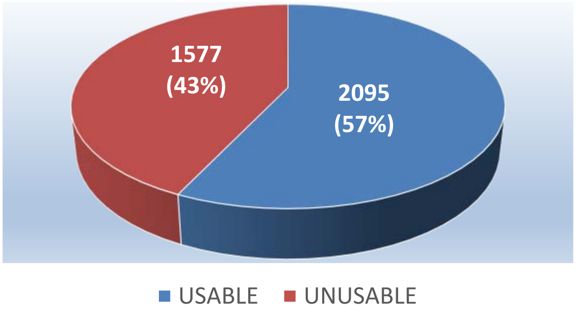
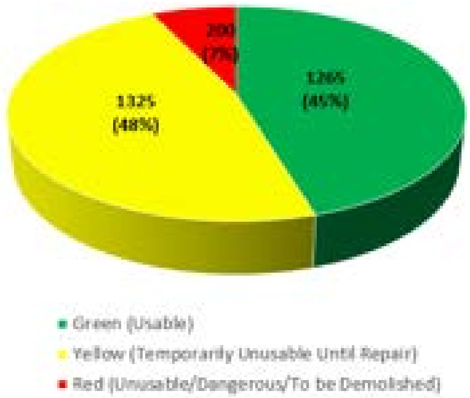


Figure 5.10 Usable and Unusable buildings according to Rapid Visual Inspection

Figure 5.11 Re-inspected buildings according to their usage (a) and structural type/material (b)

After the rapid inspection assessment, 2790 buildings were re-inspected (Figure 5.12) and 45% were deemed Usable (Posted in green), 48% Temporarily unusable (Posted in yellow) and 7% Unusable / Dangerous (Posted in red). It is important to notice that the 73% of the dangerous reinspected buildings are made of masonry indicating, therefore, their age and the construction period which was possibly before the application of new seismic codes. It is important to notice that only 28% of the masonry structures were marked green whereas 60% of the reinforced concrete structures were marked green.



STRUCTURAL TYPE	TOTAL	GREEN	YELLOW	RED
MASONRY	774	28%	53%	19%
REINFORCED CONCRETE	1185	60%	38%	2%
MIXED TYPE	746	40%	57%	3%
OTHER	85	48%	44%	8%

Figure 5.12 Results of Re-inspection by DAEFK (a) and structural type/material of buildings (b)

5.1.4. Post-earthquake inspection of road network and water supply system

Most of the damages observed at the road network concerned road surface failure, subsidence, disintegration and collapses of retaining fences. A total amount of about 326 km of the road network of Ithaca and Kefalonia was inspected, as presented in Figure 5.13. Information about the importance of the damage (Figure 5.14) has been recorded in a Rapid Visual Inspection Form. Moreover, the locations of each damage have been defined, setting as reference the distance from the closest city. It is worth mentioning that the total amount for the recovery of the damages of the water supply system and the road network was 15.000.000 € and 30.000.000€ respectively.

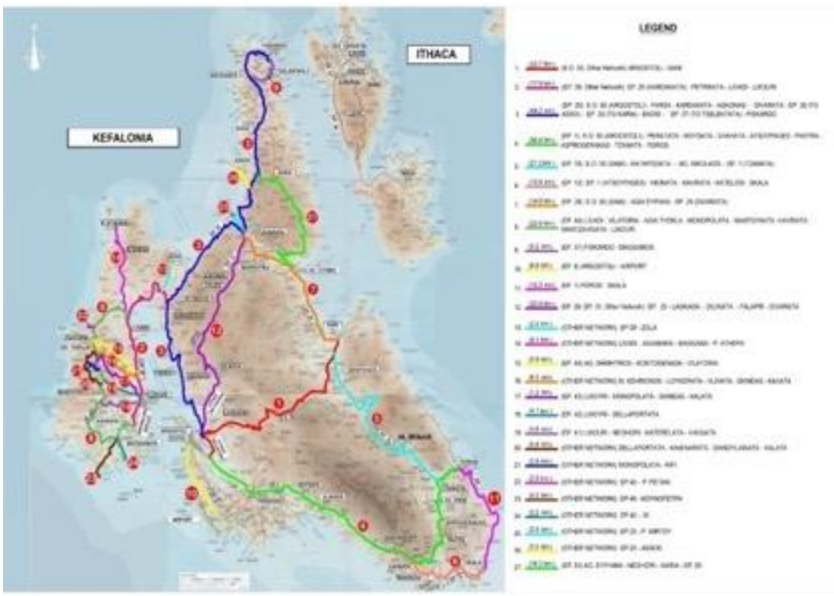


Figure 5.13 Parts of the road network inspected by the Local Authorities

Figure 5.14 Damages recorded along the road network of Ithaca and Kefalonia

According to their category of socio-economic system-sector (Figure 5.15), residential was by far the sector with more inspections however the expenses (Figure 5.16) for rehabilitation (15.500.000€) were similar to those needed for the restoration of water supply damages (15.000.000€) and less than the amount needed for road network damages (30.000.000€), as mentioned in the second paragraph of the current section. The expenses for repairs or reconstruction were covered either receiving special housing allowance, or free state aid or interest-free loan (Figure 5.17).

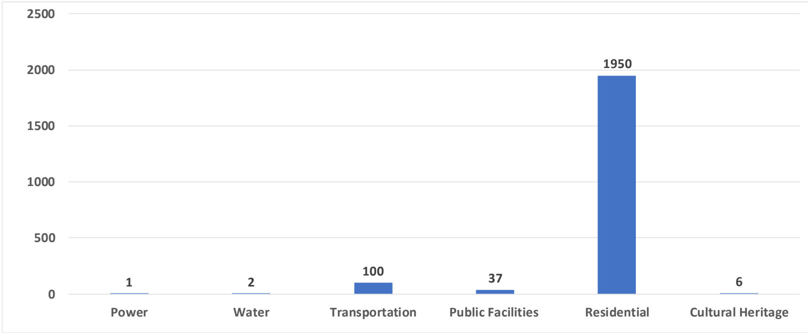


Figure 5.15 Inspections according to the socio-economic sector

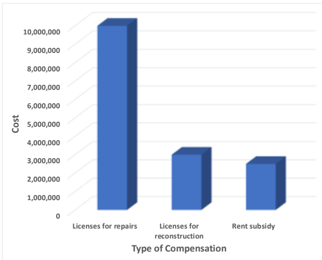


Figure 5.16 Cost of Rehabilitation

Figure 5.17 Sources of Funding for residential rehabilitation

5.1.5. Post-earthquake inspection of school units

After the earthquakes of 26/01/2014 and 03/02/2014, engineers of the Organization of Building Infrastructures-KTYP carried out post-earthquake inspections in Kefalonia and Ithaca in 149 statically independent buildings, housing 62 school units. The inspections marked as appropriate for use 128 (86%) and inappropriate 21 (14%) buildings.

Deviating from the post-seismic control process described in the previous section, the buildings, according to KTYP inspections, were assigned to six categories (A,B,C,D,E,F) depending on the damages appeared after the earthquakes (Table 5.1). In the 58.4 % of buildings no damages were observed, while the 1.3 % had severe damages at the bearing elements (Figure 5.18). It should be mentioned that no damage to the bearing elements of any school building was reported after the aforementioned strong earthquakes.

The structural types of the school buildings (Figure 5.19a) in the area are divided in load-bearing masonry (21, 14.1%), reinforced concrete (98, 65.8%), prefabricated reinforced concrete (22,14.8%) and prefabricated structure of low weight (8,5.4%). Most load-bearing masonry buildings, usually ground floor with horizontal moldings, were built after the devastating earthquakes of 1953. On the contrary, buildings with load-bearing body of reinforced concrete are up to three stories high, frame or mixed type. Most of the buildings in Kefalonia (Figure 5.19b) and Ithaca were designed and constructed according to older Seismic

Codes (Royal Decree of 1954, Seismic Code of 1959, Regulation of 1985) than the ones in force (NEAK, EAK).

Proper for use	No damage occurs. It can be used immediately.	**A**
Proper for use	Slight damages to the non-bearing elements (damages in infill walls, small detachments from the frame in extent and width, small cracks in coatings, etc.). Can be used. It can be repaired in non-	**B**
Improper for use	Extensive damages to the non-bearing elements (but no inclinations from the vertical directions). No damage to the Bearing System. It can only be used after repair.	**C**
Improper for use	Severe damages at the Bearing Elements (cross cracks, inclinations from the vertical direction, etc.). A few light local damages to the vertical elements of the Bearing System.	**D**
Improper for use	Damage to the Bearing System with possible effects on the overall stability of the building. Indicate whether supporting measures are required, or access prohibition measures should be	**E**
S**To be demolished**	Partial or total collapse. Very dangerous. Access is prohibited	**F**

Table 5.1 Classification of the school buildings according to the earthquake damages

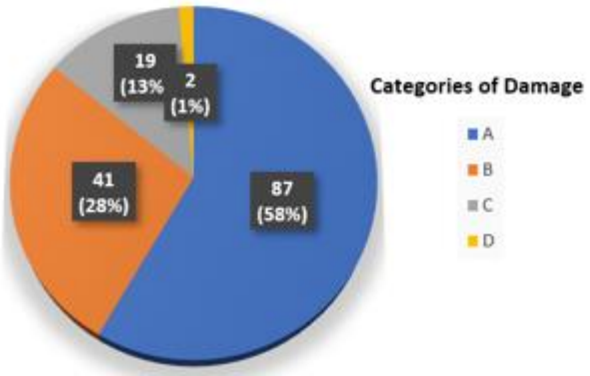


Figure 5.18 The distribution of statically independent school buildings to categories of earthquake damages (number of buildings and ratio)

Finally, apart from a two-story prefabricated building in Lixouri, only ground floor constructions were implemented with the heavy prefabricated system of the former Schools Building Organization.

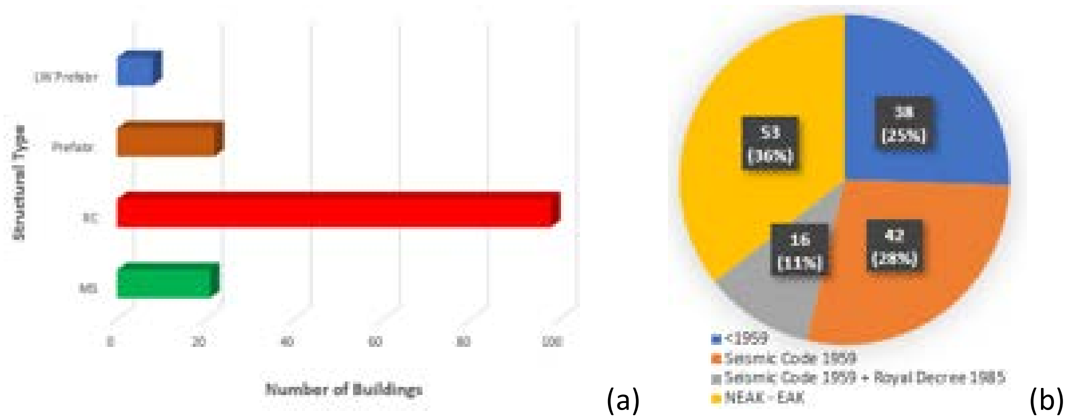
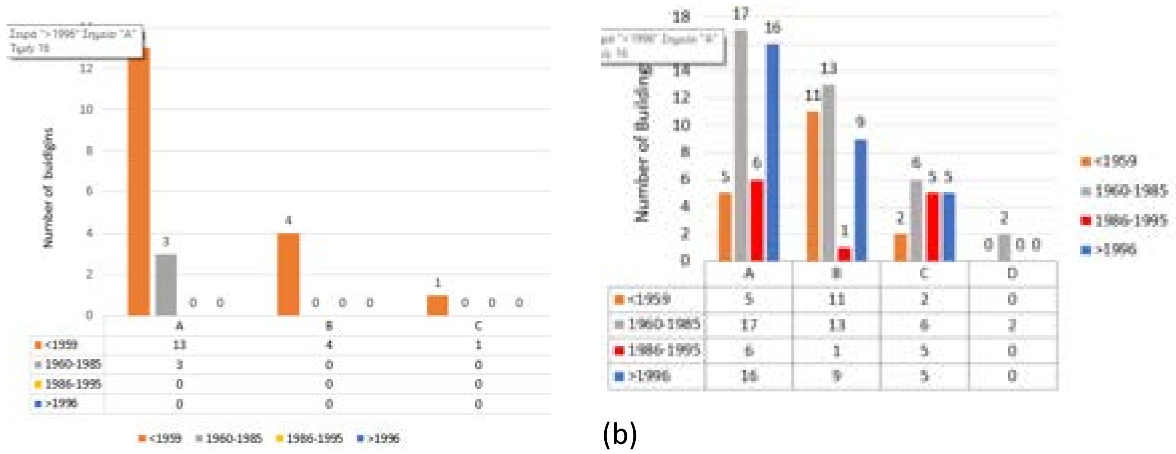


Figure 5.19 The distribution of statically independent buildings according to structural type (a) and Design Seismic Code (b) according to their period of construction.

The damages of the buildings per structural type and Seismic Code are shown in the following diagrams. Masonry structures, despite being about 60 years old, responded well due to their special construction method, as 20 out of 21 buildings were posted appropriate (Figure 5.20a) and one suffered minor damages because a large load-bearing part was removed to unite two rooms (Class C). On the other hand, the reinforced concrete structures, constructed before 1959, had slight and extensive damages (Figure 5.20b).



(a)

Figure 5.20 Categories of damages of the masonry (a) and reinforced concrete (b) structures according to their corresponding period of construction.

5.1.6. Geocoding of the post-earthquake building damage data

<u>5.1.6.1. Address Geocoding</u>

The field data collected in order to record damages after an earthquake event, comprise a set of structured information focusing, merely, to the extent of the damage and its effect to the sustainability of structures. Further collected information also includes the structure's owner, the type of structure, the date and any other data could possibly assist the Authority to analyze the existing situation and extract useful results for handling the effect of the hazard.

An important piece of information, also collected during the field campaigns, is the location of the inspected structure. So far, this information used to be recorded in the form of street address (name and number) whilst new regulations for data collection impose the use of mobile devices' location services (GPS, A-GPS etc.) in order to record the geographical coordinates (ϕ,λ in WGS84) of the structure.

The existence of sufficiently accurate geographical coordinates of every inspected structure allows the Authority to develop new procedures for analyzing recorded data, based on the technology of Geographical Information Systems. However, existing datasets are dated 2014 and therefore geographical coordinates of inspected structures need to be extracted from the address information records.

Address Geocoding is the procedure for deriving location information in the form of geographical coordinates from a street address descriptive text including street name, street number, postal code, municipality, prefecture, and country.

5.1.6.2 The available data

The data provided for the implementation of address geocoding technique refer to an earthquake event located in Kefalonia island in 2014 and comprises two (2) Microsoft Excel WorkBooks where field data are recorded according to the official "2 steps" damages inspection procedure of the Authority:

The first damages inspection (Figure 5.21), usually referred as "rapid inspection", takes place immediately after the earthquake event and its purpose is to quickly identify the extent of the hazard. This dataset contains 2814 records.

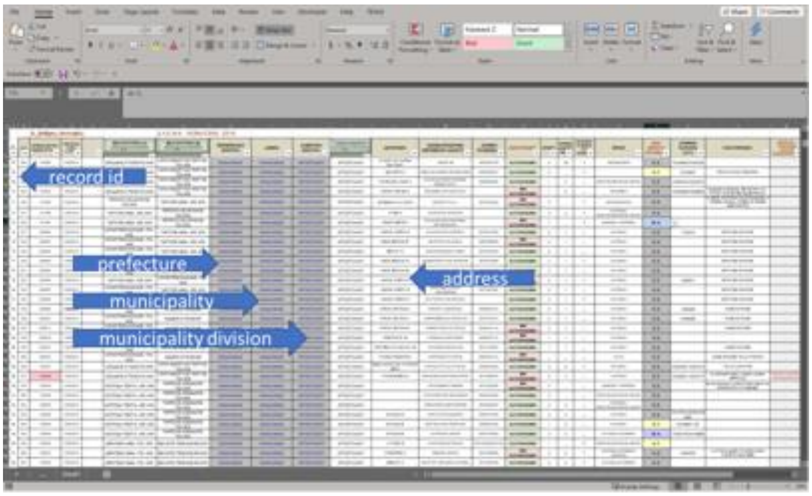


Figure 5.21 Address information in rapid inspection data

The second damages inspection (Figure 5.22), referred as "re-inspection", is a detail description of the structures' damages. This dataset contains 2790 records.

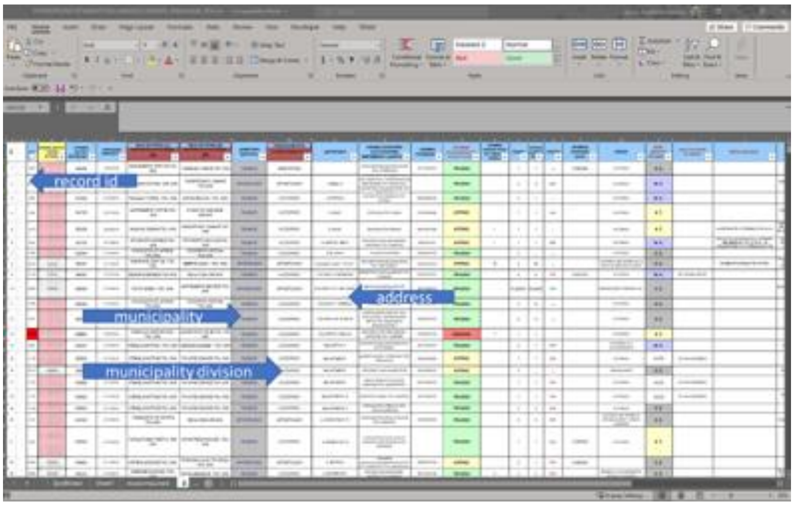


Figure 5.22 Address information in re-inspection data.

Both Excel Sheets include address geocoding related information in specific columns and a unique id for each record. However, in many records, the quality of the address information is poor due to specific problems including:

- the lack of specific elements such as the street name or the street number
- the use of an unformal street name (ex. “ΚΑΠΟΔΙΣΤΡΙΟΥ” or “Ι.ΚΑΠΟΔΙΣΤΡΙΟΥ” instead of “ΙΩΑΝΝΟΥ ΚΑΠΟΔΙΣΤΡΙΟΥ”.
- Unexistence of street name and/or street number in rural areas

5.1.6.3 The geocoding procedure

The theoretical background of address gecoding algorithm is based on the Address Interpolation method according to which existing data from a street GIS are used in order to divide streets into segments, each of which has a range of addresses associated with it. Geocoding software identifies and matches physical addresses to particular segments in order to interpolate the location of a given address based on where it should be located within each segment.

Nowadays, existing APIs (Application Programming Interface), software libraries or Web services (SaaS) provide both the necessary GIS data (street segments) and software functionality in order to allow the use of geocoding services with Goggle Map Geocoding API, ESRI Geocoding API and OSM Geocoder being the most famous geocoding services in the market.

The procedure for implementing address geocoding to the records of the inspections datasets comprised the development of a geocoding software in Python 3.8 (“googlemaps_geocoding.py) that was able to consume geocoding web services feeded with the records of the inspections datasets and return the geographical coordinates for each address. After evaluating the aforementioned geocoding services, the Google Maps Geocoding Service was chosen to be most suitable to the project’s needs, merely because of its large address database which also includes landmarks as locations of known geographical coordinates (ex. “Starbucks” in Argostoli).

The main steps for executing the procedure is shown in the following schema (Figure 5.23).

Figure 5.23 Geocoding procedure steps

5.1.6.4. Geocoding results

Practically, the result of the address geocoding procedure was the addition of 3 new columns to the Excel sheets of the inspections datasets:

1. The ϕ coordinate of the structure in WGS84 geodetic system
2. The λ coordinate of the structure in WGS84 geodetic system
3. The quality of the geocoded results according to the Google Map geocoding web service i.e.:
   3.a. ROOFTOP. The geocoded address is located on the rooftop of a building (assumed as good accuracy)
   3.b. RANGE_INTERPOLATED. The geocoded address is located by interpolating street segment (assumed as good accuracy)
   3.c. APPROXIMATE. The geocoded address is approximately located (assumed as bad accuracy)
   3.d. GEOMETRIC_CENTER. The geocoded address is located on the centroid of administrative boundaries (assumed as bad accuracy)
   3.e. VOID. Unable to geocode address

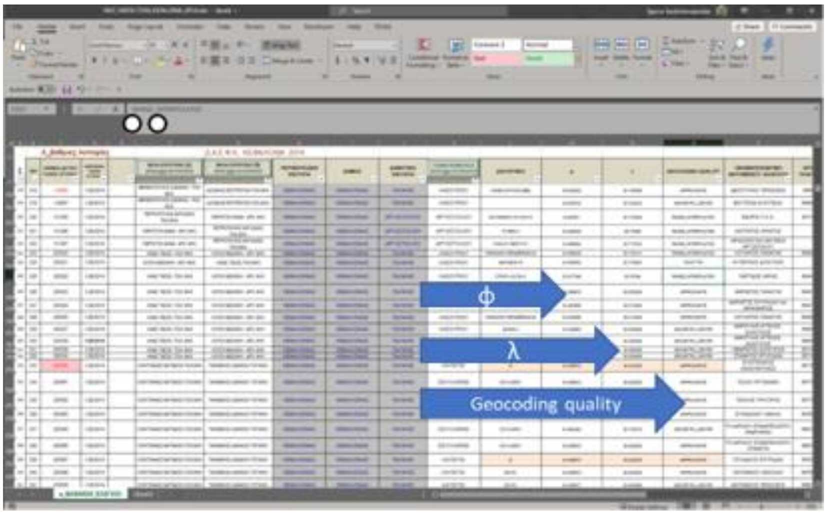


Figure 5.24 Geocoding sample results for re-inspections

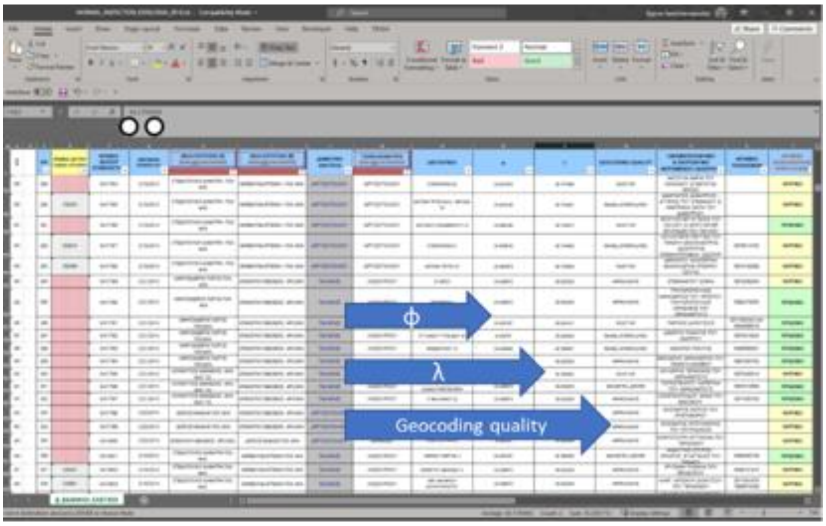


Figure 5.25 Geocoding sample results for rapid inspections

The resulted locations of the structures, as they were by the address geocoding procedure, added a spatial information on both rapid and re inspections datasets. However, the uncomplete, incorrect or erroneous address information recorded leaded the procedure to fail in special situations where the Google Geocoding Web Service was unable to locate the given addresses.

6.1.6.5. Verification of geocoding quality

The dataset of Rapid Inspections included 2843 records and the results of the address geocoding procedure are shown in the following pie chart (Figure 5.26).

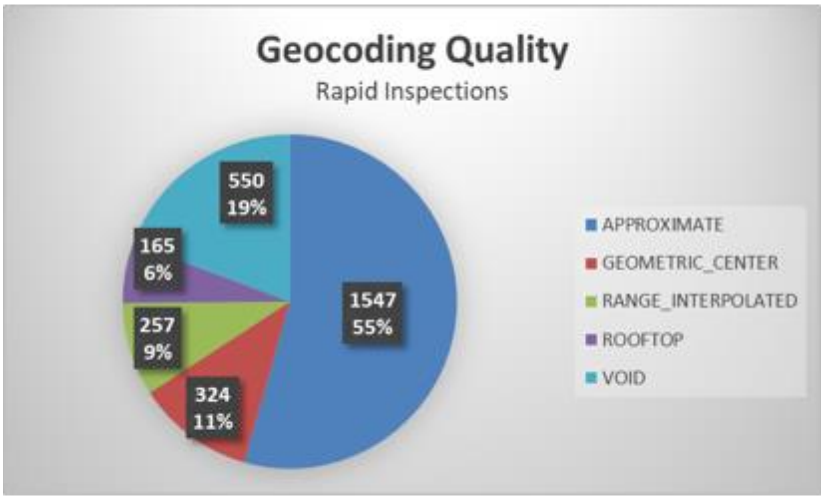


Figure 5.26 Quality of geocoding results for rapid inspections.

Since the Rapid Inspections contains spatial information (VOID results are excluded) in the form of point coordinates, it can be easily imported into any GIS software for further analysis.

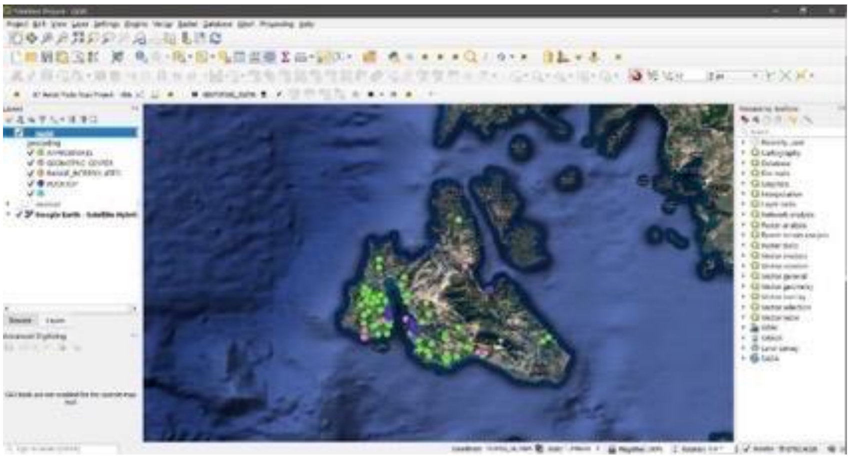


Figure 5.27 Rapid Inspections geocoding results viewed in QGIS

The dataset of Re - Inspections included **2794 records** and the results of the address geocoding procedure are shown in the following pie chart (Figure 5.28).

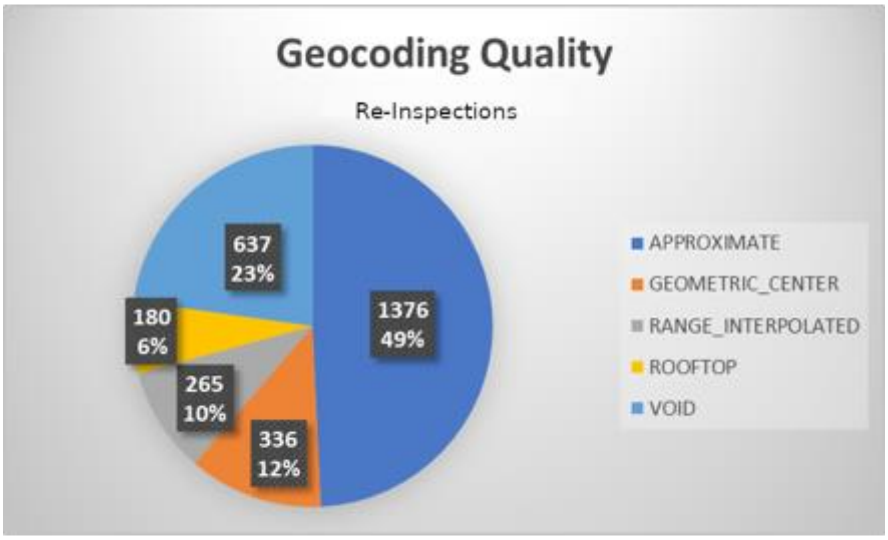


Figure 5.28 Quality of geocoding results for re-inspections

Further analysis can be performed in a GIS software, since all the records of the re-inspections contain spatial information (VOID are excluded) for any recorded structure.

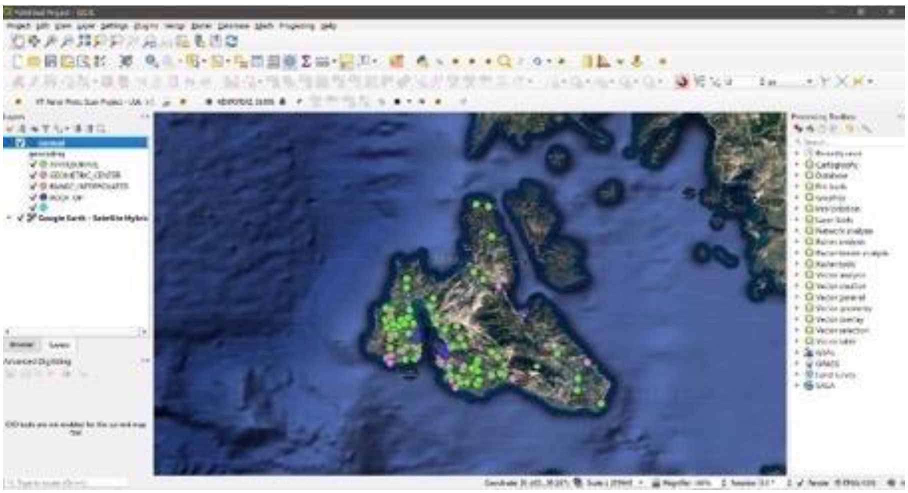


Figure 5.29 Re-Inspections geocoding results viewed in QGIS

5.2 Vulnerability assessment in Greece and in the Kefalonia case

5.2.1. Vulnerability assessment of buildings in Greece

The showcase of Kefalonia has used the rather extensive damage data collection to provide a sort of validation of pre-event risk and damage assessments using the vulnerability evaluations and inspections that are carried out by the OASP institution. Also, in the report different seismic scenarios are presented and compared with the 2014 earthquake.

As the socio-economic cost of a possible earthquake may be significant, a major effort has been made worldwide, mainly during the last two decades, towards the development of organized large-scale actions for the enhancement of the safety and serviceability of the building stock, the upgrade of the seismic performance of the infrastructure, as well as for the mitigation of potential environmental impacts and any other direct or indirect consequences.

This effort, which is primarily made in countries exposed to high seismic risk (due to high seismic hazard and/or high exposure caused by dramatic increase of the size of the cities), is related to the pre- and post-earthquake damage assessment of buildings and to the subsequent technical, social, administrative, legal, and financial necessary measures for the foreseen actions.

The **Pre-Earthquake Vulnerability Assessment of buildings**, is aimed at evaluating the safety level of buildings against the maximum considered seismic action to develop risk assessment and damage scenarios.

The **Post-Earthquake Inspection of buildings**, includes two degrees of inspection. The First Degree Rapid Visual Inspection (RVI) and the Revised Inspection (Re-inspection /Second degree Inspection). The two provide an assessment of buildings usability based on damage estimation.

5.2.2. Purpose and practice of vulnerability assessment of buildings

One of the most effective ways to mitigate the damage of earthquakes from an engineering standpoint is to design and construct structures capable of withstanding strong ground motions. In Greece, having the highest seismicity in Europe, many important decisions have been taken in recent years, especially with the establishment of strict seismic codes, which provide modern buildings with a high level of seismic safety. However, given that the first Seismic Code was implemented in Greece in 1959 and the first significant improvement was made in 1985, the question arises as to how safe the buildings built before 1959 or even before 1985 are.

According to the census of 2011, a 43 % of the building stock in Greece was built between 1961 and 1985 (that is with the first Seismic Design Code implemented in Greece) and a 26% was built without seismic code. The question is of great importance when it refers to public buildings such as hospitals, schools, administration buildings, telecommunications, energy production, transportation, and fire stations, etc. Since the upgrading of the building stock with new structures is of the order of 1-2% annual renewal rate, the majority of existing buildings today is potentially vulnerable to earthquakes.

Seismic upgrade of the building stock and the subsequent mitigation of seismic risk may be performed either: a) through a gradual replacement of the under-designed (old) buildings with seismic resistant ones or b) through seismic strengthening of existing buildings. The first, being quite natural but slow approach, does not lead to remarkable results. However, it is of low cost. The second can upgrade the building stock faster but is inevitably associated with enormous cost, which is unbearable even in the most developed countries.

Selective intervention is therefore the only realistic solution. When the scope is to assess and upgrade a particular building, it seems that the Codes can give a rather reasonable answer. When the question is to locate those buildings which - among similar others - have a priority on intervention (in terms of seismic risk), the problem is quite complex. Detailed assessment of the structural capacity of all individual buildings is extremely costly and time consuming, practically inevitable.

In Greece, the Earthquake Protection and Planning Organization (OASP) assigned the preparation of a proposal for a pre-earthquake vulnerability assessment framework for buildings of public use in a Working Group leading to a document submitted in 2000. The proposed framework, strongly influenced by the relevant system of USA (FEMA 154), includes three degrees of assessment:

- First degree inspection, is a Rapid Visual Screening Procedure for a first estimation of the bearing capacity of the building. Buildings found insufficient, need further examination.
- Second degree inspection, is an approximate seismic evaluation which is based on simplified calculations through the study of the building design drawings, verification of building geometry and critical section and reinforcement dimensions and on-site non-destructive testing of material for insufficient buildings from the first-degree inspection. In case that the structure is found adequately safe it is excluded of further examination. In case it is not of adequate safety, the assessment proceeds to the next stage.
- Third degree inspection is a detailed assessment of seismic performance. It is conducted based on the legislative framework (Greek Code for Seismic Intervention KANEPE or EC8 - Part 3).

5.2.2.1 The procedure of the pre-earthquake vulnerability assessment of buildings of public use

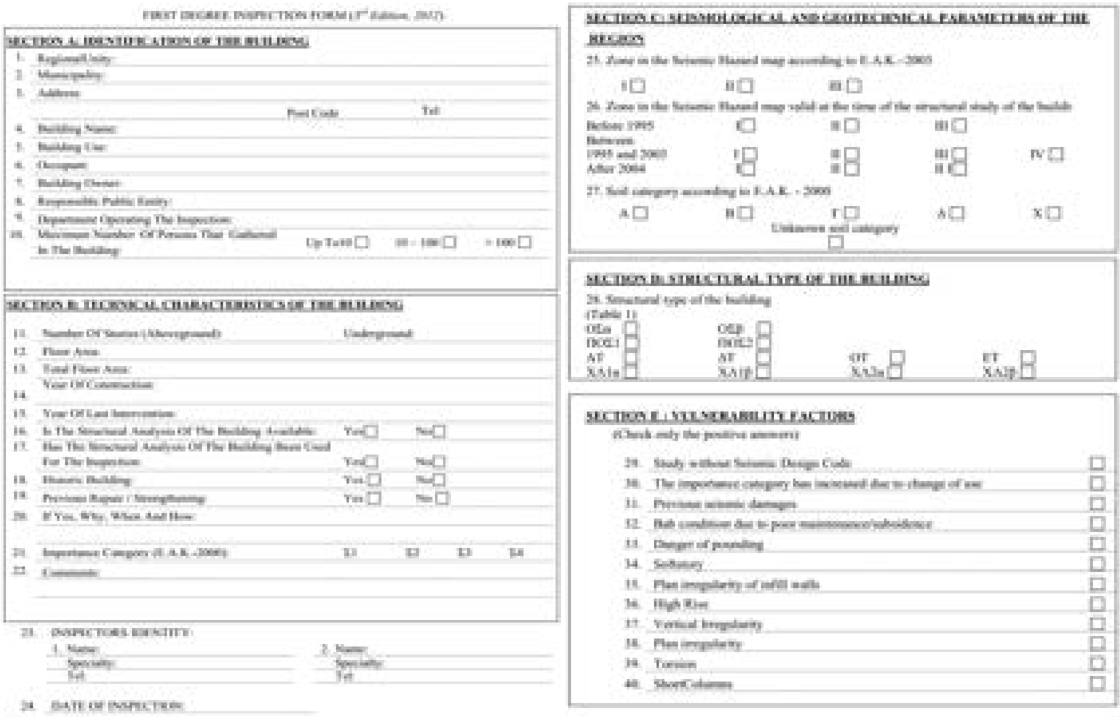
The Pre-Earthquake Vulnerability Assessment (first degree) of buildings of public use was initiated in Greece for the first time in spring of 2001. The purpose of the first degree inspection is a first estimation of the bearing capacity of the building in order to identify priorities at national level for further assessment and interventions if needed (to identify those buildings which present inefficient earthquake performance might pose a risk of loss or injury, or severe interruption of community services in the event of a damaging earthquake).

The first-degree inspection is carried out at every administrative level of the country in collaboration with the respective Technical and Civil Protection Departments. The inspection of each building is carried out by the service responsible for the operation and safety of the building.

The inspections are performed by two structural engineers (from the technical Department of each authority) to all public owned or leased buildings such as hospitals, schools, public administrative services, telecommunication buildings etc.

For each building a Pre-earthquake Vulnerability Assessment Inspection Form is filled (Figure 2.5). The process is designed to be simplified and standardized in terms of data collection. An important factor for the reliability of the inspection is to have the study of building which is something that is not always possible. In case that certain data is not fully known, at the completion of the form, a star (*) next to the corresponding checkbox should be indicated. The method is meant to be fast and relatively inexpensive.

The inspection form includes basic characteristics of each individual structural unit (year of construction, design and construction codes and regulations, damage from previous earthquakes, use, structural system etc.). The buildings are classified in 13 categories according to the construction material (concrete, precast concrete, steel, masonry), and the regulatory framework according to which the building is designed for. More analytically, the Structural types of buildings as shown in Section D of the Inspection Form (Figure 5.30), are: a) Reinforced concrete structures (ΟΣα, ΟΣβ, ΟΣγ), b) Precast concrete structures (ΠΟΣ1, ΠΟΣ2), c) Masonry structures (ΑΤ, ΔΤ, ΟΤ, ΕΤ), d) Steel structures (ΧΛ1α, ΧΛ1β, ΧΛ2α, ΧΛ2β).


FIRST DEGREE INSPECTION FORM

SECTION A: IDENTIFICATION OF THE BUILDING

1. Regional Unity:
2. Municipality:
3. Address:
Post Code Tel:
4. Building Name:
5. Building Use:
6. Occupant:
7. Building Owner:
8. Responsible Public Entity:
9. Department Operating The Inspection:
10. Maximum Number Of Persons That Gathered In The Building: Up To 10 ☐ 10 - 100 ☐ > 100 ☐

SECTION B: TECHNICAL CHARACTERISTICS OF THE BUILDING

11. Number Of Stories (Aboveground): Underground:
12. Floor Area:
13. Total Floor Area:
14. Year Of Construction:
15. Year Of Last Intervention:
16. Is The Structural Analysis Of The Building Available: Yes ☐ No ☐
17. Has The Structural Analysis Of The Building Been Used For The Inspection: Yes ☐ No ☐
18. Historic Building: Yes ☐ No ☐
19. Previous Repair / Strengthening: Yes ☐ No ☐
20. If Yes, Why, When And How:
21. Importance Category (E.A.K. -2000): Σ1 Σ2 Σ3 Σ4
22. Comments:

23. INSPECTORS IDENTITY:
1. Name: Specialty: Tel: 2. Name: Specialty: Tel:

24. DATE OF INSPECTION:

SECTION C: SEISMOLOGICAL AND GEOTECHNICAL PARAMETERS OF THE REGION

25. Zone in the Seismic Hazard map according to E.A.K. - 2003
I ☐ II ☐ III ☐

26. Zone in the Seismic Hazard map valid at the time of the structural study of the building
Before 1995 I ☐ II ☐ III ☐
Between 1995 and 2003 I ☐ II ☐ III ☐ IV ☐
After 2004 I ☐ II ☐ III ☐

27. Soil category according to E.A.K. - 2000
A ☐ B ☐ Γ ☐ Δ ☐ X ☐
Unknown soil category ☐

SECTION D: STRUCTURAL TYPE OF THE BUILDING

28. Structural type of the building (Table 1)
ΟΣα ☐ ΟΣβ ☐
ΠΟΣ1 ☐ ΠΟΣ2 ☐
ΑΤ ☐ ΔΤ ☐ ΟΤ ☐ ΕΤ ☐
ΧΛ1α ☐ ΧΛ1β ☐ ΧΛ2α ☐ ΧΛ2β ☐

SECTION E: VULNERABILITY FACTORS
(Check only the positive answers)

29. Study without Seismic Design Code ☐
30. The importance category has increased due to change of use ☐
31. Previous seismic damages ☐
32. Bad condition due to poor maintenance/subsidence ☐
33. Danger of pounding ☐
34. Softstory ☐
35. Plan irregularity of infill walls ☐
36. High Rise ☐
37. Vertical Irregularity ☐
38. Plan irregularity ☐
39. Torsion ☐
40. ShortColumns ☐

Figure 5.30 Pre-earthquake Vulnerability Assessment Inspection Form

The classified buildings receive an Initial Seismic Risk Grade. This grade is modified, considering the Seismicity Zone and additional structural features. The factors that reduce the grade are:

Design without seismic code: Construction before 1959.

The importance category has increased due to change of use: If the importance category of the building has changed (from S2 to S3 or S4), then the building grade must be reduced.

- Previous seismic damages (not restored or insufficient restored): Damage to the load-bearing elements of the structure from previous earthquakes which have not been repaired.
- Poor condition: Existence of poor-quality concrete or exposed and corroded reinforcement. Existence of weak mortar in stone buildings and cracks. Cracks due to subsidence.
- Danger of pounding: Danger of embolism of the columns of one building by structural elements of the other, large difference in stiffness between the two neighboring buildings, corner or diagonal buildings.
- Soft story building: The term "soft-story" refers to one level of a building that is significantly more flexible or weak in lateral load resistance than the other stories of the building. The most common cases of soft floor are pilotis.
- Plan irregularity of infill walls: This feature mainly applies to buildings with a load-bearing structure made of reinforced concrete. The existence of infill walls symmetrically arranged on each floor and in the entire height of a building contributes positively to the seismic behavior of the building.
- High rise: Constructions from load-bearing masonry or prefabricated elements with height over 2 floors or reinforced concrete buildings with height over 5 floors.
- Vertical irregularity: Structures with recesses or towers.
- Plan irregularity: Buildings with complex shapes such as L, E, P, T, buildings with large lengths relative to width etc.
- Torsion: Asymmetric arrangement of vertical load-bearing elements.
- Short columns: The problem concerns reinforced concrete columns that are designed to operate along their entire height (floor height), but due to the subsequent addition of beams to a certain height, or to the existence of partial constructed walls in one side, have an active length significantly shorter than full.

The completed inspection forms sent to OASP are entered into an electronic data base and they are classified in three categories A, B, C. The outcome of the assessment is the relative scoring of the seismic capacity of the examined buildings. When score is above a predefined threshold value the building is deemed safe and further assessment is not necessary (buildings classified C). For scores below the threshold, the building is deemed as not meeting the current requirements and further investigation is needed. The necessity of buildings classified in Category A for further assessment is greater than that of buildings belonging to Category B, and so on.

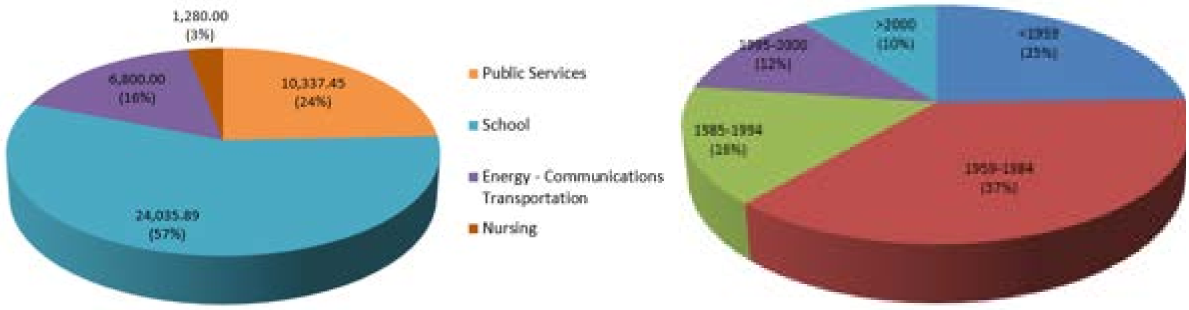
The results of building scoring, that determine the priority for the second-degree inspection, are forwarded in the form of classified documents to the higher levels of administration (Prefecture Director, General Secretary of Decentralized Administration). It is important that the process of the First-Degree Inspection does not inhibit the responsibilities and obligations of the competent bodies to take immediate and urgent measures in order to protect the public and the employees in the buildings deemed hazardous under current legislation.

5.2.3.Vulnerability assessment in Kefalonia before 2014

5.2.3.1 Data from OASP

Before the 2014 earthquakes of Kefalonia and in the framework of vulnerability mitigation of buildings, a Pre - earthquake assessment (first degree) was carried out in the island of Kefalonia for existing buildings of public use. These buildings are not all public buildings in Kefalonia but a part of them.

The Earthquake Planning and Protection Organization assessed 57 public buildings in Kefalonia, specifically: 14 of Public Services, 41 Schools, 1 Energy-Communications-Transportation and 1 Hospital. The total area of the inspected buildings according to their use is presented in Figure 5.31a while the period of their construction is presented in Figure 5.31b. It is easily concluded that the majority of the inspected structures (90%) corresponds to construction periods before the regulations in force.



(a) (b)

Figure 5.31 Total area (square meters) of inspected buildings with respect to their public use (a) and the rate of inspected buildings according to the Seismic Code applied during their construction period (b). In diagram (a) the ratio % of the area of the specific public use to the total area of buildings inspected is shown in parenthesis.

Most of the inspected buildings are constructed of reinforced concrete, while the rest are made of masonry and prefabricated reinforced concrete (Figure 5.32).

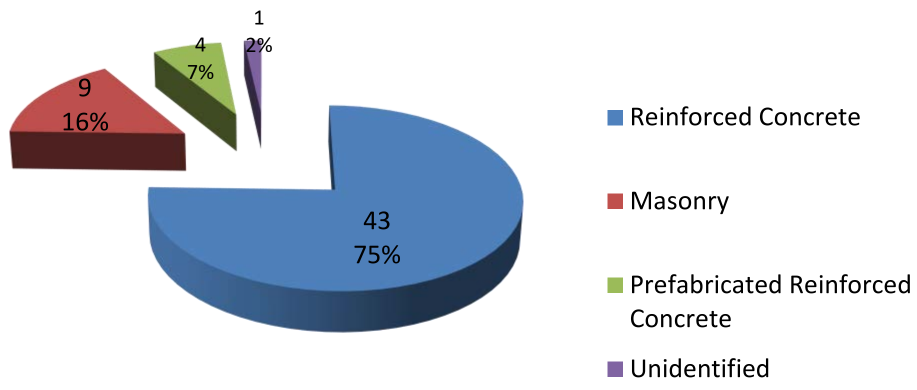
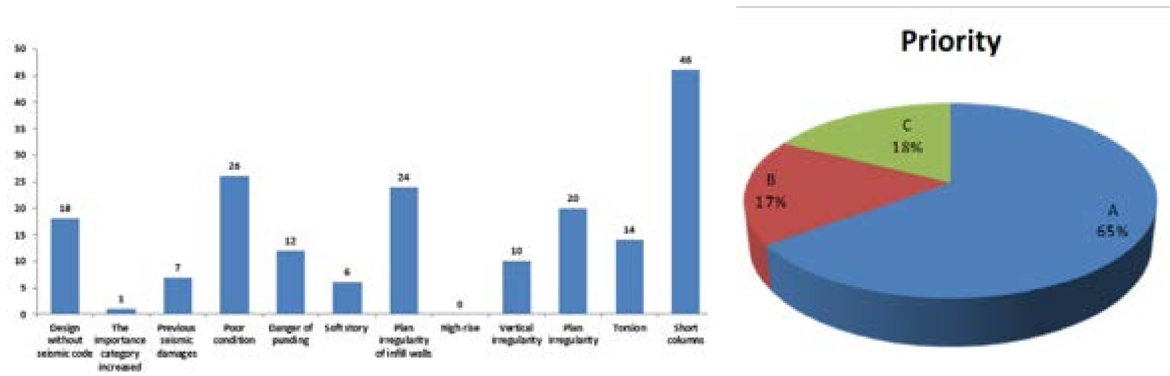


Figure 5.32 Number of buildings and their rate in parenthesis according to their construction material

Although, there were no significant damages observed in most of the buildings after the 2014 earthquakes, they received low grades according to the OASP pre-earthquake assessment procedure presented in section 3.1. This is due firstly to the fact that Kefalonia island is located in the third seismic hazard zone (highest seismicity) and secondly to the fact that the structures were constructed with no or old regulations, and therefore have many vulnerability issues (section E of pre-earthquake assessment evaluation form). For example, it is worth mentioning that 46 out of 57 buildings have short columns and 20 have plan irregularities. The number of buildings and the corresponding vulnerability factors are presented in Figure 2.10.

According to the grading resulted from the processing of the first-degree evaluation forms by OASP, the buildings were sorted to 3 categories concerning the priority for second degree pre-earthquake vulnerability assessment, namely A, B and C (Figure 5.33). It is noted that category A corresponds to higher priority for second degree assessment than category B and C, and so on.

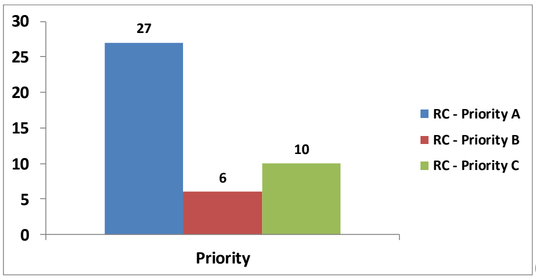


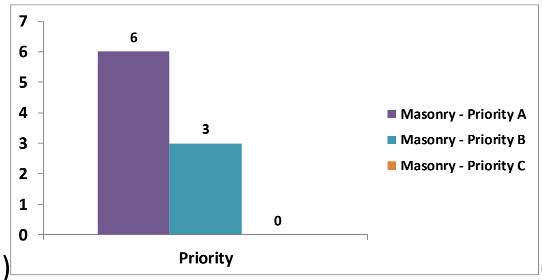
(b)

(a)

Figure 5.33 Number of buildings with specific vulnerability factors (a) and classification of buildings according to their priority for second degree assessment (b)

In detail, 27 out of the 43 reinforced concrete buildings receive a priority of A for second degree inspection while for masonry structures the ratio is 6 out of 9 (Figure 5.34).



(a)


(b)

Figure 5.34 Number of buildings with priority a, b and c for second degree assessment with respect to their construction material, namely reinforced concrete (a) and masonry (b).

<u>*5.2.3.2 Data from Organization of building infrastructure (KTYP)*</u>

The pre-earthquake vulnerability assessment evaluation form, proposed by the Earthquake Planning and Protection Organization, was modified by the Organization of Building Infrastructure (former Schools Building Organization SA- OSK SA) to include the following categories concerning **school buildings**:

- bearing unarmed masonry, mainly stonework (slow, semi-constructed stones), either without moldings-barriers with wooden roof or with reinforced concrete moldings-barriers and connecting mortar limestone or clay
- frame or mixed bearing structure made of reinforced concrete
- prefabricated load-bearing structure made of reinforced concrete
- ground floor of a frame or mixed load-bearing structure made of reinforced concrete and the remaining floors A and B made of prefabricated load-bearing structure
- ground floor prefabricated buildings (metal, wooden "loose")
- load-bearing masonry that has been repaired and reinforced with moldings-barriers and appropriately established light reinforcement in one or both sides.

Moreover, other additions - modifications were included in the datasheet concerning the identification of the school (kindergarten, elementary school, high school, etc.) , the special use (if the specific building houses classrooms, offices, the canteen, the boiler room, etc.) in order to correctly assign the importance of the structure according to Greek Seismic Design Code.

At the first stage, the Organization of Building Infrastructure decided to inspect the school buildings designed and constructed without Seismic Design Codes for all the country, while for the school buildings located in the seismic risk zone III, **(**prefectures of Kefalonia, Zakynthos and Lefkada), it was decided to assess all school buildings, regardless of the construction period.

In Kefalonia, a Pre earthquake Rapid Visual Inspection was carried out in the period April-August 2005, in 177 statically independent buildings which housed 69 autonomous administrative school units by the Organization of Building Infrastructure. The inspection was held in collaboration with the Department of Civil Engineering of the Polytechnic School of the University of Patras.

One of the main purposes of this Rapid Visual Inspection was the identification of buildings that have obvious local or general problems. The results of the inspections pointed out buildings of two school units that need to be repaired. The Organization of Building Infrastructures informed the respective Local Authorities and the Prefecture as competent bodies for intervention. Eventually, the buildings of one school unit were strengthened by KTYP, while for the intervention in the other unit, the Municipality was financed by a Programmatic Agreement.

After the calibration of the evaluation forms, their registration to the Electronic Database and according to the Procedure (OSK3 scenario) proposed by the Earthquake Planning and Protection Organization (OASP), the following results-grades emerged:

1≤2,00 , 2<**8** ≤3,00, 3<**22** ≤4,00, 4<**76**≤5,00, 5<**33**≤6,00, 6<**14**≤7,00, 7<**23**

where the number in bold corresponds to the number of school buildings which received the specific grades. The lower the grade is, the higher the priority for second degree assessment becomes. The lowest grade of 1.80 was given to a two-story building of 1980 at Lixouri.

5.2.4. Comparison of pre- and post-earthquake inspections of buildings in Kefalonia

5.2.4.1 Comparison carried out by the Organization of Building Infrastructures-KTYP

As mentioned in section 1.4.1.2, in 2005 prior to the earthquakes of 2014, the Organization of Building Infrastructure inspected 177 statically independent buildings which housed 69 autonomous administrative school units (thus the 100% of the school buildings). The lower grade a school building received, the higher the priority for second degree assessment was. The building with the lowest Grade = 1.80, according to the pre-earthquake assessment, was given to a two-story building of 1980 in the coastal zone of Lixouri. During the earthquakes of 2014, the building responded extremely well. The second with the smallest Grade = 2.40 was a building in Ithaca and the third, receiving grade 2.45, concerned a building that was characterized as improper for use after the earthquakes (belonging to D category namely according to the re-inspection sheets).

In addition to the aforementioned remarks, the main post-earthquake conclusion is that the school buildings responded satisfactorily well during the two strong earthquakes. However, great attention should be given to supporting the interior moving items and furniture of each school unit. Wardrobes and libraries were overturned in several buildings.

The Schools Building Organization’s "heavy prefabricated" system responded very well, as it had already been concluded during previous earthquake (Athens 1981, Kalamata 1986, Athens 1999, Achaia - Ilia 2008). As a general conclusion the pre- earthquake assessment provides a conservative prediction of the seismic response of the school buildings.

5.2.4.2 Inspections from local authorities and General Directorate of Natural Disasters Rehabilitation - DAEFK

Based on the data collected by Municipality Civil Protection, the Technical Department of Kefalonia Prefecture and the Department of Rehabilitation from Earthquakes in Kefalonia, the results of the pre- and post - earthquake assessments have been compared. Specifically, in Figure 5.35, the results of the post- earthquake assessment for 14 buildings which had received grade A during the pre-earthquake assessment (highest priority for further assessment) are presented. It is easily concluded that all buildings behaved well during the earthquake, however most of them have damages that need repair (marked yellow). On the other hand, it is important to notice that among the three building that had received a grade C (lowest priority for further assessment, Figure 2.39), one (2nd Elementary School of Lixouri) had damages that need repair, therefore was marked yellow (Temporarily unusable).

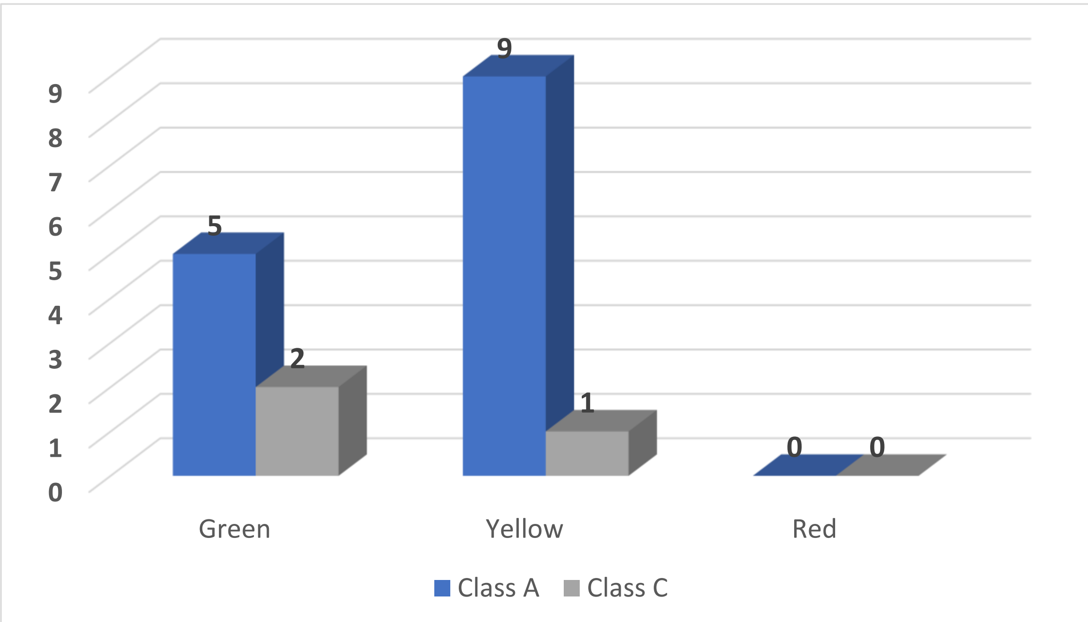


Figure 5.35 Post-earthquake assessment of 14 buildings of Class A and 3 buildings of Class C according to pre-earthquake assessment

As a conclusion the pre- earthquake assessment provides a conservative prediction of the seismic response of the buildings of public use. It is worth mentioned that there was not any public building with significant damage that was not indicated from the pre-earthquake assessment.

Additionally the Pre-earthquake vulnerability data can be used not only during mitigation phase of an earthquake in order to identify those buildings which present inefficient earthquake performance so as to take the appropriate measures, but also during response phase in helping with the prioritization of the buildings inspection in the affected area.

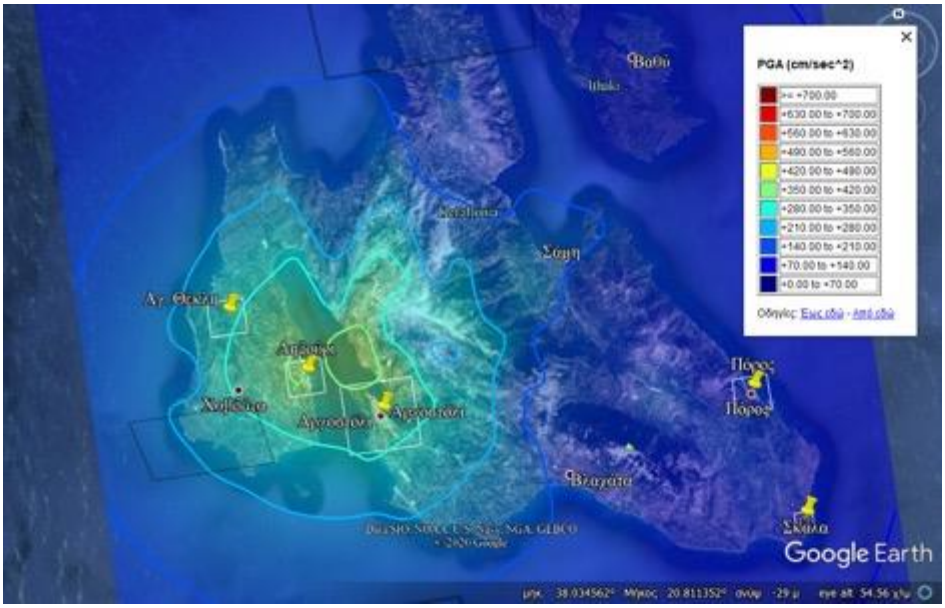
5.3. Pre-event damage scenario assessment

5.3.1. The seismic scenario

In the following sections, the methodology for the seismic loss estimation in Kefalonia, for various seismic scenarios, is presented. The term scenario refers to a given earthquake (maximum credible, or standard design, or frequent) and provides a comprehensive description of what happens when such an earthquake occurs. The seismic loss estimation is linked to the structural seismic risk (R) which expresses the expected degree of loss of all construction elements located in the area of interest.

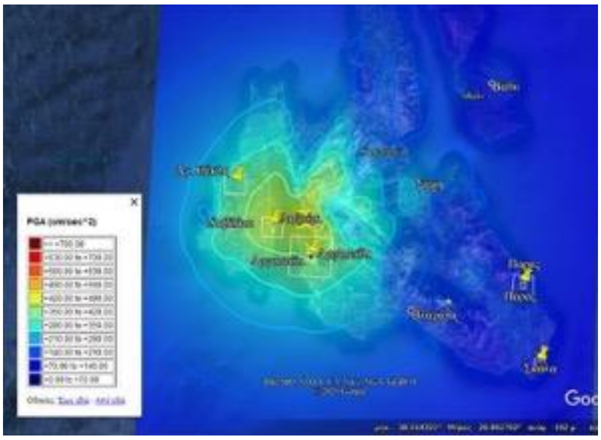
More specifically, the seismic risk (R) depends on the seismic hazard of a region, H, the vulnerability of the existing structures, V and the number of elements in danger, E. The seismic hazard is determined at the area of interest and is represented by the ground accelerations raised due to the seismic scenario considered. In our case, the seismic hazard is determined for an earthquake, caused by the typical focal mechanism for Kefalonia area (Papazachos and Papazachou, 2003) with magnitude Mw=6.0 and epicentral depth 16km. The reason for this scenario is that it is near to the most recent earthquake in 6.0 moment magnitude, Mw, which happened at 23/2/2014 (Mw=6.1). Based on ground motion prediction equations derived from stochastic optimization analysis (Margaret Segou and Voulgaris, 2013), the horizontal peak ground acceleration all over the area of interest is estimated. Soil condition in Kefalonia is considered, leading to the values of peak ground acceleration presented in Figure 3.1. Therefore, the area is subdivided into grid of specific dimensions, with defined local soil conditions. Adopting appropriate attenuation relationships (Margaret Segou and Voulgaris, 2013), the acceleration at each point in the center of the grid square is calculated. The PGA of Argostoli (Figure 5.36) according to the scenario (0.34g) is close to the maximum acceleration recorded during the earthquake (0.39g).

Although the main scenario studied is the one presented in Figure 5.36, the distribution of peak ground acceleration for gradually increased magnitude of the earthquake by 0.2 step up to Mw=7, assuming the same epicentre and epicentral depth as in the 1st scenario, is presented in Figure 5.37. This was implemented for comparison reasons.

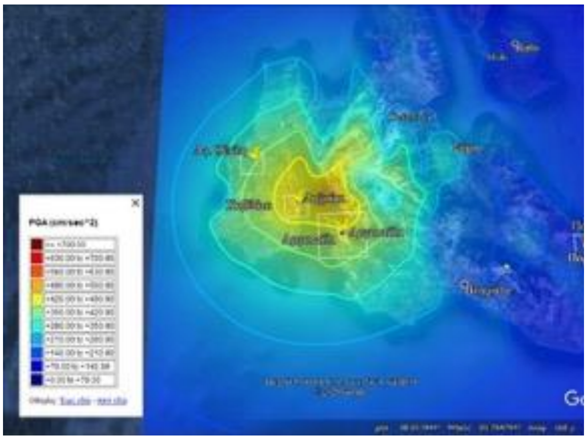


(b)

Figure 5.36 Peak ground acceleration resulted from the scenario of earthquake of Mw=6, epicentral depth 15km



(a)



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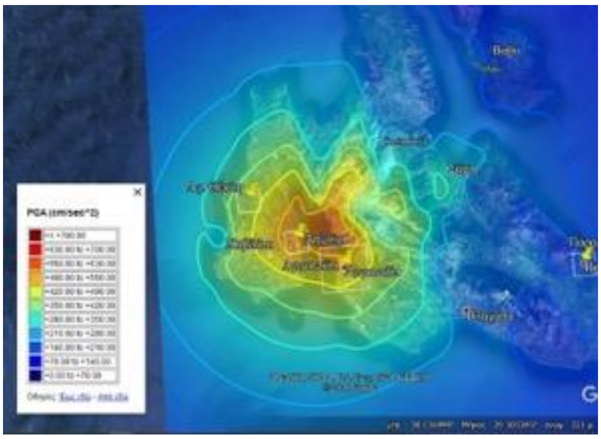
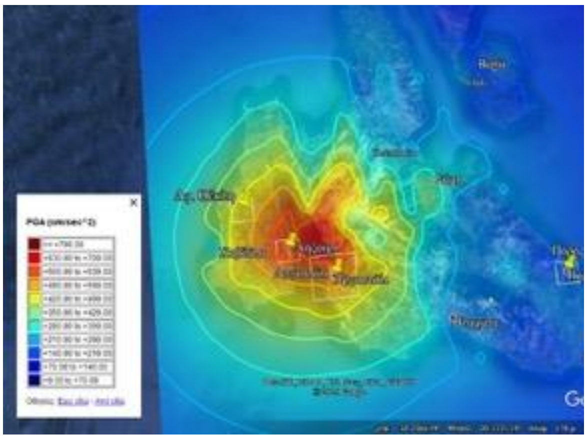
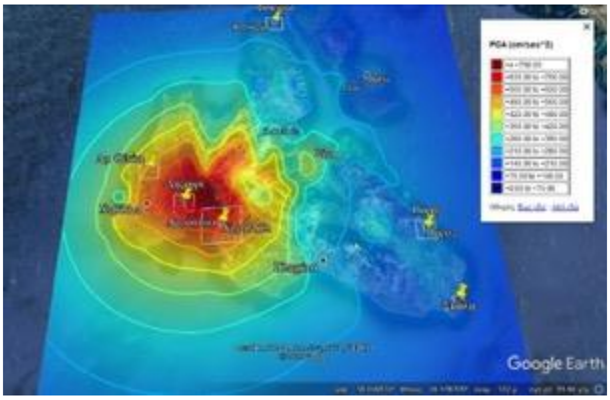


(c)



(d)



(e)

Figure 5.37 Peak ground acceleration resulted from the scenario of Mw=6.2 (a), Mw=6.4 (b), Mw=6.6 (c), Mw=6.8 (d) and Mw=7 (e) earthquakes for epicentral depth 15km

5.3.2. Classifying the buildings according to a predefined taxonomy

Subsequently, the majority of buildings of Kefalonia, as they were recorded by the Hellenic Statistical Authority during the census of 2011, are classified in four basic categories according to their structural bearing system, material, height, construction date and the corresponding design code namely:

- Unreinforced masonry structures with diaphragms, up to two floors, built till 1960 (M3wL).
- Reinforced Concrete moment frames with unreinforced masonry infill walls, regularly infilled frames (RC3.1), up to three floors (Low rise 1-3), built between 1960-1985 (Low level of seismic design-Code before 1986) (RC3.1LL)
- Reinforced concrete dual systems (RC frames and walls), regularly infilled dual systems, RC4.2, up to three floors (Low rise 1-3), built between 1986-1995 (Medium level of seismic design-Code 1986-1995) - R/C buildings with medium level of seismic design (roughly corresponding to post-1980 codes in S. Europe, e.g., the 1985 Supplementary Clauses of the Greek Seismic Codes) and reasonable seismic detailing of R/C members. (RC4.2LM)
- Reinforced concrete dual systems (RC frames and walls), regularly infilled, RC4.2, up to three floors (Low rise 1-3), built after 1995 (High level of seismic design- Code after 1995 - with enhanced level of seismic design and ductile seismic detailing of R/C members according to the new generation of seismic codes (similar to Eurocode 8). (RC4.2LH)
-

Type	Structural System	Height (number of storeys)	Seismic design level
RC1	Concrete moment frames		

RC3	Concrete moment frames with unreinforced masonry infill walls		
3.1	Regularly infilled frames	(L)ow -rise (1-3)	(N)o/pre code
3.2	Irregularly infilled frames (pilotis)	(M)id-rise (4-7)	(L)ow code
RC4	RC dual systems (RC frames and walls)	(H)igh-rise (8+)	(M)edium code
4.1	Bare frames (no infill walls)		(H)igh code
4.2	Regularly infilled dual systems		
4.3	Irregularly infilled dual systems (pilotis)		

Table 5.2 Types and design levels of R/C buildingς in Greece (Kappos et al.2006)

	M3wL	RC3.1LL	RC4.2LM	RC4.2LH
Number of buildings	1307	15671	2927	6491
Percentage	4.9%	59.3%	11.1%	24.5%

Table 5.3 Number and percentage of building types in Kefalonia according to 2011 census

The nomenclature used for the buildings is of the type RCixy where i indicates the structural system, x the height and y the code level as defined in Table 5.2 (Kappos et al, 2006).

Of course there are also structures constructed according to Reinforced concrete dual systems (RC frames and walls) with bare frames (no infill walls) built before (12 buildings) or after 1995 (32 buildings) or masonry structures built after 1960 (165) or other structures not belonging to any aforementioned categories, however, these are a small ratio of the total number of buildings and therefore are not examined. In fact, 26396 buildings were divided in the previous four categories (Table 5.3) and were studied out of the total number 28700 buildings recorded in the census of 2011.

After recording the structural groups of building types of the area and assign the number of each type of construction to the center-point of the grid square, the fragility curves for each category for specific levels of damage are determined.

5.3.3. Fragility curves

In this step, the concept is that the hazard is computed and extracted in terms of the intensity measure that the fragility curves are expressed to. In our case, the fragility curves determined, expressed the conditional probability of being in, or exceeding, a particular damage state DSi, given the PGA peak ground acceleration. The fragility curves were determined following the procedure presented by Kappos et al, 2006.

Each fragility curve of Figure 5.38 corresponds to a specific damage state DSi as presented in Table 5.4. It is obvious that given a specific ground acceleration, the probability of exceeding a damage level is higher when the damage state level is less important, etc. slight damages. On the contrary, DS5 which represents collapse damages has a smaller probability for the same ground acceleration.

At each grid center point in the grid region based on the fragility curves, the probability of damage for each type of construction to a particular level is calculated. Then, the number of constructions that will suffer a damage levels is calculated by multiplying the probability of damage for each type of construction, derived from fragility curves, with all of constructions located at the grid square point. Then, all the corresponding constructions are summed up at each grid square point and the total number of constructions having damage at various levels is calculated.

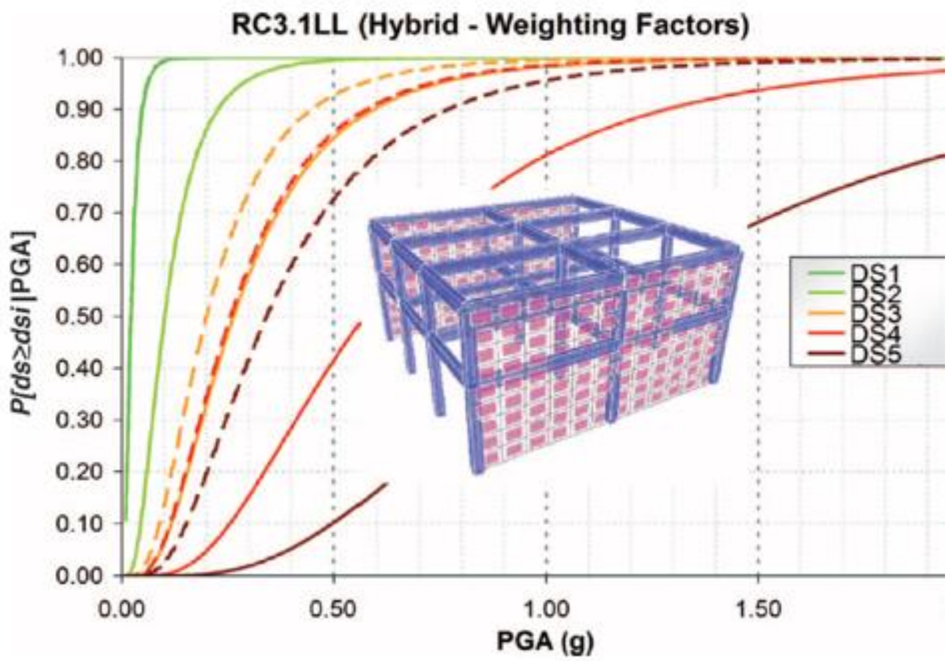


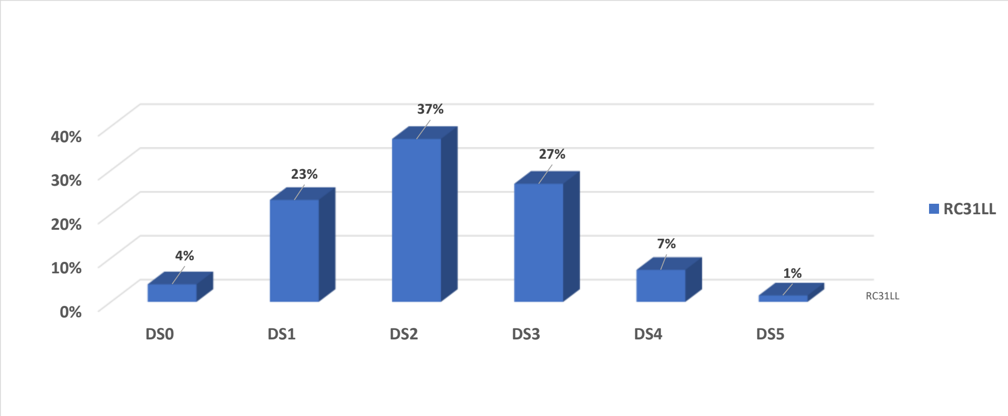
Figure 5.38 Fragility curves (in terms of PGA) for Reinforced Concrete moment frames with unreinforced masonry infill walls, regularly infilled frames (RC3.1LL)

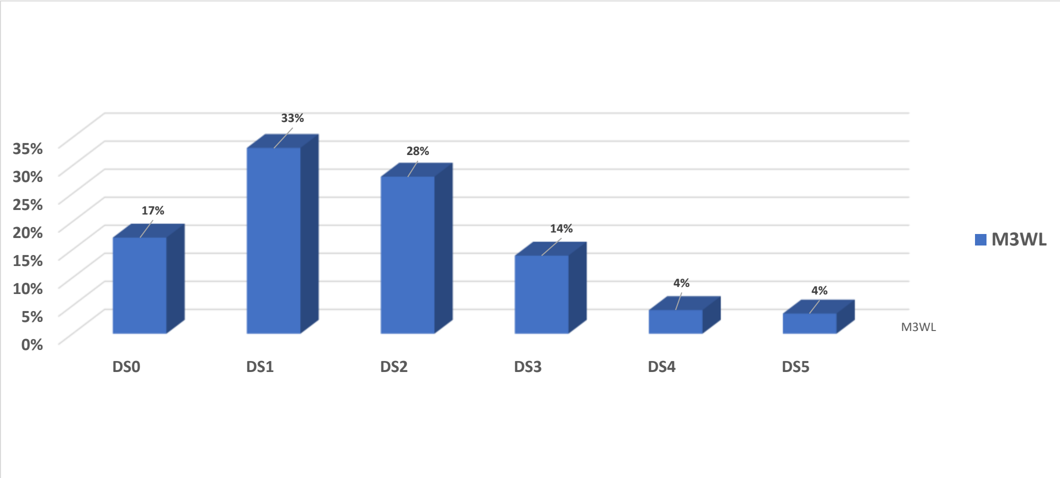
Damage state	Damage state label	Range of loss index	Central index (%)
DS0	None	0	0
DS1	Slight	>0-1	0.5
DS2	Moderate	1-10	5.5
DS3	Substantial to heavy	10-30	20
DS4	Very heavy	30-60	45
DS5	Collapse	60-100	80

Table 5.4 Damage grading and loss indices (% of replacement cost)

5.3.4. Results of the scenario modelling

In Figures 5.39, the percentage of structures suffering from various damage levels are presented, for the examined scenario of Mw=6.0. More specifically, the figures describe the percentage of the total number of **1307** M3wL, **15671** RC3.1LL, **2927** RC4.2LM, **6491** RC4.2LH buildings that will suffer from the 5 damage levels (DS0 – DS5). The total number of buildings of Kefalonia, with respect to each damage level, are presented in Figure 5.40.





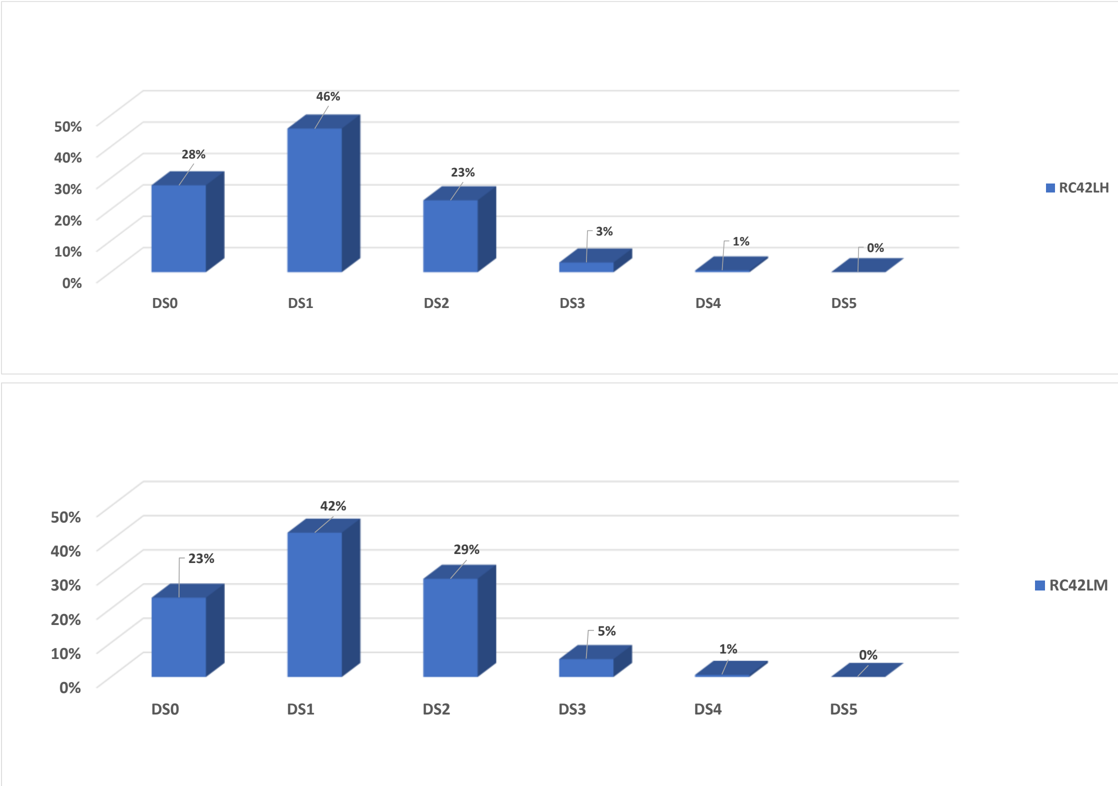


Figure 5.39 The percentage of buildings of every structural category (M3WL,RC31LL,RC42LM,RC42LH) with respect to their damage level due to the seismic scenario.

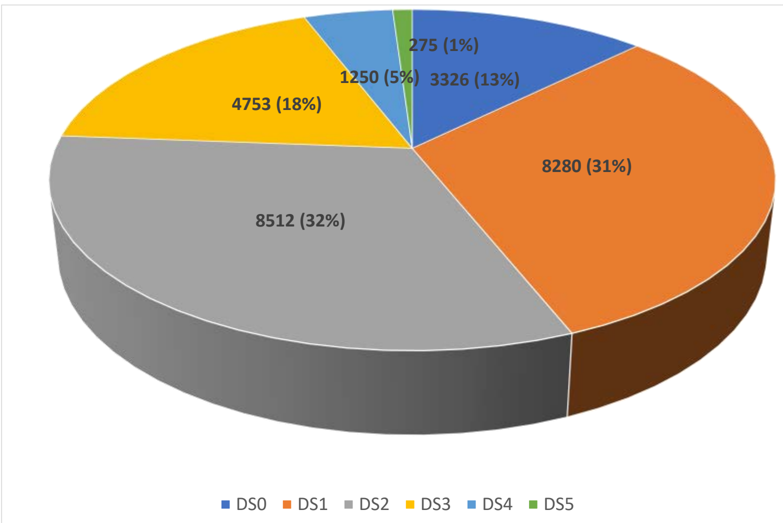


Figure 5.40 The total number of buildings of Kefalonia, with respect to each damage level.

A picture of the expected distribution of post-earthquake tagging of buildings using the familiar Green, Yellow, and Red tag scheme is desirable for earthquake planning purposes. The correspondence between tag color and DS was assumed as follows (Kappos, A.J. 2013)

- Green: DS0 & DS1

- Yellow: DS2 & DS3
- Red: DS4 & DS5

5.4. Comparing the pre- event scenario and the post-event damage survey

The buildings in each tag category are shown in Figure 5.41 and can be compared with the results of post-earthquake rapid visual inspection combined with the ones of re-inspection. Moreover, the distribution of buildings according to Green, Yellow and Reg tag scheme for six places, namely Ag.Thekli, Lixouri, Argostoli, Skala, Fiskardo and Poros, are presented in Figure 5.42 according to the loss estimation procedure.

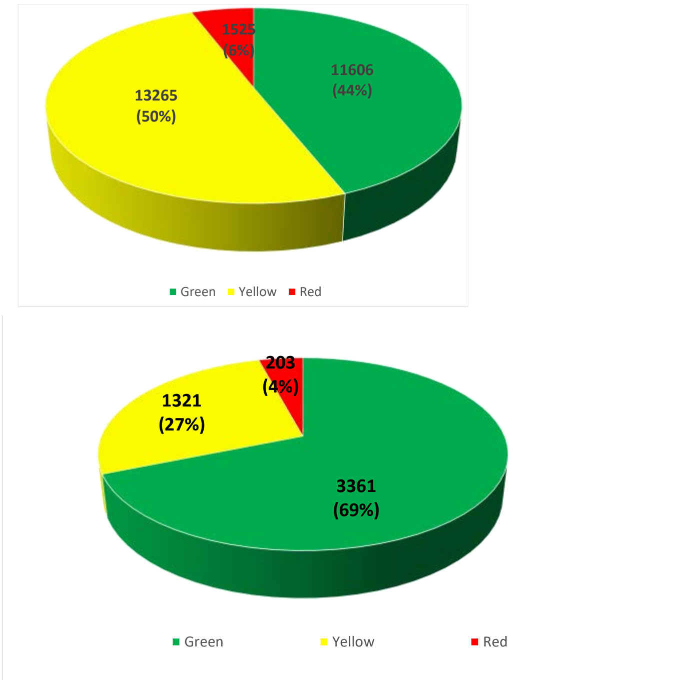


Figure 5.41 Categorization according to Green, Yellow, and Red tag scheme of the seismic loss estimation procedure results (a) and the first- and second-degree vulnerability assessment records by DAEFK (b).

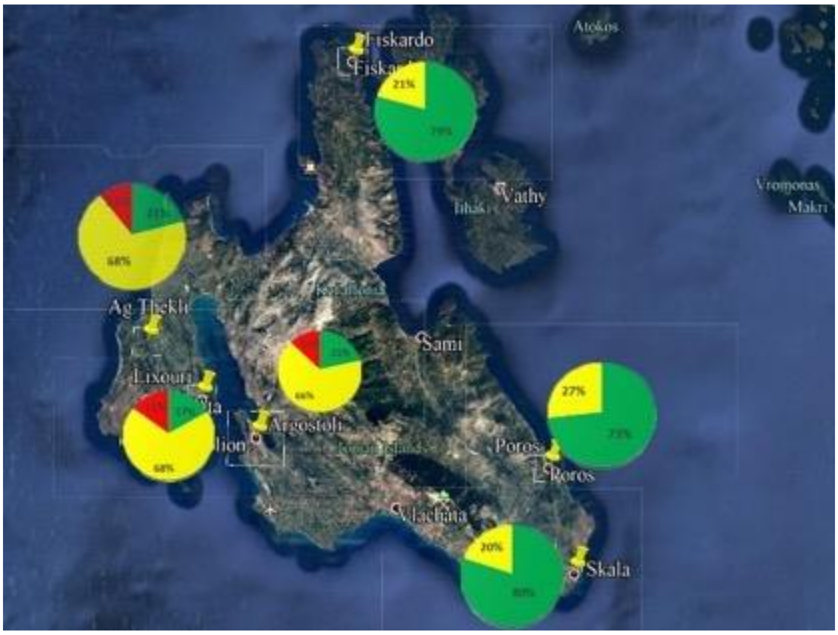


Figure 5.42 Distribution of buildings according to Green, Yellow, and Red tag scheme of the seismic loss at various places of Kefalonia.

According to the comparison of the loss estimation procedure results for the examined earthquake scenario which is similar to the earthquake occurred in 26/01/2014, it is concluded that the method presented can be used as a tool for the estimation of damages in the area of interest in order to design the necessary interventions for future earthquakes. In addition, the areas with the most vulnerable structures are easily highlighted and the local authorities can set a plan for a retrofit scenario. The supporting measures can include financial aid or guidelines for reduction of structures vulnerability. Since the proposed methodology gives the opportunity to approximate the magnitude of damages expected for each structural type, the budget of the financial aid can be estimated.

From the examination of the present study results, it is significantly positive that the buildings in Kefalonia had a better actual seismic response than the estimated. More specifically, 69% of the inspected buildings were marked green while the corresponding ratio was estimated to 44% of the total buildings. Similar were also the results about the magnitude of damages expected.

However, it should be mentioned that a key factor that strongly influences the results of the loss estimation procedure is the selection of fragility curves which should always approach the seismic behavior of buildings existing in the examined area. Regarding the inspection results, it is easily noticed that they depend mainly on the human factor and its judgment to fit a building into a category. Any false estimation or assumption of the aforementioned factors, which do not correspond to the area under consideration, can lead to very large differences.

It is significantly positive that the buildings had a better actual seismic response than the estimated. However, it should be mentioned that a key factor that strongly influences the results is the selection of fragility curves and the training of inspectors who carry out the post-earthquake inspections.

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6. USING DAMAGE DATA TO ENHANCE FIRE SURVEILLANCE AND PREVENTION AND TO IMPROVE RISK ASSESSMENT

Authors:

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6.1. Analysis of the location of the fire surveillance system

The damage caused by wildfires is reduced by fulfilling three preconditions which require automatic surveillance systems and data collection.

They are:

1. Early detection of fire in the onset phase,
2. Implementation of timely and fast measures necessary to extinguish the fire, for which objective and relevant information is required and
3. Detection and sanctioning of intentional fires.

A technologically advanced open space surveillance involves video surveillance, where an observer from the observation center simultaneously monitors several cameras. The automatic surveillance system aims at fire prevention and fire extinguishing in two segments:

- fire prevention activities including 24-hour surveillance with the visible spectrum and infrared cameras connected to the alarm expert system for early detection of wildfires that detect smoke and fire and quickly transmit and store images on the central server
- firefighting activities that imply the distance video presence and user-friendly camera management to support fire monitoring and fire fighting management.

Such detection systems enable quick response. Early detection and reporting of forest fires have financial advantages. The costs are lower due to early fire detection and fast alert, regardless of the time of day and weather conditions.

Fire brigades have more time to prepare and arrive on time, which increases the firefighting efficiency. This method of fire monitoring enables faster reaction in the initial phase of a fire, requires fewer people, and reduces the amount of firefighting equipment. Linking such integrated forest fire detection systems with the forest fire risk index and geographic information systems that support the area of forest fires will enhance the prevention and organization in the protection of forests against fires.

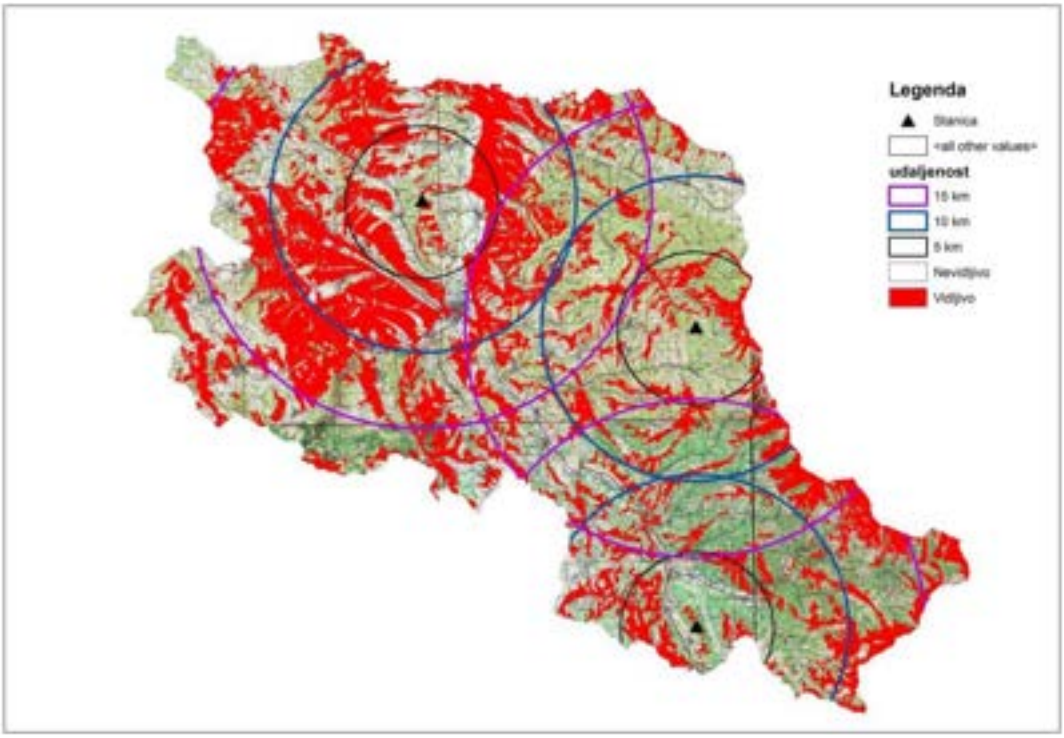

Figure 6.1 Map of installed cameras and visibility zones.

Figures 6.3 and 6.4 show the layout of locations for setting up cameras and visibility zones by different distance degrees.

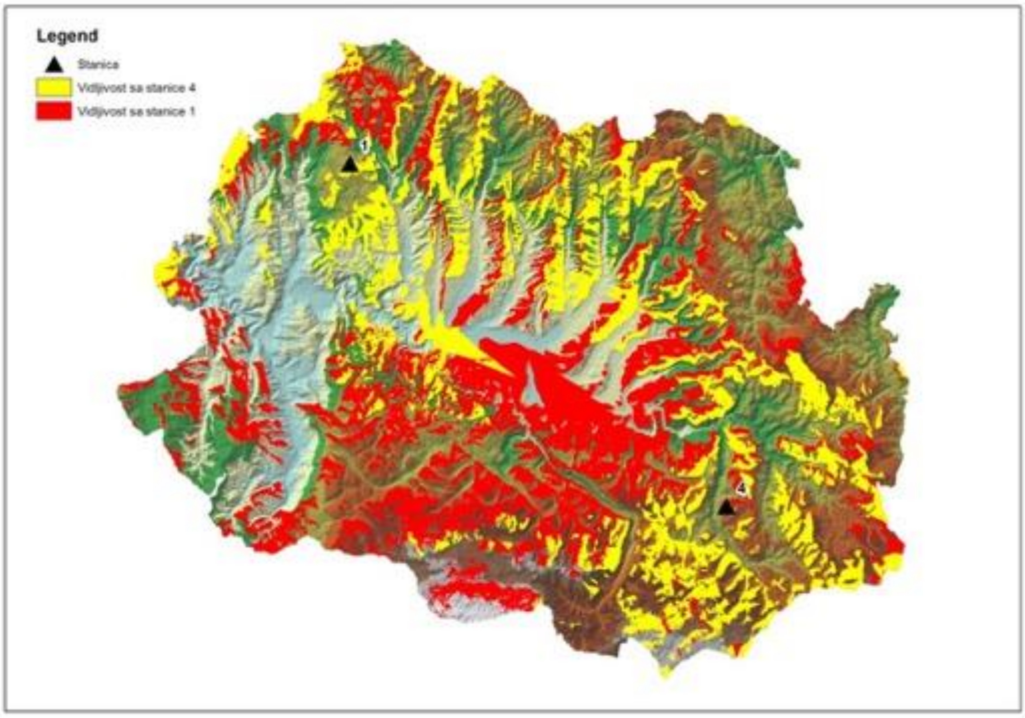

Figure 6.2 Map of installed cameras and visibility zones

Figure 6.3 Location: Bitovik
Coordinates: 43 26 54.04 N; 019 41 33.09 E
Elevation: 1367.4 meters
Access road: yes, vehicle access
Existing pillars: yes, 15 meters high
Power supply (low voltage network): yes

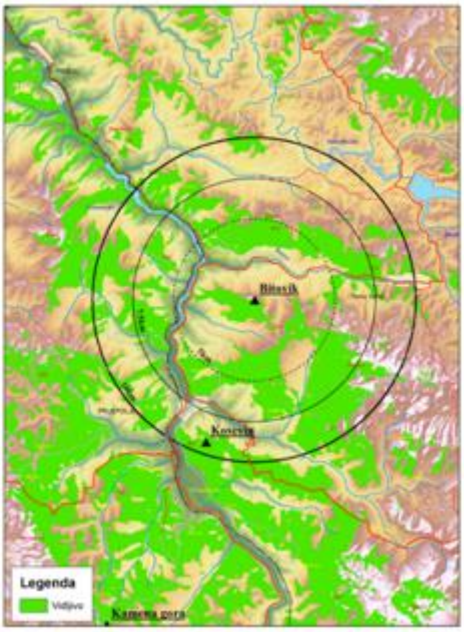

Figure 6.4 Location: Koševine
Coordinates: 43 22 54.48 N; 019 37 45.65 E
Elevation: 744.5 meters
Access road: yes, vehicle access
Existing pillars: yes, 15 meters high
Power supply (low voltage network): yes

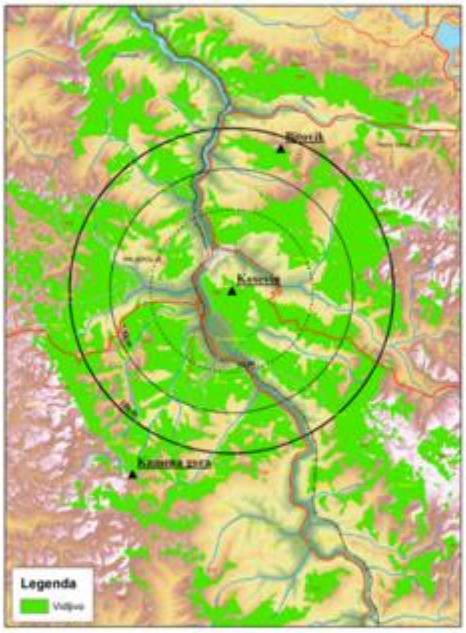

Figure 6.4 Location: Bitovik

Figure 6.5 Location: Koševine

Figure 6.6 Location: Kamena Gora

6.2. Selection of the optimal Forest Fire Danger Forecasting System

Forest fire danger forecasting is one of the most important tasks carried out as part of forest fire prevention. It can minimize fire damage. A good detection system, preparations for the fire season, good mobility, and preparedness can prevent the occurrence of forest fires. Forest fire danger assessments are based on a forest fire scenario including the time, place, and manner of development. The elements for determining the time of fire occurrence are defined by the fire season, i.e., the dynamics of forest fires, which is defined by long-term monitoring.

Figures 6.7 and 6.8 Meteorological station

As part of the LODE project, a mobile meteorological station was procured and set up in the forest, with the aim of directly measuring microclimatic characteristics.

Criteria for assessing where a fire will occur include the area, the type of fuel in the area, the orographic and climatic conditions, and the availability of the fire agent. These parameters also affect the way fires will develop, i.e., what measures should be taken to suppress them.

The assessment system consists of indices that describe the condition of the basic components of the fire danger:

- condition of combustible material defined by the type, quantity, moisture, and spatial distribution and
- fire risk, i.e., the probability of a fire to occur in the forest, defined by nature and activities that cause them.

The condition of forest fuel is determined directly (by taking a sample in the field) and indirectly based on meteorological data.

Fire danger indices	Year	Area characteristics	Measured parameters	Model characteristics	Tested and accepted for application in
Angstrom	1949	Polar climate, high rainfall and high air humidity	Temperature and air humidity	Daily experiential index, easy to measure	Sweden, Germany
M-Nestorov	1968	Polar climate, high air humidity	Dew point and temperature	Cumulative index, easy to measure	Russia, Canada
KBDI	1968	Hot and warm summers with high air humidity	Temperature and mean annual rainfall	Cumulative index, complicated to measure	Usa, Australia, Indonesia
Baumgartner	1967	High precipitation, cold and cloudy during the winter	Precipitation and evapotranspiration	Cumulative index, easy to measure	Germany
M-KBDI	2011	Mediterranean area	Temperature and mean annual rainfall	Cumulative index, complicated to measure	Greece, Indonesia, Malaysia
FWI	1970	Wet with a high precipitation during the summer, very cold winter	Temperature, relative air humidity and precipitation	Cumulative index, complicated to measure	Canada, Mexico, New Zealand, Spain, Sweden, England, etc.
F	2008	High precipitation and high air humidity in summer	Temperature and relative air humidity	Cumulative index, easy to measure	Australia, Switzerland
FD	2014	Hot and dry summer, cold winter with strong wind	Relative air humidity, temperature, wind	Cumulative index, easy to measure	Czech Republic, Germany and Sweden

Fire danger indices	Year	Area characteristics	Measured parameters	Model characteristics	Tested and accepted for application in
			speed and soil moisture		
Modified Angstrom method (Ratknić Tatjana, 2017)	2017	Dry and warm spring, summer and autumn with low precipitation	Maximum temperature and minimum air humidity	Daily index, easy to determine	Serbia

Table 6.1 Overview of forest fire risk assessment methods with the characteristics of the models.

The Angstrom Index was modified to improve the assessment of the wildfire risk (Ratknić T., 2018) as follows:

- instead of the mean air temperature, the maximum air temperature is included in the formula and
- instead of the mean relative humidity, the minimum relative air humidity is included in the formula.

By including these parameters, the formula has the following form:

$$\text{Mod } I = R\text{min} / 20 + (27 - T\text{max})/10$$

The risk of potential forest fires is divided into seven classes (Table 6.2).

Mod Arn	Code	Forest fire risk
<2.0	EU1	Extreme forest fire conditions 1
2.0 – 2.5	EU2	Extreme forest fire conditions 2
2.5 – 3.0	VV1	Very high risk 1
3.0 – 4.0	VV2	Very high risk 2
4.0 – 5.0	VO	High Risk
5.0 – 6.0	UV	Moderate risk
6.0 - 7.0	NO	Low risk
> 7.0	VNO	Very low risk

Table 6.2 Fire fire risk in Mod Arn

Seq. Number	-4	-3	-2	-1	Fire days	Fire cause	Start date	End date
1	2.61	2.52	2.32	2.23	3.26	negligence	25.04.2000	25.04.2000
2	0.33	0.47	1.61	0.45	0.21	negligence	08.7.2000	08.07.2000
3	4.34	2.48	2.08	2.12	1.57	negligence	12.08.2000	12.08.2000
4	1.18	1.31	2.21	2.31	1.94	negligence	17.08.2000	22.08.2000
5	0.69	0.83	0558	0.50	0.36	thunder	22.08.2000	31.08.2000
6	0.58	0.50	0.36	0.23	2.12	thunder	24.08.2000	24.08.2000
7	2.12	1.82	2.69	2.25	3.74	negligence	28.08.2003	28.08.2003
8	4.15	6.57	6.76	6.19	4.62	thunder	10.07.2006	10.07.2006
9	6.57	6.76	6.19	4.62	6.65	thunder	11.07.2006	11.07.2006
10	6.57	6.76	6.19	4.62	6.65	negligence	19.03.2007	19.03.2007
11	0.74	1.00	0.14	0.53	0.12	negligence	24.07.2007	24.07.2007
12	1.10	0.74	1.00	0.14	0.53	negligence	23.07.2007	23.07.2007
13	1.10	0.74	1.00	0.14	0.53	negligence	23.07.2007	23.07.2007
14	0.12	2.22	1.86	1.17	0.87	negligence	28.07.2007	28.07.2007
15	0.70	1.10	0.74	1.00	0.14	thunder	22.08.2007	25.08.2007
16	3.31	1.37	1.61	0.88	0.81	thunder	23.08.2007	02.09.2007.
17	1.37	1.61	0.88	0.81	0.78	thunder	24.08.2007	27.08.2007
18	4.91	5.05	4.35	4.30	5.15	negligence	17.01.2008	17.01.2008
19	1.25	1.53	1.33	0.48	1.93	negligence	16.08.2008	16.08.2008
20	4.66	4.75	4.70	4.74	7.92	plant management	29.03.2012.	29.03.2012.
21	2.03	1.55	1.57	0.72	0.34	negligence	06.08.2012.	06.08.2012.
22	3.51	2.40	0.90	2.35	2.71	negligence	31.07.2012.	31.07.2012.
23	2.45	2.55	2.83	2.16	1.99	negligence	14.08.2012.	10.09.2012.
24	0.82	2.57	3.06	2.64	2.13	negligence	17.08.2013.	17.08.2013
25	1.64	1.50	1.20	1.53	1.47	human factor	14.08.2015	14.08.2015
26	1.20	1.53	1.47	2.70	4.61	thunder	16.08.2015.	20.08.2015
27	2.18	1.68	0.85	0.53	1.42	unknown	19.09.2015	23.09.2015
28	1.42	4.93	5.36	3.95	3.54	human factor	23.09.2015	24.09.2015
29	0.53	1.42	4.93	5.36	3.95	human factor	22.09.2015	25.09.2015
30	6.05	4.36	4.05	3.04	2.39	human factor	31.03.2016	31.03.2016
31	4.29	2.52	1.66	1.60	1.43	human factor	06.04.2016	06.04.2016
32	4.26	6.07	6.69	6.74	6.01	human factor	07.10.2016	07.10.2016
33	7.26	7.72	7.46	4.97	4.02	human factor	15.03.2017	15.03.2017.
34	7.46	4.97	4.02	3.70	3.83	human factor	17.03.2017	17.03.2017
35	3.83	2.85	4.92	2.79	1.85	human factor	21.03.2017	21.03.2017
36	4.92	2.79	1.85	1.90	2.20	human factor	23.03.2017	23.03.2017
37	4.92	2.79	1.85	1.90	2.20	human factor	24.03.2017	24.03.2017
38	2.55	1.89	1.32	2.21	2.02	human factor	09.07.2017	09.07.2017
39	3.34	2.03	3.37	3.88	3.35	human factor	17.07.2017	17.07.2017
40	2.35	1.58	0.83	0.90	0.92	human factor	24.07.2017	24.07.2017
41	0.74	0.57	2.42	2.98	2.00	human factor	30.08.2017	30..08.2017
42	0.57	2.42	2.98	2.00	0.98	unknown	31.08.2017	31.08.2017
43	2.98	2.00	0.98	3.68	2.44	thunder	02.09.2017	02.09.2017

Seq. Number	-4	-3	-2	-1	Fire days	Fire cause	Start date	End date
44	0.88	3.54	3.64	1.25	3.38	unknown	15.09.2017	15.09.2017
45	3.64	1.25	3.38	1.28	1.80	unknown	17.09.2017	17.09.2017
46	3.40	1.79	2.30	2.17	1.97	human factor	12.04.2018.	12.04.2018
47	4.36	4.52	3.15	4.63	3.00	thunder	05.07.2018	05.07.2018
48	3.95	3.85	4.44	4.08	4.60	human factor	04.11.2018.	04.11.2018

Table 6.3 Values of the Modified Angstrom Index on the day and 4 days before the fire, cause, start and end date.

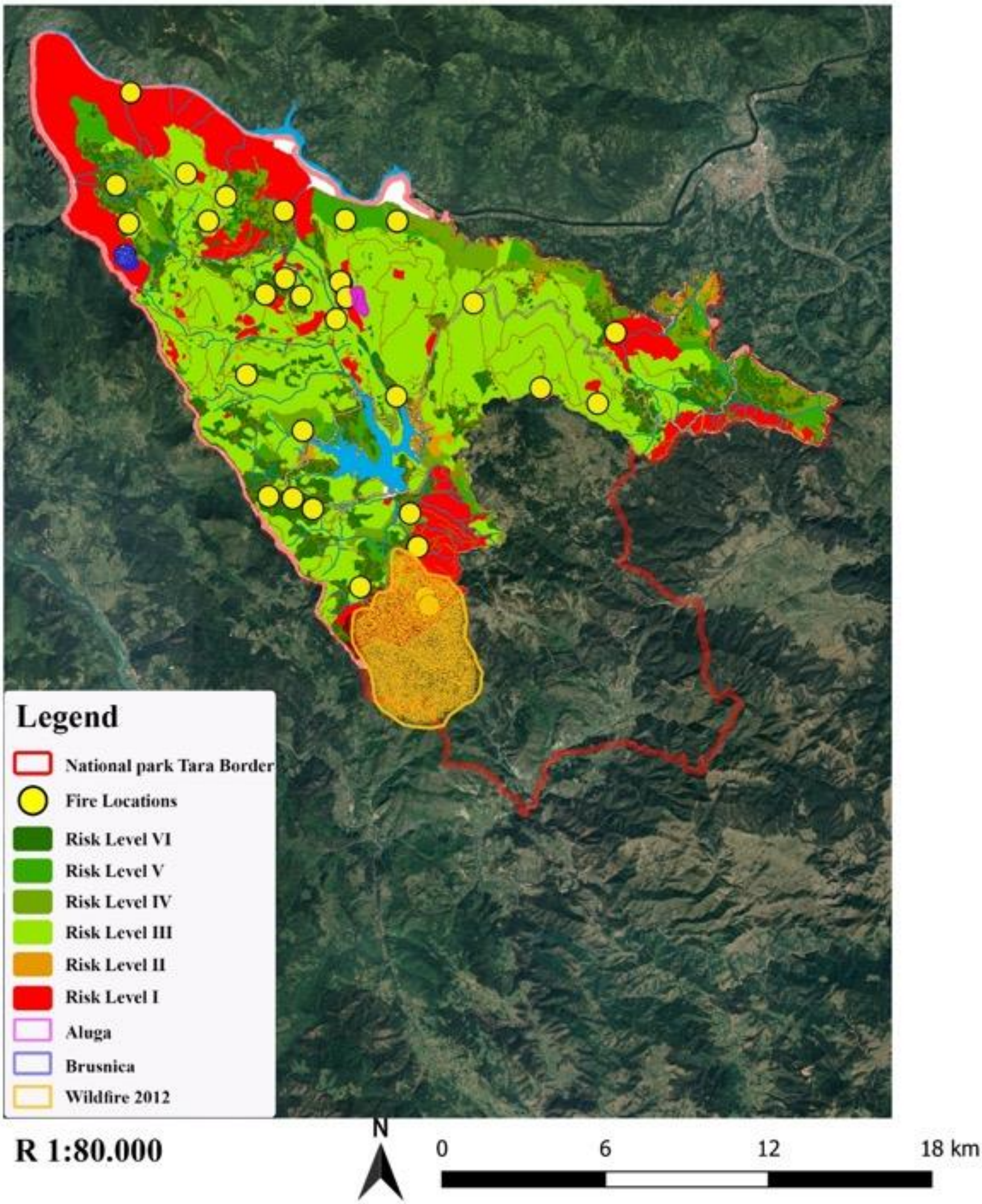

Figure 6.9 Map of forest fire risk and fire locations in the period from 2000 to 2020.

Cause	Degree of fire danger based on the Modified Angstrom Index (I mode)							
	EU1	EU2	VV1	VV2	VO	UV	NO	VNO
	<2.0	2.0 – 2.5	2.5 – 3.0	3.0 – 4.0	4.0 – 5.0	5.0 – 6.0	6.0 - 7.0	> 7.0
Negligence	10	1	1	2		1	1	
Thunder	4	2			2		1	
Plant management								1
Human factor	5	3	1	4	1		1	
Unknown	3			1				
Total	22	6	2	7	3	1	3	1

Table 6.4 Distribution of numbers depending on the degree of fire danger based on the Modified Angstrom Index (I mode). Labels in the table: EU1 – Extreme Forest Fire Conditions 1; EU2 – Extreme Forest Fire Conditions 2; BB1 – Very High Risk 1; BB2 – High Risk 2; VO – High Risk; UV – Moderate Risk; NO – Low Drisk; VNO – Very Low Risk.

In the area of Tara, a fire occurred in 1972 – it broke out in a place called “Solila” not far from the spot where a fire broke out in 2012, but it was extinguished by heavy rain. The fires had a similar development (fire behavior).

A large forest fire in 2012 burned a total of about 2,600 ha of forests and forest land.

Throughout 2012, due to extreme weather conditions, prolonged drought, and high summer temperatures, forest fires occurred in the municipality of Bajina Bašta. The largest area affected by fire was in the cadastral community of Zaovine. The fire broke out on August 16 and lasted until September 10, 2012.

The fire event with the most severe consequences ever in “Tara” National Park broke out in Zaovine Village, Municipality of Bajina Bašta, Zlatibor District. The fire spread to Mokra Gora and Kremni, where forests of black and Scots pine, black pine and hop-hornbeam, and spruce forests were greatly affected, while it did not spread in mixed forests of fir, beech, and spruce.

The forests affected by the devastating fire are mostly privately owned. The fire-affected areas are at 900-1200m above sea level. The terrain is steep and very steep and intersected by streams, which makes a typical mountainous relief, strongly intertwined with ridges and deep terrains, slopes and depressions, and very steep slopes at some points. The bedrock is limestone and serpentine that is very conducive to the spread of fire.

The harmful effects of the fire related to the disturbance of biological diversity and homogeneity of the area, its landscape value and attractiveness in general.

Degrees of preparedness are defined, and depending on the danger class, the following measures are taken:

I DEGREE PREPAREDNESS. Low risk – the first level of readiness:

- checking the execution of tasks related to the preparation phase before the start of the fire season and
- updating the elaborate operational firefighting plan.

II DEGREE PREPAREDNESS. Moderate danger – the second level of readiness:

- continuing and completing the preparation activities from the previous level,
- enhancing the weed burning control on agricultural land,
- establishing active duty service,
- establishing monitoring in coniferous forests, especially in the southern and southeastern exposures,
- improving the quick intervention readiness of workers and
- establishing cooperation between all entities responsible for fire protection (forest administrations, police administrations, fire brigades, civil protection units, municipal structures, emergency headquarters).

III DEGREE PREPAREDNESS. High danger – the third level of readiness:

- continuing and completing the preparation activities from the second level
- establishing a 24h active duty service
- active forest monitoring
- engaging small aircraft in forest surveillance according to the established schedule
- securing the readiness of nearby airports and water and chemicals necessary for extinguishing
- organizing the forest administration, police, fire brigades, and administrations and appointing the persons responsible for certain tasks and local communities
- assessing the readiness of all entities (police administrations, fire brigades, civil protection units, local self-governments, emergency headquarters)
- taking measures to inform and mobilize people and equipment
- establishing forest spots where fire extinguishing equipment and agents are provided
- organizing firefighting reception centers
- engaging local radios, newspapers, TV stations and informing the population about the danger, and
- monitoring the weather conditions daily.

IV DEGREE PREPAREDNESS. Extreme danger – the fourth level of readiness:

- checking and taking further measures envisaged by the third level of readiness

- ensuring the mobility of all entities (forest administrations, police administrations, territorial fire brigades and others, emergency headquarters, local self-government)
- systematic forest surveillance by aircraft
- increasing the mobility of firefighters
- preparing tanks and heavy machinery, and
- constant monitoring of the weather conditions in the coming period.

6.3. Risk assessment methodology and application

The methodology relates to assessing disaster risk, improving the quality and comparability of data, and improving databases on the risks of natural and other disasters in the territory of the Republic of Serbia, the Autonomous Province, and local self-government units. The process of methodology development is presented in Figure 21.

Basic information on the position and characteristics of the territory contains the following data: geographical location, hydrographic characteristics, weather and climate characteristics, demographic characteristics (population, gender structure, age structure, persons with disabilities), agriculture (land area by use and ownership structure), production of field and vegetable crops, livestock production), material and cultural goods and protected natural goods.

The Risk Assessment Analysis provides data on critical infrastructure, as follows:

a) Energy infrastructure includes: thermal and hydropower plants; thermal power plants – heating plants and other facilities for electricity production, as well as power lines, transmission lines, and transmission stations; facilities for the production of electricity from renewable sources; high dams and water reservoirs, oil and gas production plants and refineries, production of biofuels and bioliquids.

b) Transport infrastructure includes road, railway, and air traffic (highways, state roads of I and II order; categorized and uncategorized roads, bridges, tunnels, overpasses, and bus stops; railway network, railway stations; airports, river waterways, ports and border crossings.

c) Water management infrastructure includes constructions for active and passive protection of I and II order watercourses, water supply including interregional and regional water supply facilities, drinking water treatment plants, regulatory works for protection against high waters of urban and rural areas, hydraulic structures on waterways, navigable canals and ship locks that are not part of the hydropower system.

d) Food supply includes food production plants and capacities, food warehouses (silos, cold storages, etc.), and food distribution facilities and means.

e) Health critical infrastructure includes primary level facilities (health centers, hospitals, pharmacies, institutes); secondary level facilities (hospitals – general and specialized); tertiary level facilities (clinics, institutes, clinical medical centers, clinical center), and health care activities performed at a higher level (institutes).

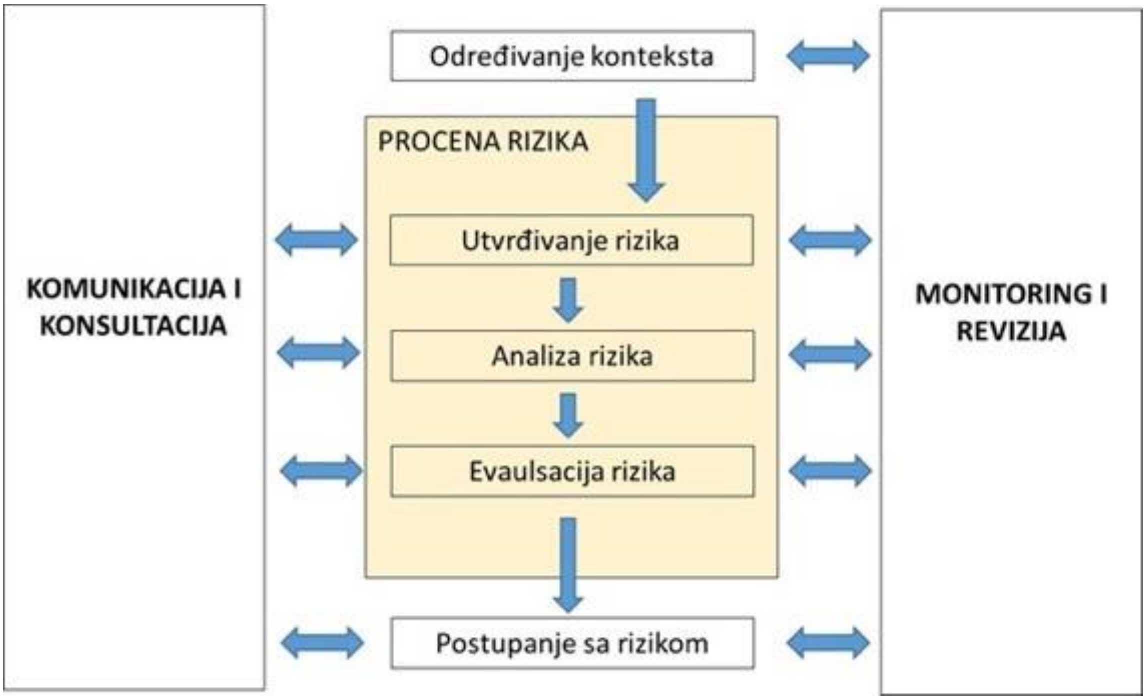

Figure 6.10 Risk Assessment Process.

f) Finance: banking, stock exchanges, investments, and insurance systems.

g) Telecommunication and information critical infrastructure comprises electronic communications system facilities and means of international and main significance; data transfer; information systems; provision of audio and audio-visual media services.

h) Environmental protection: production and storage of hazardous materials (chemicals, biological materials, radiological materials, nuclear materials, and landfills).

i) State administration bodies and emergency services (police, emergency medical care, fire and rescue units, etc.).

j) Science and education: institutions of science and education, their facilities, human and material resources.

6.3.1. Identification of disaster risks (natural and technological)

The probability of danger and probability of its occurrence and consequences is assessed for earthquakes, rockfalls, landslides, erosion, floods, extreme weather events (heavy rainfall, hail, windstorms, snowstorms, snowbanks and ice, hot wave, cold wave, drought), drinking water scarcity, epidemics and pandemics, plant diseases, animal diseases, fires, explosions, wildfires (which include forest fires), technical-technological accidents, accidents involving the transport of dangerous goods, road, air, river, and railway traffic accidents, cable car accidents, dam collapse hazards (hydro-accumulation, ash dumps, and tailings), nuclear and radiological accidents as well as the risk of a terrorist attack.

6.3.2. Scenario construction

The scenario is created for two types of events:

- The most probable adverse event - we know that it occurs frequently, the conditions in which it occurs favor its occurrence and it is expected to endanger people's lives and health and cause material damage in an area.
- An adverse event with the most severe consequences - it occurs rarely in an area, but when it occurs, it has such an intensity that its consequences are devastating for some protected values.

The scenario must meet the following conditions. It must:

- be probable, supported by facts that prove that it can happen;
- describe the consequences of adverse events that affect at least two protected values;
- be set in the time and conditions that correspond to the actual situation;
- describe events in detail so that the overall level of risk obtained provides guidelines for risk treatment;
- consider the availability of the entities and the power of the disaster risk reduction system.

Prerequisites for the selection of scenarios are:

a. probability of event and
b. severity of consequences.

Scenario results (consequences and probabilities) are combined in a risk matrix. The risk matrix consists of two axes, the consequence axis and the probability axis. Each axis has five values, which gives a matrix of 25 fields.

These 25 fields are divided into four risk categories: low, moderate, high, and very high risk (Table 6.5).

	Very high (red)	Unacceptable	Very high and high level of risk, require risk treatment in order to reduce it to the level of acceptability
	High (orange)	Unacceptable	
	Moderate (yellow)	Acceptable	Moderate risk may require some action to be taken.
	Low (green)	Acceptable	Low risk may mean that no action is taken.

Table 6.5 Risk levels and acceptability

6.3.3. Developing the risk map

Maps are an important document presenting risk in the whole area, both individual risk and overall risk. The maps help all participants involved in the assessment, facilitate the presentation of the results of risk matrices and understanding the level of risk, as well as the visualization of the risk situation so that adequate decisions can be made.

Risk maps show the location and spatial distribution of protected values, sources of risk, zones of spreading, protection and rescue facilities, facilities that can cause risk and multi-risk, position of neighboring areas and critical infrastructures, distribution of protection and rescue forces, etc.

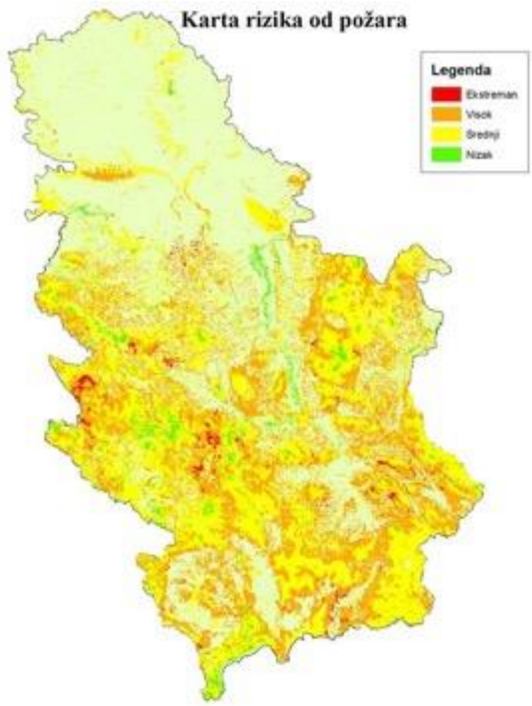

Figure 6.11 Forest fire risk map of the Republic of Serbia

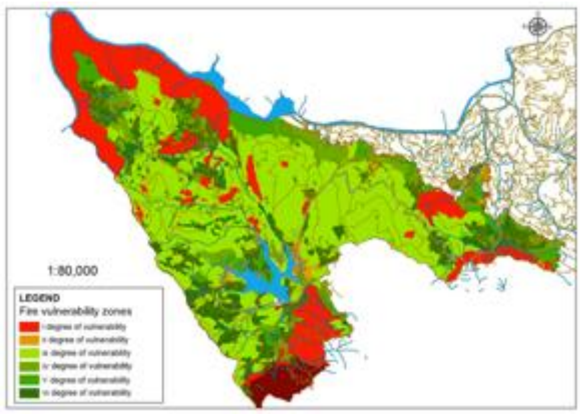

Figure 6.12 Forest fire risk map of the territory of "Tara" National Park

6.3.4. A possible forest fire scenario

Having studied the records of forest fires in the territory of the Republic of Serbia in the last twenty years, we determined that the fire with the most disastrous consequences occurred in the village of Zaovine in 2012.

Based on the above, our scenario for an adverse event with the most severe consequences would include a high forest fire in the forests of the first and second degree of fire endangerment located in the territiory of PE "Tara" National Park, PE "Serbia Forests", FE "Užice". In such conditions, when it is not possible to control the situation, it is necessary to engage all available resources and forces from all over the country. The burned area could exceed 10,000 ha, i.e., half of the territory of the National Park. The fire would spread to the villages of Zaovine, Mokra Gora, Kremna, Kaluđerske Bare, Mitrovac, and parts of the Tara plateau.

Before creating a scenario, some parameters were analyzed to predict the behavior of the worst-case scenario fire. The analysis included forest chronicles data and data related to vegetation types, diverse fauna, orographic conditions, meteorological parameters, and forest ownership categories and structures.

A large-scale fire event would have a very negative impact on the lives and health of people, both locals and tourists. A large forest fire would endanger up to 50 people. However, more tourists are estimated to stay there in the summer (1,000-1,500). Evacuation of the settlements and tourist complexes and taking care of people should be done following the assessment of the situation in the field.

Material damage caused by a catastrophic fire includes the loss and damage to infrastructure, i.e., accommodation and dining facilities, rural households, holiday homes, and cultural and historical facilities.

It should be noted that Zaovine has four out of 22 Serbian spruce sites on Mt. Tara. The number of plants recorded in Zaovine accounts for about 50% of the flora of the entire Tara Mountain, or about 15% of the flora of Serbia. Furthermore, 55 plant species that are on the preliminary Red List of Flora of Serbia and Montenegro, 25 species of international importance, 14 species protected by the CITES Convention, and 15 rare species, all emphasize the importance of this area not only for the preservation of the diversity of Serbian flora but also overall improvement of flora protection of Mount Tara outside the National Park.

Based on these facts, the harmful effects of fire are related to the disturbance of biological diversity, homogeneity, and landscape value of this area.

Besides Serbian spruce and *Euphorbia pancicii Beck*, endangered species include *Euphorbia glabriflora* Vis (*Ser*. golocvetna mlečika), *Linaria rubioides* Vis. & Pančić (*Ser*. brоćoliki lanilist), *Silene pusila* W. et K. subsp. *monachorum* (*Ser*. monaški pucavac), *Scabiosa fumarioides,* *Eryngium palmatum, Leontopodium alpinum (Ser. runolist)*, *Viola biflora* (Ser. dvocvetna ljubičica) and several other representatives of the Beli Rzav Canyon vascular flora.

The fire would endanger *Pyrgomorphulla serbica*, Pancic, 1882, (Serbian stick grasshopper), Tichodromamuraria with less than 20 nesting pairs in Serbia (Puzović et al., 2004), golden eagle (*Aquila chrysaetos*), and Peregrine falcon (*Falco peregrin*). The rock partridge (*Alectoris graeca*) would also be endangered.

The habitats of roe deer (*Capreo luscapreolus*), wild boar (*Suss crofa*) and rabbit (*Lepus europeaus*), bear, and chamois, i.e., the game itself, would be endangered. It would be necessary to take measures to monitor the state of forced migration and protect wildlife during the fire.

Consequences for wild species of mammals and birds may include: endangerment/ destruction of part of the wildlife fund; long-term endangerment/ destruction of part of the parent fund of hunting species of mammals and birds, especially their broods, nests, offspring, eggs, as well as individuals that cannot be rescued from the fire-affected area, endangerment/ destruction of wild species habitats; forced (temporary/ final) migration of a part of the wildlife fund; change in the structure of hunting areas where there are no longer conditions for survival, preservation, and growth of certain species of mammals and birds, etc.

This scenario would mainly affect the forests of black and Scots pines, black pine and European hop-hornbeam forests, spruce and Serbian spruce forests, and mixed forests of fir, beech, and spruce. The forests that would be affected by the catastrophic fire are mostly privately owned. The areas threatened by the fire are located at 900-1200 m above sea level, with steep and very steep terrains and intersected by streams, which makes a typical mountainous relief, strongly intertwined with ridges and deep terrains, slopes and depressions, and very steep slopes at some points. The bedrock is composed of limestone and serpentine that are very conducive to the spread of fire.

A fire event with the most severe consequences to "Tara" National Park could occur in the village of Zaovine, on the territory of the municipality of Bajina Bašta, Zlatibor District. The fire would spread to the plateau of Tara, Mokra Gora, Kremni, Kaluđerske Bare (tourist and recreational complex including the Omorika Hotel, the Beli Bor Hotel, the Javor Hotel, and other private lodging facilities where, according to tourist organizations, a large number of tourists stay in August. There, it would mainly devastate forests of black and Scots pines, black pine and European hop-hornbeam, spruce and Serbian spruce, while it would spread less in the mixed forests of fir, beech, and spruce.

Considering the intensity of the 2012 fire, which damaged about 2,000 ha in just ten days, we can say that it takes about 10-15 days for an unwanted fire event to cause the most devastating consequences, i.e., the estimated burned area of about 10,000 ha.

Parameter	General issues
Danger	• Name: Wildfires – Forest fires • Description: High forest fire with devastating consequences
Occurs in	the village of Zaovine and in several locations in the area of the southern and southwestern part of Mt. Tara.
Location	Zaovine has a minimum altitude of 784 m (the confluence of Jajački and Zmajevački Streams) and a maximum of 1,412 m above sea level (Miloševac Peak). In regional terms, this area is located in the extreme northwest of the Old Vlach-Raska Plateau (*Ser.* Starovlaška-raška visija), in the contact zone with Eastern Bosnia that stretches to the west. Zaovine is located in the southern part of Tara Mountain in a spatial landscape known as “Ravna Tara”. It is bordered by plateaus, the most prominent of which are Zborište (1,544 m above sea level), Gavran (1,453 m above sea level), Kamalj (1,353 m above sea level), Pasak Vis (1,253 m above sea level), Kik (1,208 m above sea level), Tomića Brijeg (1,261 m above sea level) and Lipovački Vrh). In geomorphological terms, this area represents the natural link of Tara Mountain with the Zlatibor Massif and the Mokrogora Valley. Zaovine Lake is only 4 km away from Mitrovac on Tara, 25 km from Kremna and 26 km from Bajina Bašta. The distance to Mokra Gora (45 km) and Užice (55 km) is slightly greater.
Intensity	It is estimated that in the worst conditions, the fire could affect an area of about 10,000 ha, with fires occurring not only in the village of Zaovine but also in Mokra Gora, Kreman, Kaluđerske Bare, Mitrovica, and parts of the Tara plateau. Due to unfavorable weather parameters, primarily a strong southwestern wind, the fire would spread very quickly from the start points (southern parts of Tara Mountain) with a tendency to advance to the north, northeast, and east.
Time	Fires of this kind occur in the summer due to prolonged drought and high temperatures. They most often occur in August and September in the afternoon, every 20-100 years. The most common causes are human negligence and lightning strikes.
Dierection	The fire would spread in the following directions: 1. The southern part of the village of Zaovine (Tetrebica, Božurice, Solila)→ along the Beli Rzav Canyon→the hamlet of Trifkovići→over the Lipovica River → Metaljka→Pasja Kosa→Sekulić→Tara Plateau→Dobro Polje→Kaluđerske Bare. The northern direction of fire spread.

Parameter	General issues
	2. The southern part of the village of Zaovine across the Beli Rzav Canyon→Građenica→Kik→Mramorac→Oštrelj→Kršanje→hamlets of Timotijevići and Milekići (Mokra Gora, Kremna)→Šargan→Tara Mountain→Kaluđerske Bare. The eastern and northeastern direction of fire spread.
Duration	Given the intensity of the fire, an estimated area of about 10,000 ha would be affected. The fire would last for 10-15 days.
Early warning	In critical periods, measures of precaution and preparedness of people and equipment are always intensified.
Preparedness	"NP Tara" has a Forest Fire Protection Plan that is regularly updated. The population and state bodies are partially prepared. Following the provisions of the Law on Forests, forest users take preventive measures to extinguish forest fires in the initial phase, for which they are equipped.
Impact	Protected values affected by forest fires include human life and health, economy/ ecology, and social stability. A large-scale fire event would have a very negative impact on the lives and health of people, both locals and tourists. Material damage caused by a catastrophic fire is reflected in agriculture (livestock, farming, and fruit growing), damage to tourist complexes and dining establishments (hotels, restaurants), rural households (houses, ancillary facilities, etc.), holiday homes (holiday settlements on the edges of the forest), etc., as well as cultural and historical heritage: House of Rade Jelisavčić, Zaovine – Ethno-household in Kaluđerske Bare. Based on these facts, the harmful effects of fire are related to the disturbance of biological diversity, homogeneity, and landscape value of the area.
Other dangers generated	Due to fires, wild animals might occur in human settlements and endanger human lives and health. High fires in natural and artificially established coniferous stands are regularly followed by outbreaks of secondary pests of bark beetles and weevils. They most often use partially burned and physiologically weakened trees for their outbreaks. From there, they spread to the surrounding forests not affected by the fire. If measures are not taken on time, which is in the circumstances of fires affecting several thousand hectares usually impossible, the stability of much larger areas of forest ecosystems is disturbed due to the outbreaks of different types of weevils. The weevil outbreak control entails cutting down and removing all infested trees, as in the case of fire remediation, which further decreases the interceptive function of forests on large areas and increases the risk of torrential floods in lowland parts of Serbia.
Reference incidents	In the area of Tara, a fire occurred in 1972 – it broke out in a place called "Solila" not far from the spot where the fire broke out in 2012, but this fire was extinguished by heavy rain. The fires had a similar fire behavior (developed in a similar way).

Parameter	General issues
Informing the public	As part of regular activities on forest fire protection, forest users carry out preventive fire protection measures, i.e., regularly conduct campaigns (including appeals, warnings and prohibitions) to inform the population about the fire.
Further information	The affected privately owned forests do not have adequate infrastructure (forest roads, fire lines). Therefore the degree of fire intervention would not be sufficient. The local population and forest owners are not sufficiently aware of the importance of prevention. Consequently, they are not involved in the system of protection against forest fires. On the other hand, there is a sufficient number of water bodies in the area affected by the potential fire that could be used for water supply in fire extinguishing.

Table 6.6 The scenario.

Protected values	Criteria
Human life and health	An estimated 1500 people would be affected and possibly evacuated due to the fire event. Holiday settlements on the edge of the forest and accommodation establishments surrounded by the forest would be particularly endangered.
Economy/ ecology	The total material damage would include (estimated around 68,814,538,100.00 dinars) the following parameters: • Costs of sanitary felling: 10,000 ha x 4,808.33 dinars = 48,083,300.00 dinars • Artificial regeneration (planting seedlings): 10,000 ha x 252,504.49 dinars = 2,525,044,900.00 dinars). • The fire would burn or damage the wood volume of 1,500,000 m^3, worth 3,036,750,000.00 dinars. • Silvicultural and protection works (hoeing, harrowing, cutting of shoots and secondary shoots), in the first five years from the plantation establishment, currently cost 64,598.89 dinars/ ha. The total costs for an area of 10,000 ha would amount to 645,988,900.00 dinars. • Environmental damage is estimated as ten times the value of direct damage (6,255,867,100.00 dinars) and amounts to 62,558,671,000.00 dinars.
Social stability	Total material damage to critical infrastructure (estimated around 10,200,000.00 dinars): – food supply 1,200,000.00 dinars – traffic around 9,000,000.00 dinars Total material damage to institutions/ buildings of public social importance (estimated at around 53,000,000.00 dinars): – House of Rade Jelisavčić, cultural and historical heritage of Zaovine, about 500,000.00 dinars

Protected values	Criteria
	– the ethno household in Kaluđerske Bare, about 500,000.00 dinars – accommodatioon establishments in the area of “Mokra Gora” Nature Park around 10,000,000.00 dinars – holiday settlements on the edge of the forest, about 12,000,000.00 dinars – tourist complexes surrounded by forest, hotels (Javor, Beli Bor, Tara) around 30,000,000.00 dinars

Table 6.7 Protected values.

Note: The total budget of the Municipality of Bajina Bašta amounts to 1,351,085,000.00 dinars (website of the Municipality of Bajina Bašta).

Category	Probability and frequency			
	(a) Qualitative	(b) Probability	(c) Frequency	Selected
1	Negligible	< 1%	1 event in 100 years or less	
2	Low	1-5%	1 event in 20-100 years	X
3	Medium	6-50%	1 event in 2-20 years	
4	High	51-98%	1 event in 1-2 years	
5	Very high	>98%	1 event a year or more often	

Table 6.8 Fire probability.

Consequences for human life and health			
Category	The magnitude of the consequence	Criterion	Selected
1	Minimum	< 50	
2	Slight	50-200	
3	Moderate	201-500	
4	Serious	501-1500	X
5	Devastating	>1500	

Table 6.9 Consequences for human life and health.

Consequences for the economy and ecology			
Category	The magnitude of the consequence	Criterion	Selected
1	Minimum	Amount > 1% of the budget	
2	Slight	Amount > 3% of the budget	

3	Moderate	Amount > 5% of the budget	
4	Serious	Amount > 10% of the budget	
5	Devastating	Amount > 15% of the budget	**X**

Table 6.10 Consequences for the economy and ecology

Consequences for social stability – total material damage to critical infrastructure			
Category	**The magnitude of the consequence**	**Criterion**	**Selected**
1	Minimum	Amount <1% of the budget	**X**
2	Slight	Amount 1-3% of the budget	
3	Moderate	Amount 3-5% of the budget	
4	Serious	Amount 5-10% of the budget	
5	Devastating	Amount > 10% of the budget	

Table 6.11 Consequences for social stability – total material damage to critical infrastructure for the most probable adverse events.

Consequences for social stability – total material damage to institutions and buildings of public social importance			
Category	**The magnitude of the consequence**	**Criterion**	**Selected**
1	Minimum	Amount < 0.5% of the budget	
2	Slight	Amount 0.5-1% of the budget	
3	Moderate	Amount 1-3% of the budget	
4	Serious	Amount 3-5% of the budget	X
5	Devastating	Amount > 5% of the budget	

Table 6.12 Consequences for social stability – total material damage to institutions and buildings of public social importance for the most probable adverse events.

Matrix 1: Risk to human life and health

Consequ

5					
4		#			
3					

2					
1					
	1	2	3	4	5

Probability

Matrix 2: Risk to the economy/ ecology

Consequences					
5		#			
4					
3					
2					
1					
	1	2	3	4	5

Probability

Matrix 3a: Risk to social stability –

total material damage to critical infrastructure

Consequences					
5					
4					
3					
2					
1		#			
	1	2	3	4	5

Probability

Matrix 3b: Risk to social stability –

total material damage to institutions/ buildings of public social importance

Consequences					
5					
4		#			
3					
2					
1					
	1	2	3	4	5

Probability

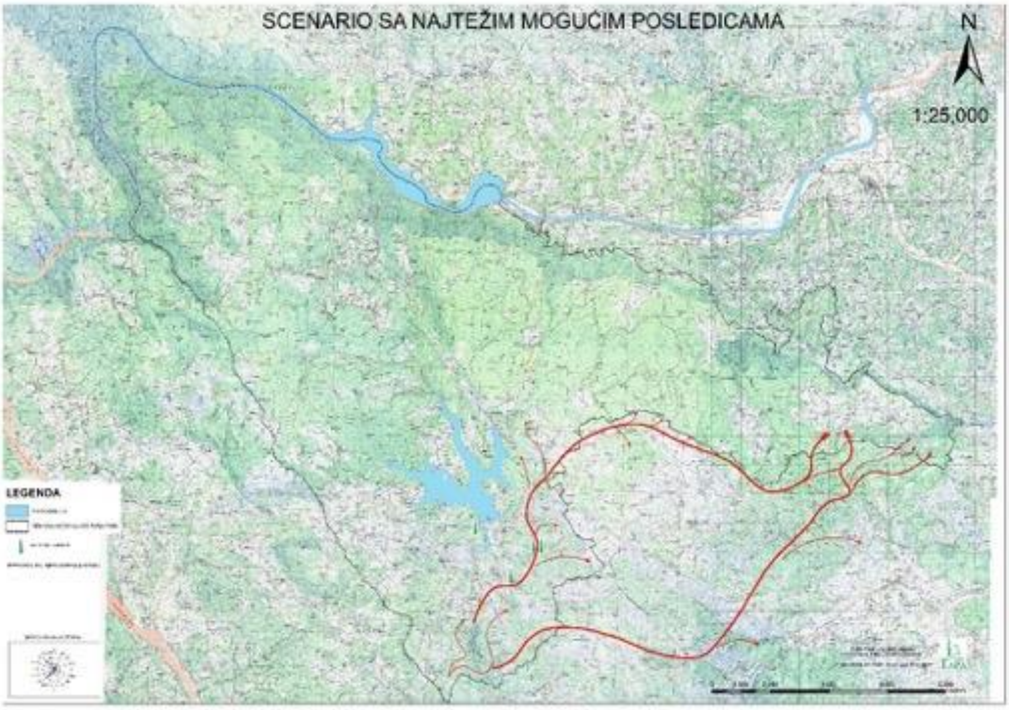

Figure 6.13 Scenario with the worst possible consequences.

Matrix 3: Collective matrix 3a and 3b – risk to social stability

Consequences					
5					
4					
3		#			
2					
1					
	1	2	3	4	5

Probability

Matrix 4: Total risk

Consequences					
5					
4		#			
3					
2					
1					
	1	2	3	4	5

Probability

It can be seen from the above that there is a high level of risk of forest fire in the area of PE "Tara National Park".


Figures 6.14 and 6.15 Location: Kamena Gora – fire index board

Multi-risk is a combination of two or more potential hazards if they:

- occur at the same time or occur sequentially,
- depend on each other or they are caused by the same event or trigger event,
- pose a threat to the same elements (vulnerable/ exposed elements) without chronological coincidence.

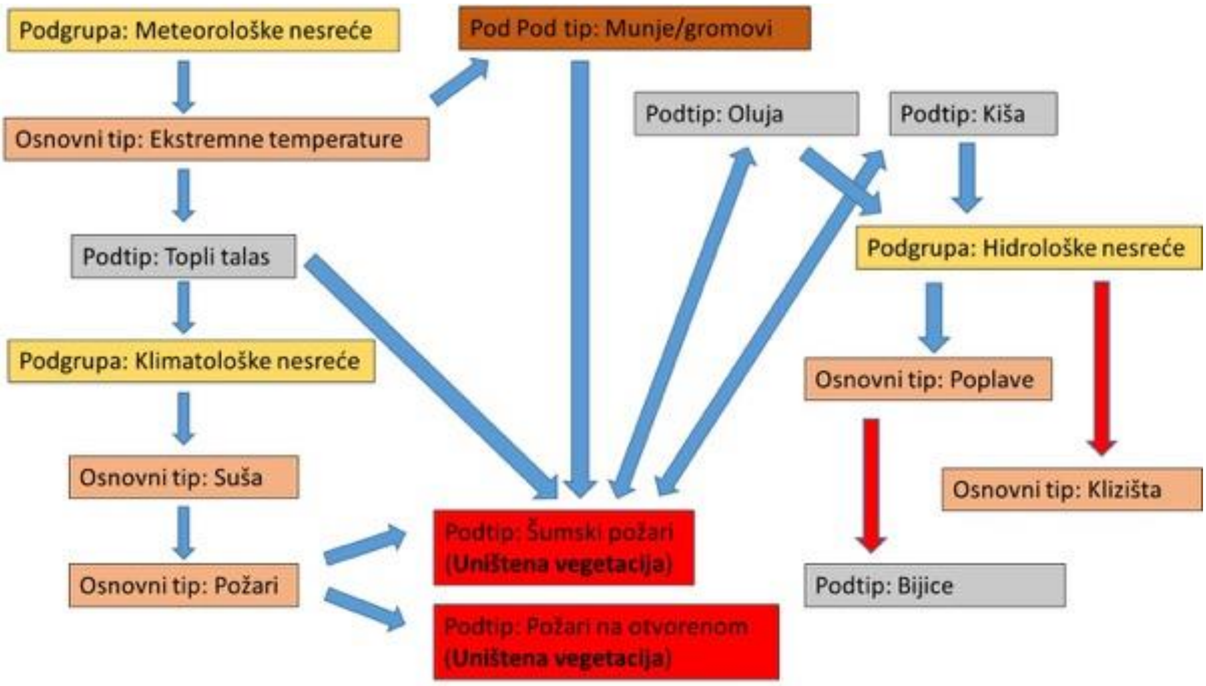

Figure 6.16 Multi-risk scheme.

Besides their significant impact on the destruction of the biodiversity of the area, forest fires also have an impact on the frequent occurrence of torrential floods. In these circumstances, torrential floods occur as secondary events, most often caused by loosened soil and erosion previously caused by the primary event – forest fire. The main characteristic of torrential floods is that they occur suddenly (after heavy rainfall), last for a short time (usually not longer than 30 minutes) and cause havoc.

7. THE LORCA SHOWCASE, SPAIN, 2011: LEVERAGING ON THE EXPERIENCE OF DATA ANALYSIS TO DEVELOP THE DATA MODEL FOR ENHANCED POST DISASTER DATA COLLECTION FOR THE BUSINESS AND CULTURAL HERITAGE SECTORS

Authors:

María-José Jiménez, Mariano García-Fernández - CSIC

7.1. Leveraging on the Idea project results

Usual applications of collected damage and loss data include emergency management, compensations, subsidies and aids, accounting (e.g., Sendai indicators), and basic statistical analysis. Additionally, they have proven to be essential for detailed forensic analysis, enhanced risk assessment and mitigation actions, more accurate risk modelling, risk management, and supporting cost-benefit analysis.

The significant amount of damage and loss data collected after the 2011 Lorca earthquake encouraged the different administrations involved (local, regional, and national) to update and improve existing practices on emergency management, risk assessment, and mitigation actions.

The basic data on building evaluations and damage assessments quickly collected immediately after the 2011 Lorca earthquake supported the emergency management carried out by the Civil Protection units of the different administrations (including the Military Emergency Unit, UME), whose main aim is devoted to people's protection. It allowed a quick identification of the amount of people to relocate away from their homes and thus evaluate the needs for temporary shelters. It also helped on prioritization of buildings for the subsequent re-evaluations accomplished in the following weeks.

Figure 7.1 Technical guides of the CARM published after the 2011 Lorca earthquake (CARM, 2012a, 2012b, 2013a, 2013b).

The acquired experience on quick and detailed damage assessment of buildings after the earthquake, including the significant amount of Cultural Heritage assets, motivated also the CARM to drive an initiative to develop and publish several technical guides and recommendations (Figure 7.1) on emergency damage evaluation of buildings (CARM, 2013a), retrofit of structural elements (CARM, 2013b), and good practices for re-buildings (CARM, 2012a,b). A technical manual on Rapid Emergency Damage Evaluation has been published later (CARM, 2015a) that includes the contents of a training course, and updated forms for rapid evaluation of masonry and framed structures (Figure 7.2).

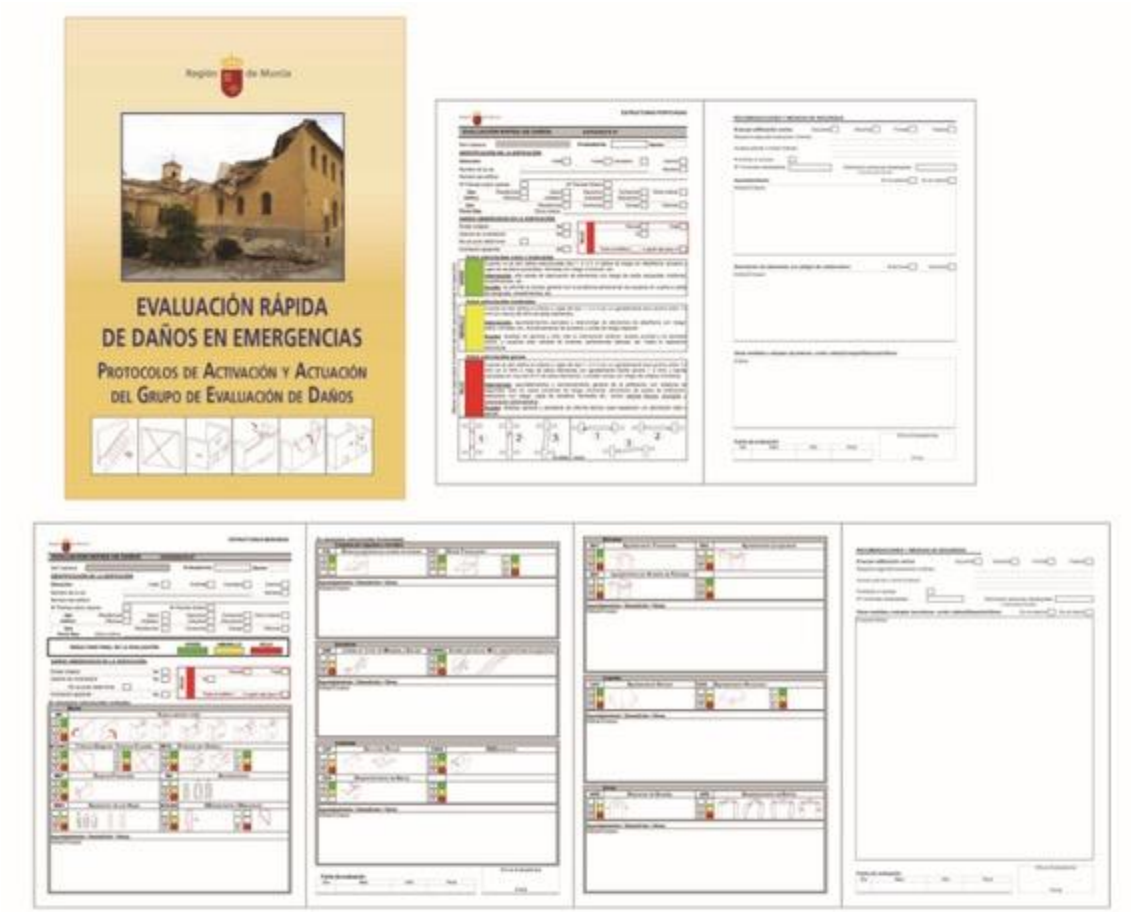

Figure 7.2 *Technical manual on Rapid Emergency Damage Evaluation and updated forms for rapid evaluation of masonry and framed structures (CARM, 2015a).*

Lessons learned from the effects and impact of the 2011 Lorca earthquake encouraged the regional government, CARM, to update (RISMUR II, 2015) of the existing seismic risk assessment of the Murcia region as developed 10 years earlier (RISMUR, 2005). These reports are the base of the two editions of the Seismic Emergency Plan of the Civil Protection Unit of the CARM, SISMIMUR, published in 2006 (CARM, 2006) and 2015 (CARM, 2015b), respectively.

After the experience of the 2011 Lorca earthquake, the Spanish Ministry of Culture and Sport developed and published (IPCE, 2015) a National Plan of Emergencies and Risk Management in Cultural Heritage (Figure 7.3). The aim of the Plan was to unify criteria and to develop a homogeneous methodology for damage evaluation of the Cultural Heritage, promotes the coordinating of the different institutions and administrations involved in emergency and risk management in Spain. The Plan was developed to contribute to the design and implementation of prevention and protection actions in the pre-event phase, and to the rapid intervention and damage evaluation during the emergency phase after the occurrence of any natural- or man-made hazards.

Figure 7.3 National Plan of Emergencies and Risk Management in Cultural Heritage (IPCE, 2015).

Due to the changes experimented in the urban environment of the Old Town complex (see section 2.4) after the earthquake, and the significant amount of empty plots after building demolitions, the Lorca City Council undertook the revision and update of the existing Protection and Rehabilitation Plan of the Old Town of Lorca (PEPRI, 2000), which was completed in 2017 (PEPRICH, 2017).

In what regards damage and loss data applications on forensic analysis and risk modelling these were also developed in the framework of the European project IDEA (http://www.ideaproject.polimi.it/?page_id=283). Forensic analysis (Figure 7.4) provided clues for identifying those factors and drivers (organized in three classes: Hazard, Vulnerability, and Resilience) having more influence on causing and reducing damage in seven sectors (People, Emergency, Housing, Business, Infrastructure, Public assets, Cultural Heritage).

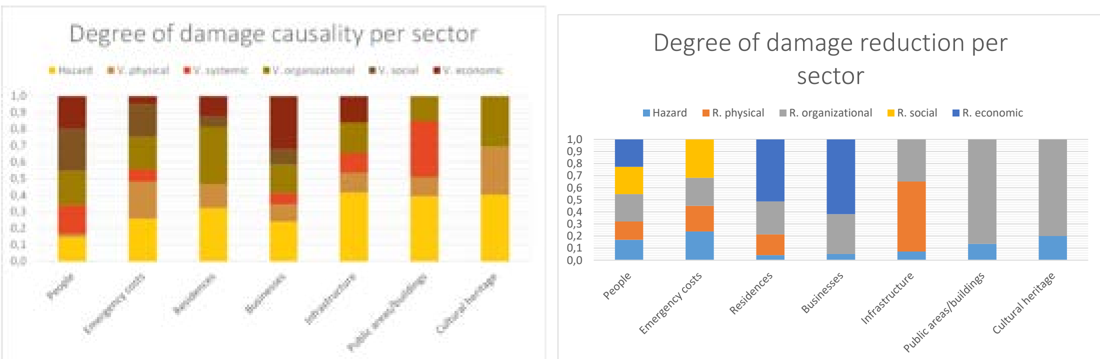

Figure 7.4 Example of forensic analysis showing causes and drivers of damage to different sectors after the 2011 Lorca erathquake. (LODE Deliverable B.3, http://www.ideaproject.polimi.it/?page_id=283, last accessed February 2021).

Also based on recorded damage in Lorca and with the aim of performing risk modelling, the application in the level 1 Risk-UE methodology (Lagomarsino and Giovinazzi, 2006) was used to generate simulations of physical damage to buildings in the city of Lorca and these were compared to observations (Figure 7.5). Following two approaches in the assessment ('direct' and 'indirect') it allowed to identify those parameters most likely explaining why pre-event risk assessment could fail to predict observed damage. In this case improved risk modelling could be achieved as based on the use of detailed damage data.. The results showed the difficulties of relying on pre-event risk assessments for predicting observed earthquake damage, and the significant differences that can be observed when comparing hindcast damage scenarios with actual damage observations.

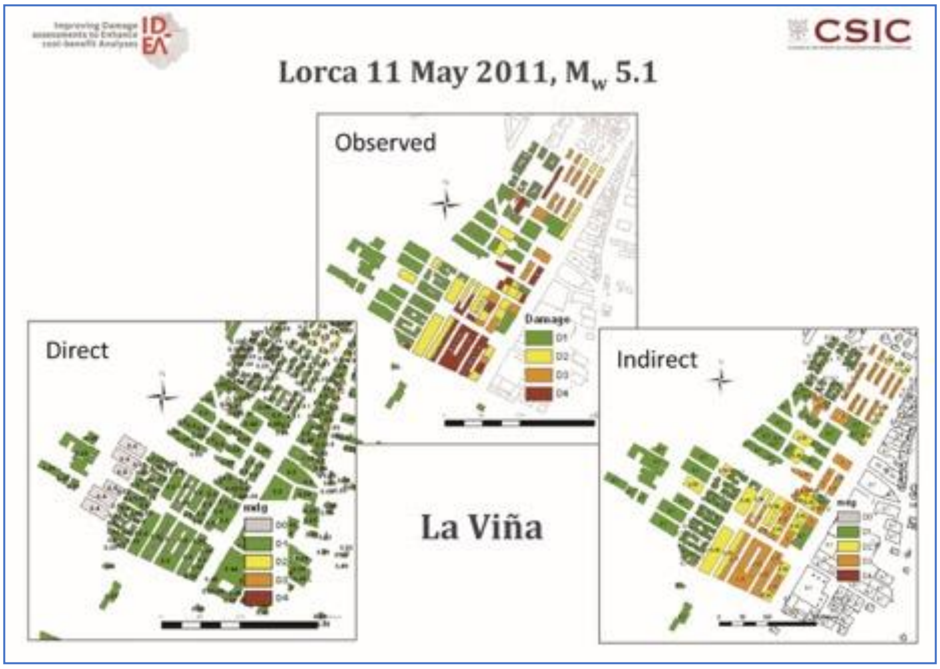

Figure 7.5 Simulation of physical damage to buildings in La Viña neighborhood (Lorca) by direct and indirect approaches (Lagomarsino and Giovinazzi, 2006) from the 2011 Lorca earthquake and comparison with observations. (http://www.ideaproject.polimi.it/?page_id=283, last accessed February 2021).

The Business and Cultural Heritage sectors have been selected to demonstrate potential applications of the collected data on the 2011 Lorca earthquake and implemented in the developed LODE platform.

Data on damage and losses to the Business sector from the CECLOR and the CCS consist basically of costs from direct and indirect damage to property and loss of profit.

CCS compensation data refer only to business covered by insurance policy, while CECLOR survey was addressed to businesses no matter if possible insurance coverage. Non-refundable subsidies to non-insured business from the Central and the Regional Governments do not have a clear relation with the level of damage mostly consisting of fixed amounts of direct aids, tax reduction or extended times for tax payment. In the application analysed in LODE, damage data from the industry area is considered as an example application for supporting cost-benefit analysis.

For damage and losses in the Cultural Heritage sector, these are addressed by using the information on physical damage, emergency actions, and the performed rehabilitation and retrofit works in the summary files of individual assets included in the two Master Plans (Plan Director 2011, 2013) described in section 3; as well as the final costs and funding sources from the monitoring carried out by the Cultural Heritage Unit of the CARM.

Identification of key issues and criteria, and main elements involved in the assessment of damage to the Cultural Heritage from the experience of the 2011 Lorca earthquake, from Emergency to Recovery phases, would provide significant information for the development of enhanced risk assessment and mitigation actions, as well as for the evaluation and revision of risk models.

The analysis of both sectors (Business and Cultural Heritage) using the information on damage and losses collected from the 2011 Lorca earthquake with the support of the identified stakeholders, has allowed to develop basic conceptual damage/loss data models contributing to the LODE Information System. The components and contents of these two conceptual models are summarized in Figures 7.6 and 7.7. The component and damage entities with their attributes, considering main direct and indirect impacts, are sketched and described in Figures 7.8 to 7.11.

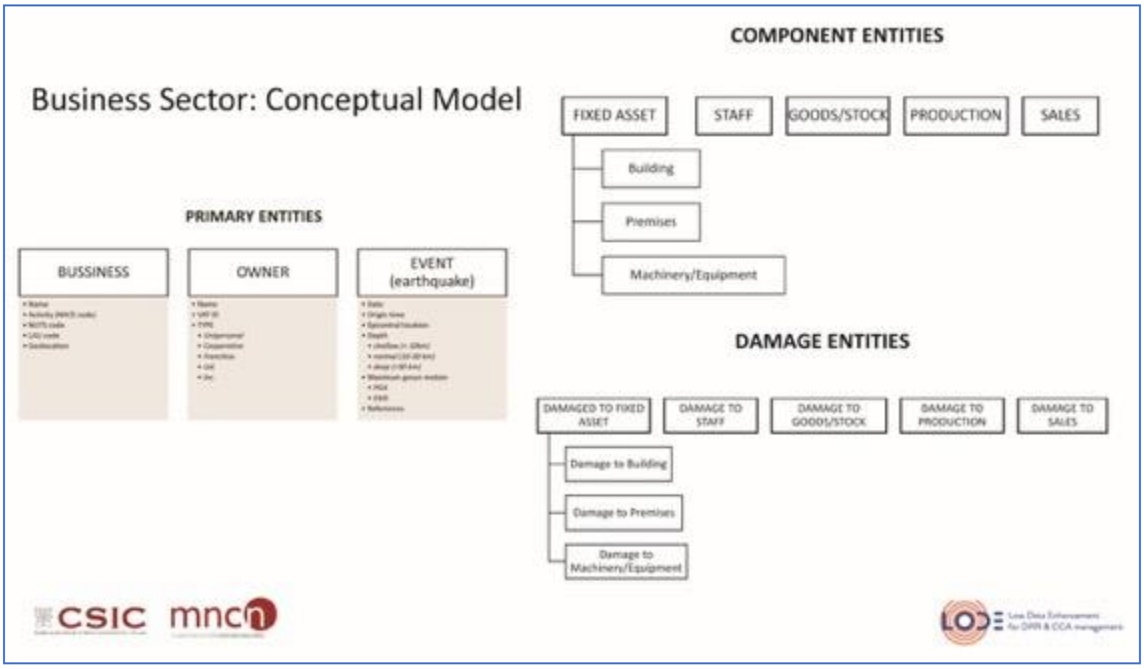

Figure 7.6 Scheme of the Conceptual Model developed for the Business sector.

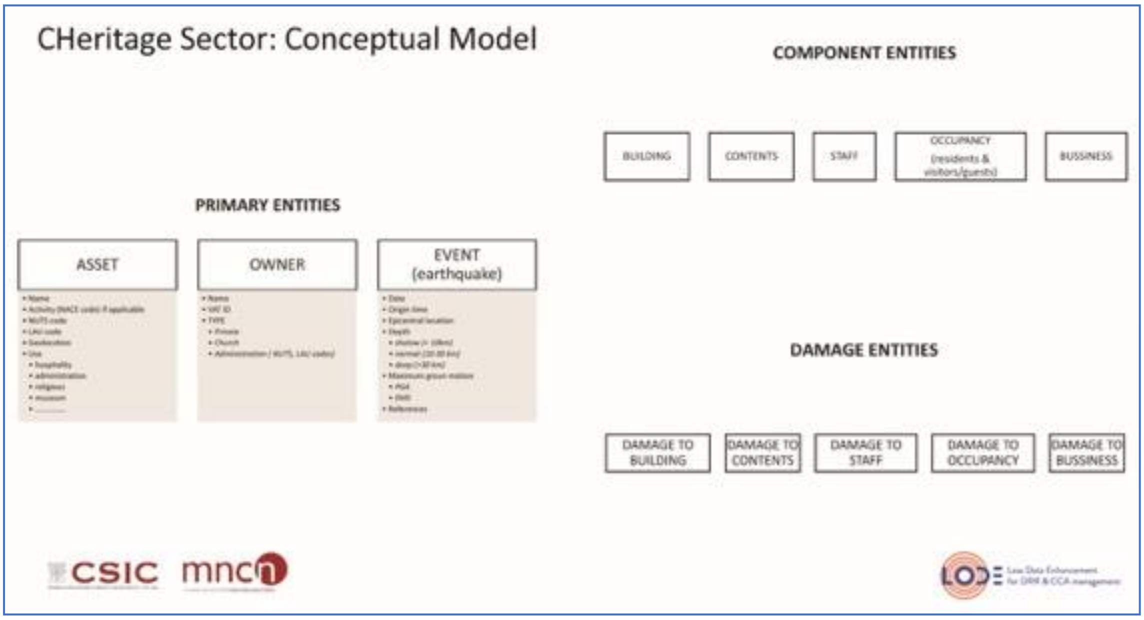

Figure 7.7 Scheme of the Conceptual Model developed for the Cultural Heritage sector.

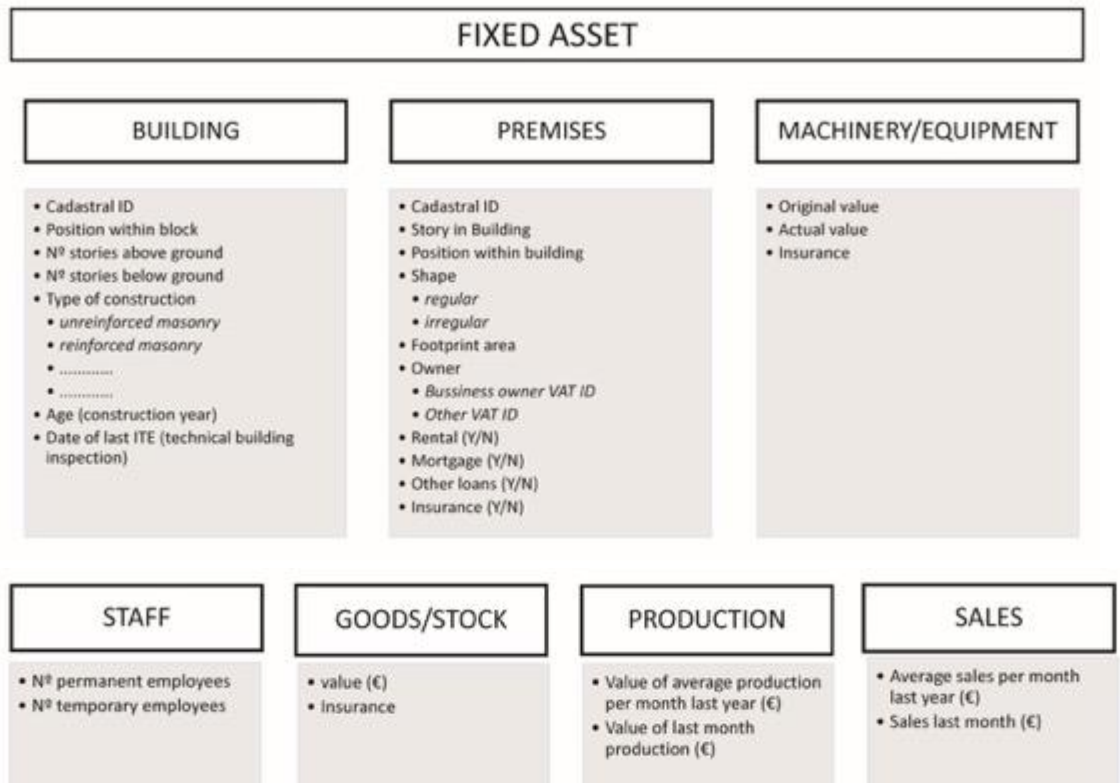

Figure 7.8 Component Entities of the Conceptual Model for the Business sector.

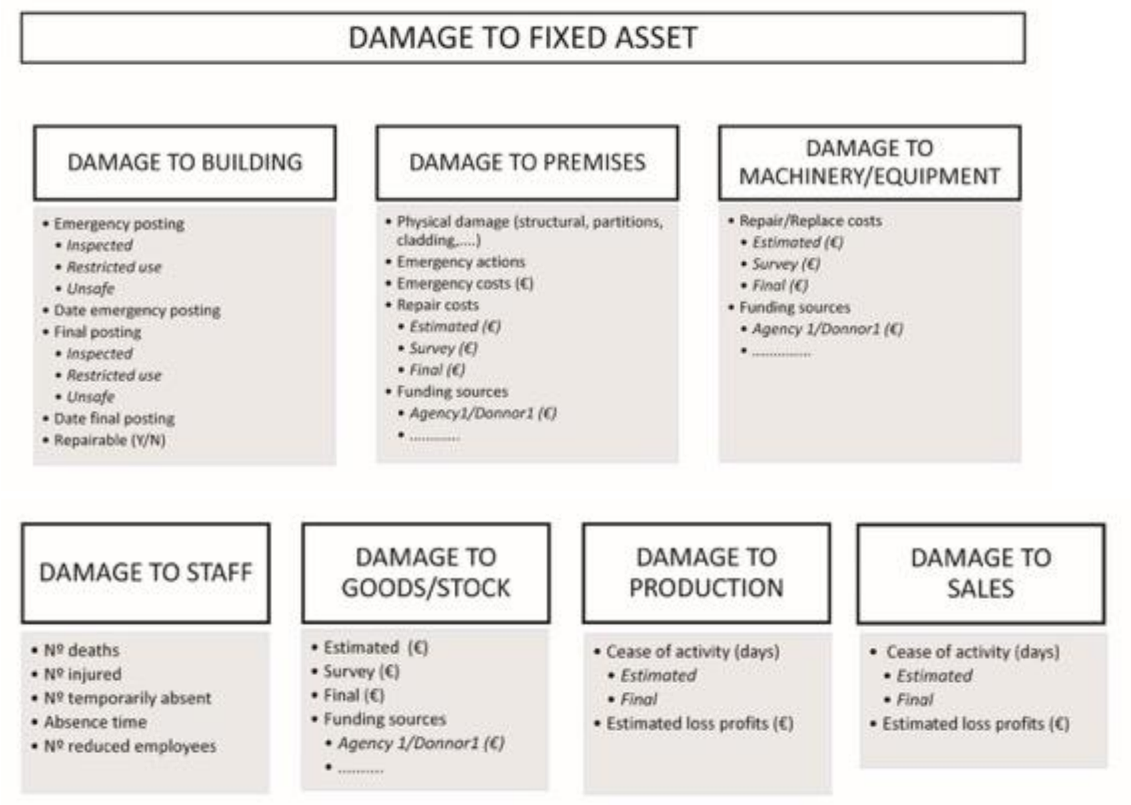

Figure 7.9 Damage Entities of the Conceptual Model for the Business sector.

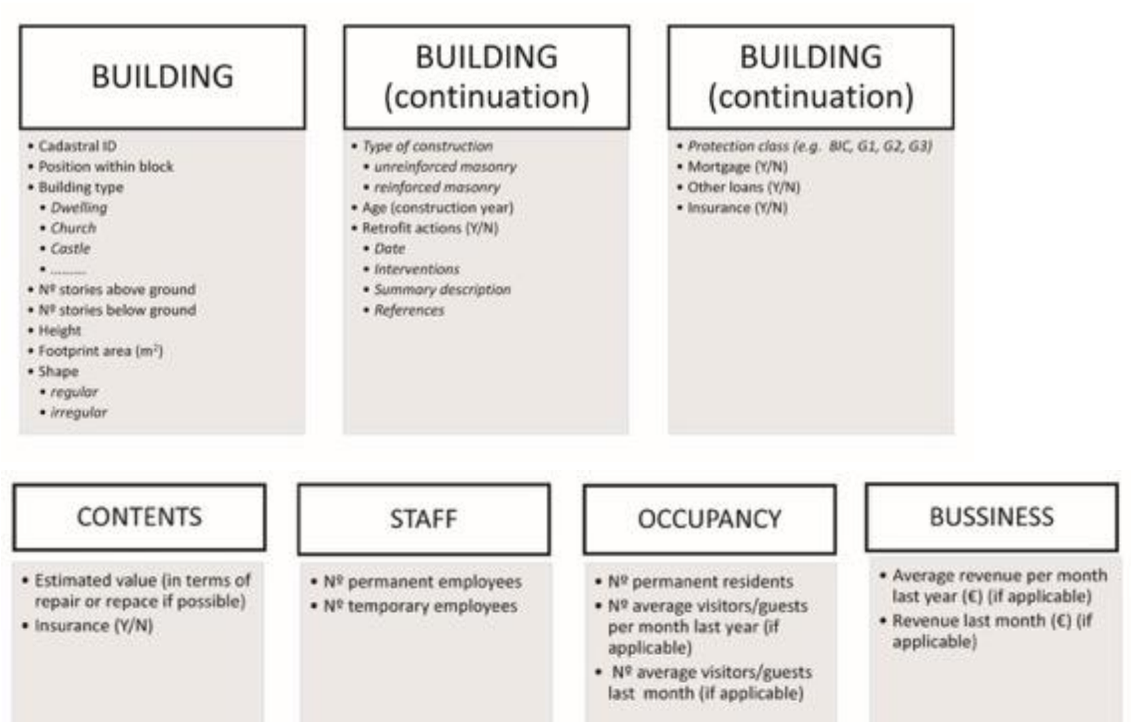

Figure 7.10 Component Entities of the Conceptual Model for the Cultural Heritage sector.

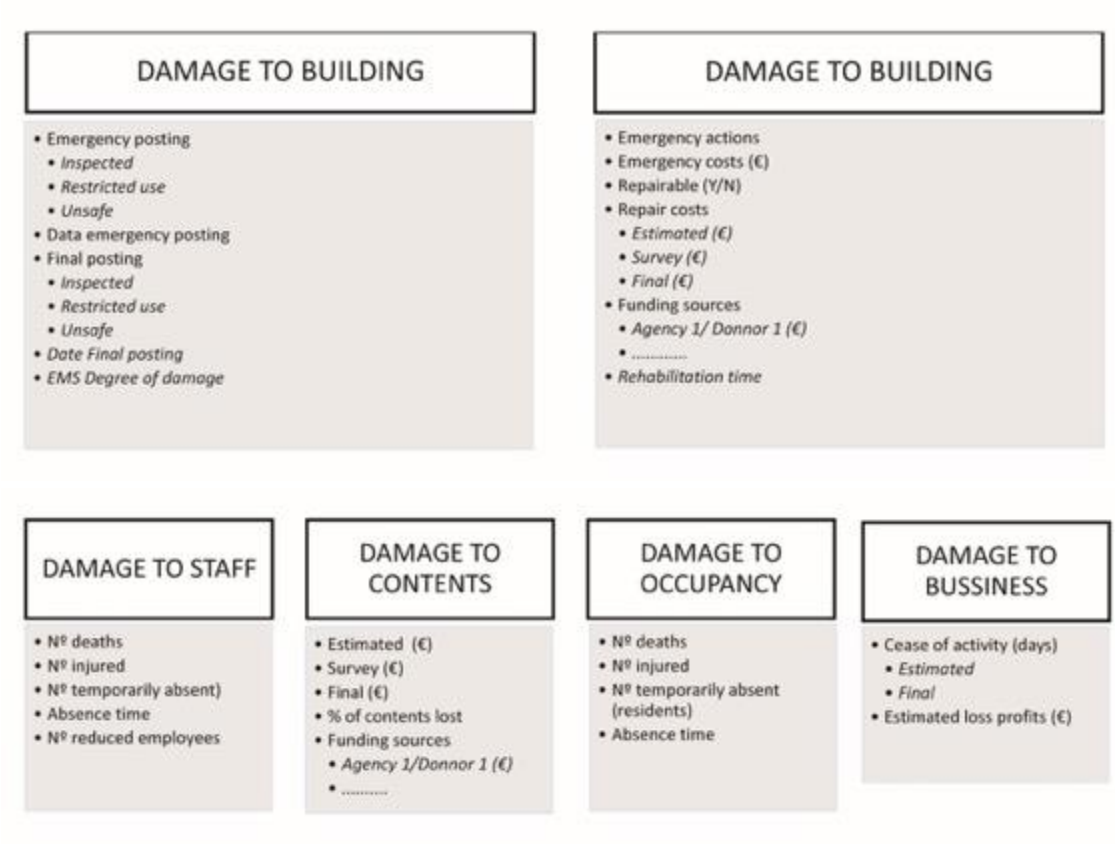

Figure 7.11 Damage Entities of the Conceptual Model for the Cultural Heritage sector

8. THE MADEIRA FLASHFLOOD, PORTUGAL 2015 SHOWCASE: LEVERAGING ON THE EXPERIENCE OF DATA ANALYSIS TO DEVELOP THE DATA MODEL FOR ENHANCED POST DISASTER DATA COLLECTION FOR ROADS

Authors:

Xavier Romão, Rui Figueiredo and Esmeralda Paupério - FEUP

The University of Porto analysed the road network damage and loss data that was obtained in detail to gain a better understanding of the impacts of the event on this sector. Furthermore, this in-depth analysis also provided relevant insights on what type of damage and loss data were collected after the event, and on the way they were collected. This, in turn, provided the background for developing a disaster damage and loss data model for road networks, leveraging on the invaluable insights provided by the data collected following a real event. To illustrate some of this background context, this section describes the disaster data available for this sector for each of the four municipalities.

8.1. Damage data to the road system in the most affected municipalities

8.1.1. Câmara de Lobos

Collected data for Câmara de Lobos is the most detailed out of the four municipalities. For each parish in the municipality, there is a list of affected roads identified by their name, which contain three data fields: damage description, description of repair and reconstruction works, and estimated budget for those works. Both descriptions are comprehensive and provide detailed characterizations of the damage and required works.

	LOCAL FREGUESIA E ACESSO	ASSUNTO DESCRIÇÃO DA OCORRÊNCIA	TRABALHOS OBRAS DE REPOSIÇÃO A EFECTUAR	ORÇAMENTO ESTIMADO (S/ LIMPEZAS)
CL 8	Estrada 1 de Julho	Várias derrocadas ao longo da via, de terrenos e escarpas rochosas, sobranceiras à mesma.	Limpeza da estrada. Reperfilamento de taludes e reconstrução dos muros de suporte sobranceiros danificados, dos muros de guarda danificados da Estrada e das valetas danificadas. Repavimentação parcial da Estrada. Reparação dos passeios nas zonas danificadas.	259.950,00 €
CL 9	Estrada de Santa Clara	Pavimento destruído devido à passagem da linha de água que vai em direcção ao córrego. Danificação da caixa de visita da rede de esgoto.	Reposição de pavimento; Canalização das águas do córrego; reparação da caixa de visita da rede de esgoto.	8.285,00 €

Figure 1.1 Illustrative road network damage and loss data for the Câmara de Lobos municipality.

Complementary high-quality photos are also available for each entry in the list, which provide further insights into those aspects. Still, no exact geolocation of the damage within a certain affected road is provided. This dataset was produced in March 2010 following the event and is illustrated in Figure 1.1. Photos are shown in Figure 8.2 for two illustrative occurrences.

Figure 8.2 Illustrative photographs associated to each entry in the Câmara de Lobos road network damage and loss dataset.

8.1.2. Funchal

Data for Funchal is also quite detailed, even if the level of disaggregation is lower. This dataset is organized into two different layers of information. The first layer contains loss figures corresponding to groups of required repair works aggregated by contract, with a corresponding brief description of those works (as illustrated in

Figure). The second layer of the dataset provides a more refined identification of the affected roads that each contract includes at a component-by-component level, with a brief description of the necessary repair or reconstruction works (Figure). However, economic loss values are not available at this level of disaggregation. An interesting aspect of the Funchal dataset is that it apparently includes both the initial estimates carried out by the joint commission and the actual value spent for that contract, even if in a majority of the cases the two values match. As for the previous municipality, no exact geolocation of the damage within a certain affected road is provided.

MUNICÍPIO DO FUNCHAL

EMPREITADAS DO TEMPORAL DE 20 DE FEVEREIRO

	Comissão Paritária				EXECUÇÃO FINANCEIRA	
Designação	ID	Valor candidatura	Valor Actual	Situação actual	2010	Observações
Execução dos trabalhos de limpeza imediata da rede de acessibilidades municipais	Estradas	883 247 €	974 594 €	Concluido	974 594 €	ANEXO 1
Execução de diversos trabalhos de recuperação da rede viária - Santo António e São Martinho	Estradas	319 883 €	319 883 €	Concluido	319 883 €	ANEXO 2
Execução de diversos trabalhos de recuperação da rede viária nas freguesis do Monte, Imaculado Coração de Maria e Santa Luzia	Estradas	338 313 €	338 313 €	Concluido	338 313 €	ANEXO 3
Execução de diversos trabalhos de recuperação da rede viária nas freguesias de São Roque, Santa Maria Maior e São Gonçalo	Estradas	191 339 €	191 339 €	Concluido	191 339 €	ANEXO 4
Recuperação de Veredas e Becos nas freguesias de Santo António e São Martinho	Estradas	196 560 €	196 560 €	Concluido	196 560 €	ANEXO 5
Recuperação de Veredas e Becos nas freguesias do Monte, Imaculado Coração de Maria e Santa Luzia	Estradas	167 357 €	167 357 €	Concluido	167 357 €	ANEXO 6
Recuperação de Veredas e Becos nas freguesias de São Roque, Santa Maria Maior e São Gonçalo	Estradas	202 800 €	202 800 €	Concluido	202 800 €	ANEXO 7
Reparação de calçadas - Zona Baixa da Cidade	Estradas	206 960 €	206 960 €	Concluido	206 960 €	ANEXO 8
Reparação de pavimentos betuminosos - Zona Baixa da Cidade	Estradas	193 362 €	193 362 €	Concluido	193 362 €	ANEXO 9
Reparação de pavimentos betuminosos - Zonas Altas	Estradas	200 057 €	200 057 €	Concluido	200 057 €	ANEXO 10
Grande reparação do Caminho do Cabeço dos Lombos	Estradas	208 416 €	208 416 €	Concluido	208 416 €	

Figure 8.3 Illustrative road network damage and loss data, aggregated by contract, for the Funchal municipality.

MUNICÍPIO DO FUNCHAL

Estradas - "EXECUÇÃO DE DIVERSOS TRABALHOS DE RECUPERAÇÃO E VEREDAS E BECOS NAS FREGUESIAS DE SÃO ROQUE, SANTA MARIA MAIOR E SÃO GONÇALO ."

ANEXO 7

Locais de Intervenção	Freguesia	Tipo de Intervenção
Caminho de São João Latrão	São Gonçalo	Limpeza de ribeiro; construção de vedação; limpeza de valetas; reconstrução de valeta transversal.
Rua Lombo do Centeio	São Gonçalo	Construção de muro de suporte; construção de muro de guarda; drenagem superficial de águas pluviais
Caminho da Hortelã	São Gonçalo	Limpeza de terras e transporte a vazadouro; construção de muros de suporte; construção de muros sobranceiros; construção de muros de guarda; limpeza de ribeiro; construção de aqueduto; construção de acessos; construção de valeta transversal; pavimentações parciais em betão.
Estrada das Carreiras	Santa Maria Maior	Restabelecimento de vereda pedonal junto à Estrada das carreiras incluindo pavimentação em betão
Vereda da Cova	São Roque	Restabelecimento de passagem pedonal incluindo pequeno murete de suporte, vedação em varanda e pavimentação em betão
Caminho da Igreja Velha	São Roque	Construção de muros sobranceiros;
Caminho Velho da Igreja	São Roque	Construção de muros sobranceiros;
Rua Conde da Alegria	São Roque	Construção de muros sobranceiros;
Beco da Bujaria	São Roque	Construção de muros sobranceiros; construção de acesso; vedação em varanda

Figure 8.4 Illustrative road network damage data at the component level for the Funchal municipality.

8.1.3. Ribeira Brava

The dataset obtained for the Ribeira Brava municipality consists in a collection of thirty images containing parts of the road network superimposed on aerial imagery of the island. An example of these images is shown in Figure . Each segment of the road network is classified according to the damage that it sustained, based on a colour-coding scheme. This damage may refer either to the road itself, the infrastructures that it contains, or both. The classes of damage that are considered are the following: damaged road; damaged bridge; damaged water supply system; damaged water supply and drainage systems; damaged road, water supply and drainage systems. Loss estimates or further component-specific damage information are not available. Furthermore, as for the previous municipalities, no exact geolocation of the damage within a certain affected road is available.

Figure 8.5 Illustrative road network damage data for the Ribeira Brava municipality.

8.1.4. Santa Cruz

Lastly, for the Santa Cruz municipality, the University of Porto was able to obtain the most detailed data of damage and losses to the road network. This data consists in the actual filled-in survey forms that were used following the 2010 event to estimate economic losses. Each form refers to a different damaged road and contains a description of the damage that occurred, the scope of the required works, and the corresponding estimated cost. An annex to each form then contains the methodology that was used to estimate the costs of the required repair and/or reconstruction works based on a bill of quantities (see Figure). This document includes descriptions and quantities of the required works for each affected road, meaning that the information is highly insightful. All loss estimates are also organized and aggregated by parish in a separate summary table. Despite the level of detail of these data, no exact geolocation of the damage within a certain affected road is available, as for the previous municipalities.

Anexo A

NOTA JUSTIFICATIVA / METODOLOGIA DE CÁLCULO DOS CUSTOS

A1. BASE DE CÁLCULO - ESTIMATIVAS SUPORTADAS EM:

- [ ] ESTUDOS PRELIMINARES
- [X] ESTUDO PRÉVIO
- [ ] PROJECTO BASE
- [ ] VALOR DA ADJUDICAÇÃO
- [ ] OUTRA (ESPECIFICAR)

A.2 MÉTODO DE CÁLCULO
(DETALHAR A METODOLOGIA UTILIZADA PARA O APURAMENTO DOS CUSTOS)

DESCRIÇÃO	Unid. de Med.	Nº de Partes Iguais	DIMENSÕES			Parc.	Totais	Preço Unitário (€)	Preço Total (€)
			Comp.	Larg.	Alt.				
Pavimentação em betuminoso	m2	1	500.00	6.00		3000.00	3000.00	50.00	150000.00
Muro em betão ciclópico	m3	1	25.00	Área =	4.00	100.00	100.00	160.00	16000.00
								TOTAL =	166000.00

A.3 APRESENTAR O VALOR DOS CUSTOS, COM DETALHE DE VALOR DE REVISÕES PREÇOS E DO IVA (CASO EXISTA)

Revisão de preços: 1 162.00 €

IVA (1,04%): 172 640.00 €

VALOR DOS CUSTOS: 173 802.00 €

Figure 8.6 Illustrative annex to a survey form for road network damage and loss in the Santa Cruz municipality.

8.2. Observation on available data and proposed data model for the road

system

Based on the analysis of the collected data, the first observation that can be made is that the level of detail regarding damage and loss characterization varies significantly from one municipality to another, from simple qualitative descriptions to comprehensive descriptions including cost estimates. In addition, the datasets include either damage descriptions, repair works descriptions, or both. The heterogeneity between datasets also exists in terms of components that are considered. For example, Ribeira Brava does not explicitly include damage to walls or slopes, and Funchal does not appear to consider water supply and sewage infrastructure usually located within roads.

Another issue of relevance is that it is almost never possible to pinpoint locations of damage occurrence. Damage information is usually provided in terms of road names, but roads can in some cases be quite long, and in those cases, it may not be possible to understand exactly where damage within the road occurred. An issue of a more technical nature is that there is no explicit association between the affected roads and a georeferenced dataset of road infrastructure. Thus, in order to map damage occurrence in a Geographic Information System, it is necessary to make the association through the road names, which in many cases cannot be done in an automated manner.

Most data presented in this section are not publicly available and were provided by the municipality at the request of the University of Porto. It should be noted that for the Madeira 2010 event, there was an established methodology for collecting damage and loss data in a homogeneous and detailed manner, which is not a common situation. However, the individual survey forms could only be obtained for a single municipality, Santa Cruz. For the other municipalities, the data that was obtained collected is aggregated at different extents, which naturally limits the understanding of the damage that occurred and the usefulness of the loss data. One of the reasons for this is related to the time that has passed since the event occurred. In fact, after 11 years, in some municipalities, some information may no longer be practically obtainable or available at all. It is believed that this emphasizes the need to make local administrations aware of the importance of making loss data publicly available, such that they are not lost and be useful for future risk assessment studies.

8.2.1. Proposed data model

Based on the post-event data that was collected about the damage to the road network of the impacted municipalities, a data model for recording disaster impacts to road network components and service was developed (Figure 8.7). The data model was defined in order to reflect the most relevant aspects of current post-disaster data collection practice, as well as to go beyond such practice by providing the ability to record more disaggregated data and more impacts (i.e. loss of service). The data model was developed to be part of an event-based database and provides the ability to record impacts (i.e. damage and losses) to individual roads from different categories (national, regional, municipal, etc.) that are part of a network managed by a certain management entity (see (1) in Figure 8.7). Disaster impacts to a given road are divided according to categories of physical damage (see (2) in Figure 8.7) and traffic disruption (see (3) in Figure 8.7), where the latter is a consequence of the former. Physical damage recording is performed for each component of a road impacted by a certain event under consideration. The components for which physical damage can be recorded include parts of the actual roadway (e.g. the surface layer, the base course, etc.) and elements such as embankments, hill slopes, retaining walls, drainage systems, sidewalks, barriers, traffic signs and other signage features, lighting structures and other street furniture, and vegetation. Bridges were not considered, as they are elements with their own specificities, and perhaps require the development of a separate (and mode detailed) data model that could then be connected to that of the road network, namely by connecting with the roads identified in that data model associated to the location of a given impacted bridge.

For each component of a given road whose damage is collected, the data model records:

- The road name/code where the component damage is located.
- The component category, e.g. surface layer, embankment, hill slope, retaining walls, etc.
- The type of distribution of the component damage along the road, i.e. “point” damage for concentrated damage in a single location of the road, or “linear” damage for damage distributed along a certain length of the road.
- The location of the damage along the road, defined by a kilometric point or a GPS coordinate. If the type of damage is “linear”, this includes both the location of the initial point and of the end point of the length of the damage.
- A text description of the damage.
- The monetary loss associated to the damage of the component, i.e. the repair costs corresponding to the damage of the component.
- A text description of the necessary repair works.
- Photos of the damaged component.

The data model was defined to also be able to record damage to road components that is not directly caused by a given event but that, instead, is caused by the need to access certain infrastructures that are buried under the road (see (4) in Figure **Error! Reference source not found.**). This situation may happen when it is necessary to access buried infrastructures, such as the water or gas supply systems, the sewage system, the electricity network or the telecommunications network, that were damaged by the event and need to be accessed for repairs. Although the damage to these buried infrastructures due to the event is recorded in another module of the database, their impacts need to be connected to the road network data model when repairing these damaged infrastructures implies damaging components of the road network that were undamaged by the event.

Aside from recording the monetary losses associated with each individual component, the data model also records the total monetary losses associated to all the impacted components of the road network. This value may not be the sum of all the monetary losses associated with the physical damage of each individual component, since it may include other aspects. Furthermore, in some cases, this total value of the monetary losses is the only existing information since the disaggregated losses by component may not be available. The other category of disaster impacts to a given road is related to traffic disruptions resulting from damaged components of the road, as referred before. In this case, for a given road or road segment, the data model records:

- The start date and time of the traffic disruption, as well as its end date and time.
- The level of traffic disruption, e.g. full or partial.
- An estimate of the number of users affected by the disruption.
- A text description of the disruption and its possible consequences.

Finally, it is referred that the collected data is also time stamped, which allows the update of some of these data in case better estimates of certain items are available over time, e.g. the monetary losses associated to the damage can be initially set as estimates which can later be updated by the actual values. In the same way, the damage to a certain road component may be unnoticed in the immediate aftermath of the event and may only be associated to the event much later. This type of situation will then be reflected by the corresponding timestamp of the damage entry in the database, which will then also keep the history of all the data entries.

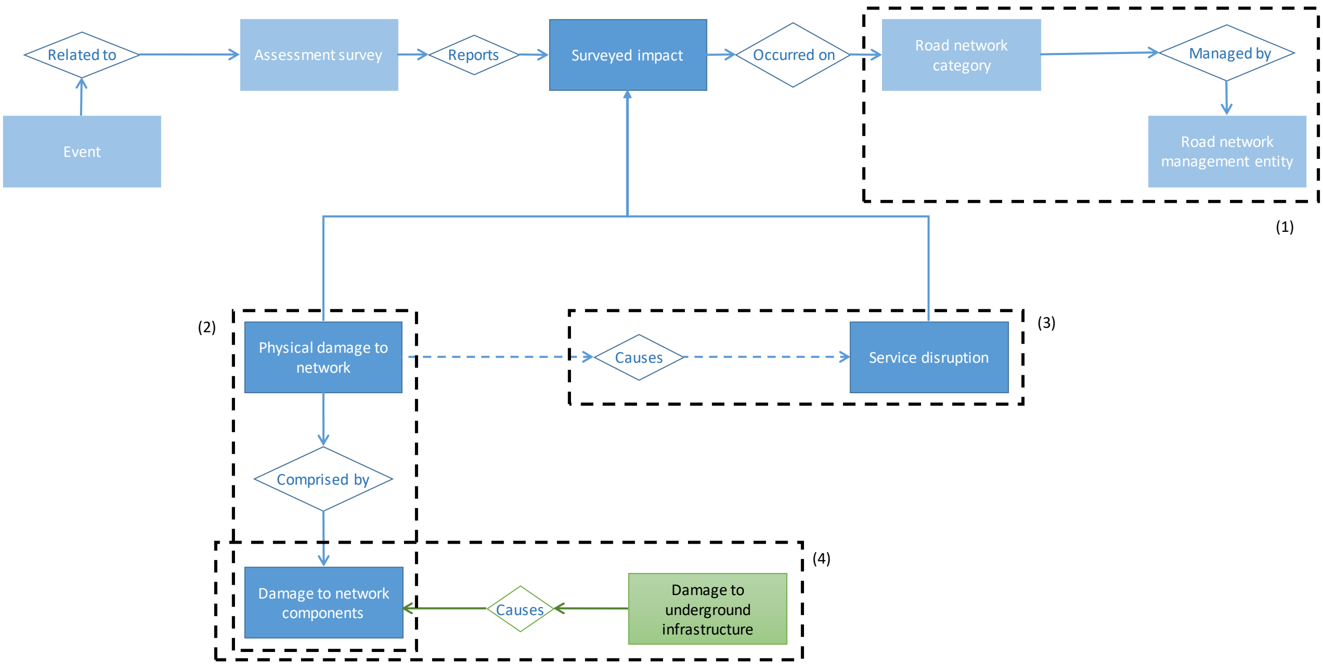

Figure 8.7 Proposed data model to record physical damage and service disruption in road networks.

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9. THE PACA FLOOD IN 2015, FRANCE SHOWCASE. USE OF DAMAGE DATA TO SUPPORT AN ASSESSMENT OF TERRITORIAL RESILIENCE

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9.1. Conceptualization of a database on the basis of needs and understanding of the PACA showcase

In what follows, we will first describe the database on the October 2015 flooding in the PACA region and secondly, we will present an approach of how to use the database for the characterization of territorial resilience to flooding at the communal level.

9.1.1. The proposed database

The database presented in Annex A has 61 columns and 98 rows. Three territorial grids are identified: the region, the departments and the collectivities. For some communities, details of locations have been added online when the data presents the request.

These three territorial grids represent the three reporting grids for the actors' data. Depending on the case, the descriptions are more precise or more general depending on the reporting grid. This point is essential to consider because it allows the effect of the regulatory constraint or the actors' field of responsibility on the level of aggregation of the data made available to be taken into account.

The columns present the reporting fields for the available data on the PACA floods of October 2015. The data can be quantitative as well as qualitative. Note that qualitative data (without units) is as important as quantitative data. The qualitative data can be of different nature. It can be ordinal, therefore usable in an exercise of comparison two by two of territorial entities. It can be of the same descriptive nature, in which case it makes it possible to report important significant elements to be taken into account in a two-by-two comparison of territorial entities.

The quantitative data includes a unit (e.g. euro, %, etc.).

After more than a year of data collection, we were able to complete the following sections:

NUMBER OF OCCURRENCES THAT CATNAT MECHANISM WAS DECLARED (CCR)-2018.

In France, natural risks are covered differently depending on the hazard. Storms, hail, the weight of snow on buildings are covered by classic guarantees by insurers. Other hazards (mainly floods, drought, earthquakes, volcanic eruptions) are covered by the Cat'Nat Plan.

The activation of CatNat mechanism give insights on the needed municipal support proportionately to the endured losses.

Then, to be covered, the risks must meet certain conditions.

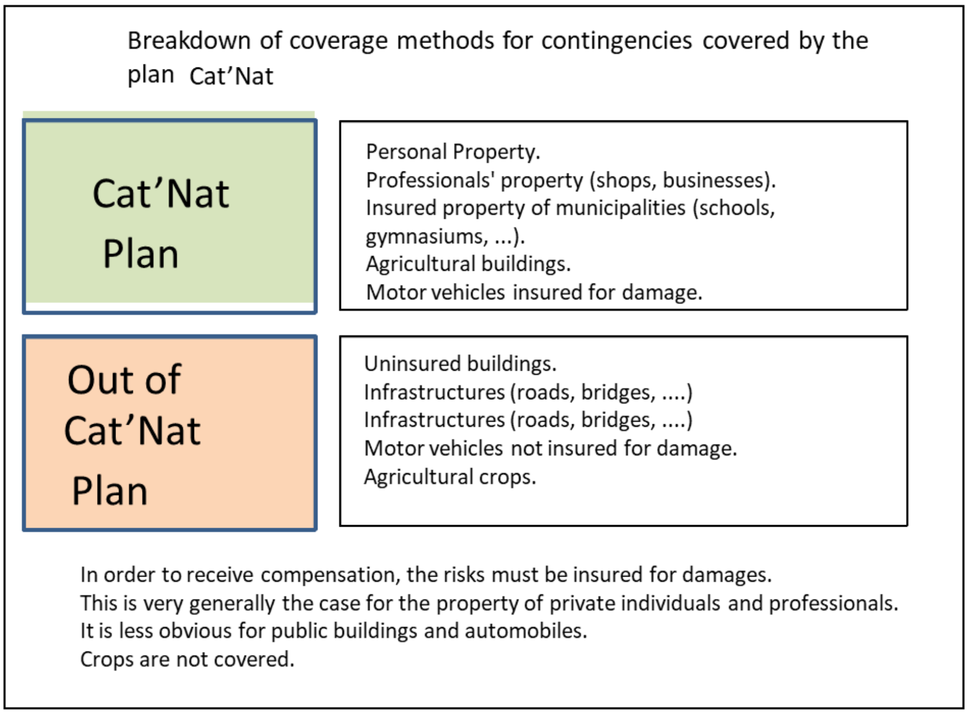

Figure 10.1 Cat'Nat plan explanation (Based on a translation of schema done by Michel Luzi)

Notice that considering this column highlights the relatively robust and more delicate issues.

It can be considered that all privately owned property is 100% insured. This is probably not entirely accurate, some risks may not be insured and others only partially. But these situations must remain marginal. It is useless to look for an improvement in the quality of these data, the cost would be exorbitant compared to the improvement. The average Cat'Nat premium per contract is 30 €.

Crops are not insured by this scheme, they benefit from another fund which does not cover the same hazards.

As far as public property and cars are concerned, it depends. Some risks are covered, others are not.

- *Prescription of DICRIM (Municipal Information Package on Major Risks).*

- *Prescription of* PPRI (Flooding Risk Prevention Plan)
- Emergency services (firefighters)
    - Zone category
    - Number of time firefighters responded to floods (2015)
    - % of the total of intervention
- Impact on health
    - Death
    - Other
- Economical impact
- Insurance - Market cost (Provided by CCR)
- Cost for Individuals (Provided by CCR)
- Cost for Professionals (Provided by CCR)
- Communal level of completeness for the flooding (Provided by CCR)
- Economical activity
    - Buildings and public services
    - Private real estate and furniture
    - Business operation
    - Industry
    - Agriculture
    - Transport infrastructure
    - Water, energy and telecom networks
- Environment
    - Impact on the environment

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- Indirect impacts
- Decree Catnat
- Waste management
- Rescue management
- Management of problems related to looting
- Social unrest episodes

- Population (municipal 2017 and department 2015)
- Population density (historical since 1876) 2016
- Ageing index 2016
- Share of over-occupied principal residences 2016
- Main empty rented HLMs 2016
- Number of hotels 2020

- Number of active companies at 31/12 2015
- No. of companies 2018
- No. of company creations 2018
- Share of public administration, education, health and social work posts in active states as of 31/12 2015
- Share of agriculture, forestry and fisheries posts in the active population as of 31/12/2015
- Share of construction jobs in active companies at 31/12 2015
- Share of trade, transport and market services in active states as of 31/12 2015
- Share of trade, transport, accommodation and catering in the creations of companies. 2018
- Part construction in the creations of ent. 2018
- Industry share in the creation of ent. 2018

Concerning the implementation of regulatory prevention measures. The website of the Ministry of the Environment provides access to the state of progress of the implementation of preventive measures at the national level. Thanks to Cypres and the significant work it has done at the regional level, we have been able to update this information.

9.1.2. Some considerations about the column (criteria) to be selected for further analysis

In order to make comparisons between municipalities, it must be possible to relate the observed expenses to elements taken into account for these costs.

It is obvious that, given the fairly complex divisions, it will be difficult to have completely pure accessible criteria. We are obliged to use simplified criteria, which are therefore not completely accurate. But that is always better than doing nothing.

For the Cat'Nat part, it seems preferable to give priority to non-automotive elements.

On the one hand, because we will never know precisely the share of insured vehicles in damages and on the other hand because the load on the vehicles remains marginal (10%).

If we focus on the Cat'Nat damage load, we have several criteria for establishing ratios.

The population (therefore average cost per inhabitant) is simple.

The number of dwellings is more complicated. Of course to do this properly, we would need to know the number of damaged risks and compare it to the number of insured risks. Knowing that not all risks have the same exposure. If it is possible to know the property of a municipality, the number of dwellings should be known. If one wants to get closer to the number of insured policies, one should count the dwellings and not the buildings.

In reality, this appreciation is more complicated. Because the exposure is not the same for an apartment on the 4th floor and a detached house. But the apartment may have a cellar or a parking space (insured by the co-ownership). It will never be possible to integrate all these subtleties, unless you incur totally disproportionate search costs.

Similarly, for properties, it would be useful to distinguish between the types of property. Businesses are generally on the ground floor. Not all apartments.

Another criterion for comparison would be to locate claims in relation to flood zones. Difficult to do without the detailed data. However, some past studies done in 2012 shows that only 1/3 of the "flood" claims were in flood risk zones. That is revealing.

Administrative damages. Some interrogations remains. Do these amounts only concern the "non-Cat'Nat" part, or is the Cat'Nat part included? Depending on the result, it's not the same message we're carrying. There are no clear answer on this part.

PPRIs and other administrative issues. Due to the diversity of declarations, some precautions should be taken with this information and how we use it. Indeed, do all these regulatory documents impose strictly the same things? What exactly do they contain? What are the concrete measures that are applied? How are they monitored? All administrative documents are the same, but are not followed similarly everywhere. In conclusion, while it is useful to present the existence of its measures in a factual manner, it is tricky to draw conclusions about their effectiveness.

9.2. From a database to “performance table”

In view of the available data, their reporting structure and their evolution over time, we considered it significant to carry out a multi-criteria decision support analysis in order to report, in view of the territorial vulnerability configurations, the damages following the flood and the elements describing the forms of economic and social rebound, the relative resilience of the communal territories.

In order to carry out the most detailed analysis, it would indeed be necessary to have a more consistent database.

In what follows, we describe the feasibility study applied to the database available to date. This can provide significant insights into disaster risk management and territorial resilience.

In order to move from a database to a use for decision support, it is necessary to transform our database into a performance table. This table contains online the entities to be compared (the communes) and the criteria for comparison. Appendix B presents this table.

The set of criteria to compare 68 impacted communities are the following in Table 9.1:

Preventive meausres	Prescription of DICRIM (Municipal Information Package on Major Risks)

	Prescription of PPRI (Flooding Risk Prevention Plan)
Losses	Number of Death
	Insurance - Market cost (Provided by CCR)
	Cost for Individuals (Provided by CCR)
	Cost for Professionals (Provided by CCR)
	Communal level of completeness for the flooding (Provided by CCR)
	Decree catnat (severity of losses)
Vulnerability - Category 1	Population (municipal 2017 and department 2015)
	Population density (historical since 1876) 2016
	Ageing index 2016
	Share of over-occupied principal residences 2016
	Main empty rented HLMs 2016
Resilience just after the disaster	Number of active companies as of 12/31/2015
	Share of public administration, education, health and social work posts in active states as of 31/12 2015
	Share of agriculture, forestry and fishing in the active population as of 31/12 2015
	Share of construction items in active companies at 31/12 2015
	Share of trade, transport and market services items in active states at 31/12 2015
Resilience after 2015	Share of trade, transport, accommodation, and catering in the creations of companies. 2018
	Part construction in the creations of ent. 2018
	Industry share in the creation of ent. 2018
	No. of companies 2018
	No. of new companies 2018
	Number of hotels 2020
	Number of time that catnat mechanism that was declared (CCR)-2018
Intensity	Average loss frequency (From 1995 to 2015)

Table 9.1 Criteria that were used to describe the performance table of the municipalities.

The performance table is recoded to prepare the comparative analysis between the 68 communities. This coding is present in Annex C. The purpose of coding is to:

- define ordinal scales for qualitative data;
- characterize scales for quantitative data;
- define the meaning of the criteria scales (ascending or descending);
- specify the uncertainty thresholds to be taken into account;
- specify the weights of the criteria.

In view of the heterogeneity of the data, the uncertainty and the way in which they are reported, we opted for a multi-criteria aggregation procedure such as outranking. These aggregation approaches are known as semi-compensatory.

9.2.1 Multi-criteria decision analysis and aid method to compare the municipalities in term of resilience to disaster

Cost-benefit approaches are one of the multi-criteria approaches to decision analysis and aid. These approaches are based, in their most traditional versions, on aggregation procedures called " Single Criterion Synthesis " type procedures (Merad, 2010, 2013). These approaches are known as compensatory approaches. Several initiatives to apply these approaches have been undertaken in France (Torterotot, 1993). For the most part, they have been based on damage projections and prevention investment projections. This can be understood in light of the incompleteness of the databases and their current structure.

For this reason, we have opted for other multi-criteria and multi-actor approaches. The main conclusions of the MCDA method (*see* Merad, 2010, 2019) to sort the resilience of the municipalities are presented in the two following tables (Table 9.2 and Table 9.3).

Municipalities were compared one to another criterion by criterion, ranked and sorted in four classes were they represent respectively:

- Total: the class 1 (communities that are the more resilient considering their losses, their vulnerabilities and their resiliencies), … the class 4 (communities that are the less resilient considering their losses, their vulnerabilities and their resiliencies),
- Preventive measure: the class 1 (communities that are the more responsible in term of preventive measures in place), … the class 4 (communities that are the less responsible in term of preventive measures in place).
- Preventive measure: the class 1 (communities that are the more responsible in term of preventive measures in place), …, the class 4 (communities that are the less responsible in term of preventive measures in place).
- Losses: the class 1 (communities that have the less losses), …, the class 4 (communities that have the more losses).
- Vulnerability: the class 1 (communities that are the less vulnerable), …, the class 4 (communities that are the less vulnerable).
- Resiliencies in 2015 and after: the class 1 (communities that are the more resiliente), …, the class 4 (that are the less resilient).

					Final Sorting					
INSEE	**Department**	**INSEE**		**Average loss frequency (From 1995 to 2015)**	**Total**	**Preventive measure**	**Losses**	**Vulnerability**	**Resilience - End 2015**	**Resilience - End 2018**
06	Alpes-Maritimes	**06004**	**Antibes**	3	4	1	4	4	3	3
06	Alpes-Maritimes	**06018**	**Biot**	5	3	1	4	2	4	3
06	Alpes-Maritimes	**06029**	**Cannes**	4	4	2	4	4	4	3
06	Alpes-Maritimes	**06079**	**Mandelieu-La-Napoule**	5	4	2	4	4	1	3
06	Alpes-Maritimes	**06161**	**Villeneuve Loubet**	4	4	2	3	3	4	3
06	Alpes-Maritimes	**06088**	**Nice**	2	4	2	3	4	4	2
06	Alpes-Maritimes	**06059**	**Eze**	0	4	3	2	3	1	4
83	Var	**83004**	**Les Arcs**	5	2	2	2	2	2	2
06	Alpes-Maritimes	**06027**	**Cagnes**	3	3	3	3	4	3	3
06	Alpes-Maritimes	**06155**	**Vallauris**	4	2	1	2	4	3	2
06	Alpes-Maritimes	**06030**	**Cannet(Le)**	0	3	2	3	4	3	2
06	Alpes-Maritimes	**06085**	**Mougins**	4	3	1	2	3	3	3
06	Alpes-Maritimes	**06105**	**Roquefort-les-Pins**	4	3	2	3	2	2	4
06	Alpes-Maritimes	**06108**	**Roquette-sur-Siagne (La)**	4	3	2	4	3	1	1
06	Alpes-Maritimes	**06138**	**Théoule-sur-Mer**	3	3	3	2	3	4	3
06	Alpes-Maritimes	**06152**	**Valbonne**	3	3	2	4	1	4	2
06	Alpes-Maritimes	**06038**	**Châteauneuf-Grasse**	4	4	3	4	3	1	4
06	Alpes-Maritimes	**06044**	**Colle-sur-Loup (La)**	4	4	4	4	3	2	3
06	Alpes-Maritimes	**06065**	**Gaude (La)**	3	3	3	4	2	2	3
06	Alpes-Maritimes	**06069**	**Grasse**	3	3	2	3	3	4	2
06	Alpes-Maritimes	**06084**	**Mouans-Sartoux**	3	4	2	4	4	3	3
06	Alpes-Maritimes	**06089**	**Opio**	5	4	3	4	2	4	4
06	Alpes-Maritimes	**06090**	**Pégomas**	5	3	2	4	3	2	4
06	Alpes-Maritimes	**06095**	**Peymeinade**	3	2	1	3	3	2	1
06	Alpes-Maritimes	**06123**	**Saint-Laurent-du-Var**	2	4	2	4	4	2	4
06	Alpes-Maritimes	**06128**	**Saint-Paul-de-Vence**	5	3	1	3	3	1	3
06	Alpes-Maritimes	**06148**	**Tourrettes-sur-Loup**	3	3	2	3	3	2	4
06	Alpes-Maritimes	**06149**	**Trinité (La).**	3	3	2	3	3	2	3
06	Alpes-Maritimes	**06157**	**Vence**	2	3	2	4	4	3	2
83	Var	**83061**	**Fréjus**	4	2	2	4	4	1	1
06	Alpes-Maritimes	**06112**	**Le Rouret**	4	3	3	3	2	1	3
83	Var	**83085**	**La Motte**	0	2	1	3	2	1	3
83	Var	**83141**	**Trans-en-Provence**	5	2	2	3	2	3	1
83	Var	**83023**	**Brignoles**	3	2	2	2	2	2	1
83	Var	**83118**	**Saint-Raphaël**	4	3	2	3	4	3	2
83	Var	**83099**	**Puget-sur-Argens**	5	2	1	3	3	3	1
13	Bouches-du-Rhônes	**13105**	**Sénas**	1	1	2	2	1	2	2
83	Var	**83001**	**Les Adrets-de-l'Estérel**	3	2	2	2	2	2	3
13	Bouches-du-Rhônes	**13035**	**Eyguières**	3	2	1	2	1	2	3
06	Alpes-Maritimes	**06159**	**Villefranche-sur-Mer**	3	3	2	2	4	4	3
06	Alpes-Maritimes	**06121**	**Saint-Jean-Cap-Ferrat**	3	3	2	2	4	2	4
13	Bouches-du-Rhônes	**13053**	**Mallemort**	5	2	2	3	1	2	3
84	Vaucluse	**84038**	**Cheval-Blanc**	3	2	3	3	2	2	2
83	Var	**83058**	**Flayosc**	5	1	2	3	2	1	2
83	Var	**83059**	**Forcalqueiret**	1	1	2	1	2	1	2
84	Vaucluse	**84088**	**Pernes-les-Fontaines**	1	1	3	1	2	1	1
83	Var	**83136**	**Le Thoronet**	4	1	2	2	1	1	1
83	Var	**83057**	**Flassans-sur-Issole**	3	1	2	3	1	2	2
84	Vaucluse	**84034**	**Caumont-sur-Durance**	3	1	1	1	2	1	2
83	Var	**83026**	**Cabasse**	3	1	2	2	1	1	2
83	Var	**83088**	**Néoules**	3	1	2	2	1	2	1
83	Var	**83028**	**Callas**	3	1	2	2	1	3	3
84	Vaucluse	**84073**	**Ménerbes**	2	1	3	1	1	1	3
83	Var	**83030**	**Camps-la-Source**	2	1	4	1	1	1	2
84	Vaucluse	**84099**	**Robion**	3	2	3	2	2	1	3
84	Vaucluse	**84080**	**Monteux**	4	1	3	2	1	4	1
84	Vaucluse	**84132**	**Le Thor**	2	1	2	1	1	1	1
83	Var	**83108**	**La Roquebrussanne**	3	1	1	2	1	2	2
84	Vaucluse	**84074**	**Mérindol**	1	1	3	1	2	2	4
84	Vaucluse	**84102**	**Roussillon**	1	1	3	2	1	1	3
83	Var	**83077**	**Méounes-lès-Montrieux**	3	2	2	3	1	2	2
83	Var	**83154**	**Saint-Antonin-du-Var**	2	1	3	1	1	4	2
06	Alpes-Maritimes	**06150**	**La Turbie**	3	2	2	1	3	4	4
84	Vaucluse	**84004**	**Aubignan**	3	1	3	2	2	1	3
84	Vaucluse	**84012**	**Beaumes-de-Venise**	3	2	3	2	2	1	3
84	Vaucluse	**84067**	**Loriol-du-Comtat**	4	1	4	2	1	1	3
84	Vaucluse	**84085**	**Murs**	0	1	1	1	1	2	4
84	Vaucluse	**84122**	**Sarrians**	4	1	3	1	2	2	2

Table 9.2. Contextual information about intervention at the departmental level following PACA flooding in October 2015

			Zone category	Number of time firefighters responded to floods (2015)	% of the total of intervention	Population (municipal 2017 and department 2015)
INSEE	Territorial coverage					
	Region	Alpes-de-Haute-Provence (04) , Var (83)				
BMPM	Department	Bouches-du-Rhône	ras	100	0,09	1 145 698
4	Department	Alpes-de-Haute-Provence	4	25	0,19	166 014
5	Department	Hautes-Alpes	5	166	1,54	143 962
6	Department	Alpes-Maritimes	1	2 094	1,76	1 097 701
13	Department	Bouches-du-Rhône	1	323	0,25	1 145 698
83	Department	Var	1	53	0,05	1 030 355
84	Department	Vaucluse	2	483	0,96	558 861

Table 9.3 Contextual information about intervention at the departmental level following PACA flooding in October 2015

The following maps show the conclusions of our MCDA analysis (from Figure 9.2 to Figure 9.9).

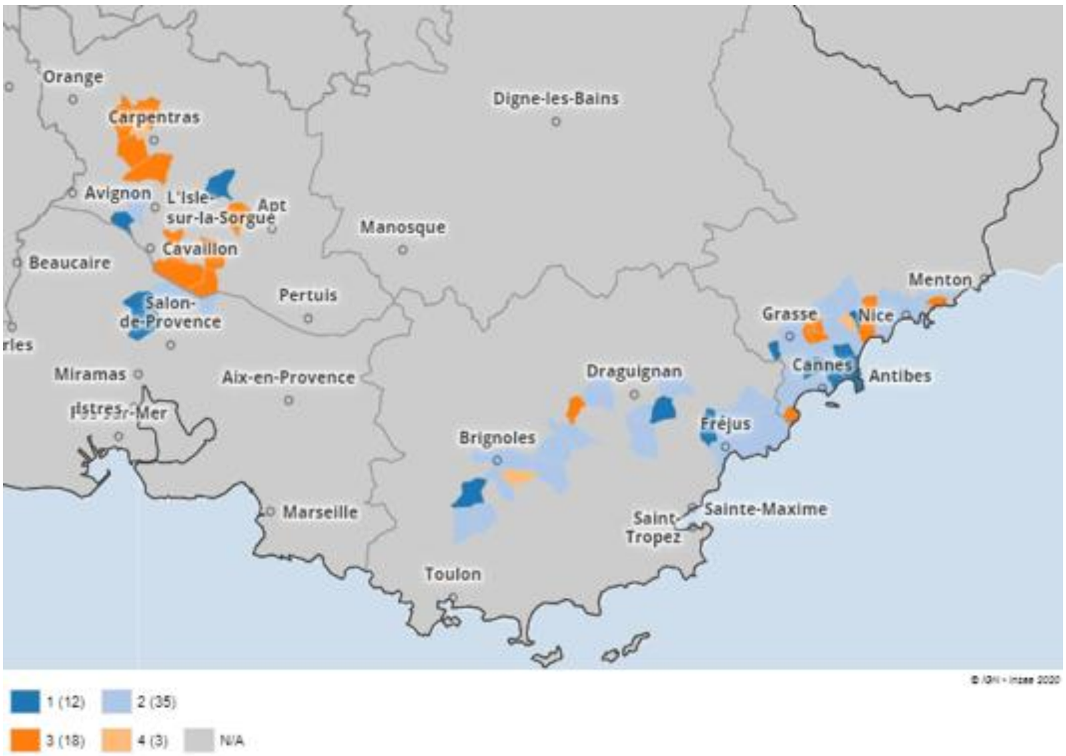

Figure 9.2 Preventive measures map following MCDA analysis

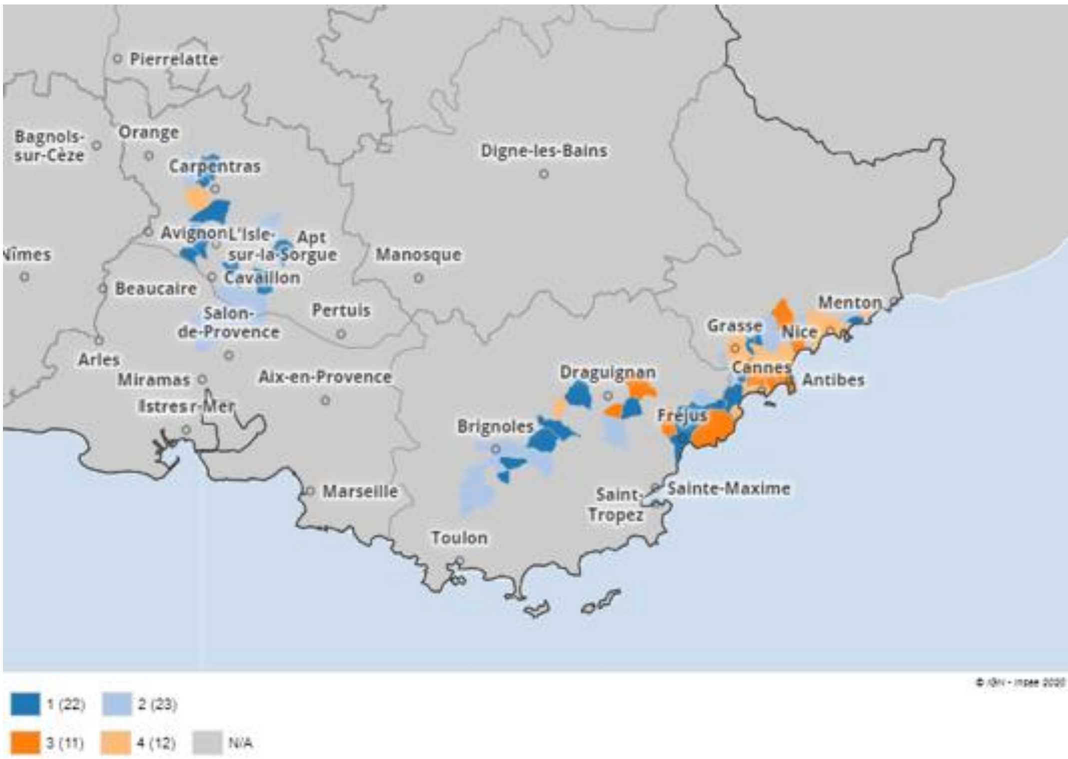

Figure 9.3 Resilience – End 2015 map following MCDA analysis

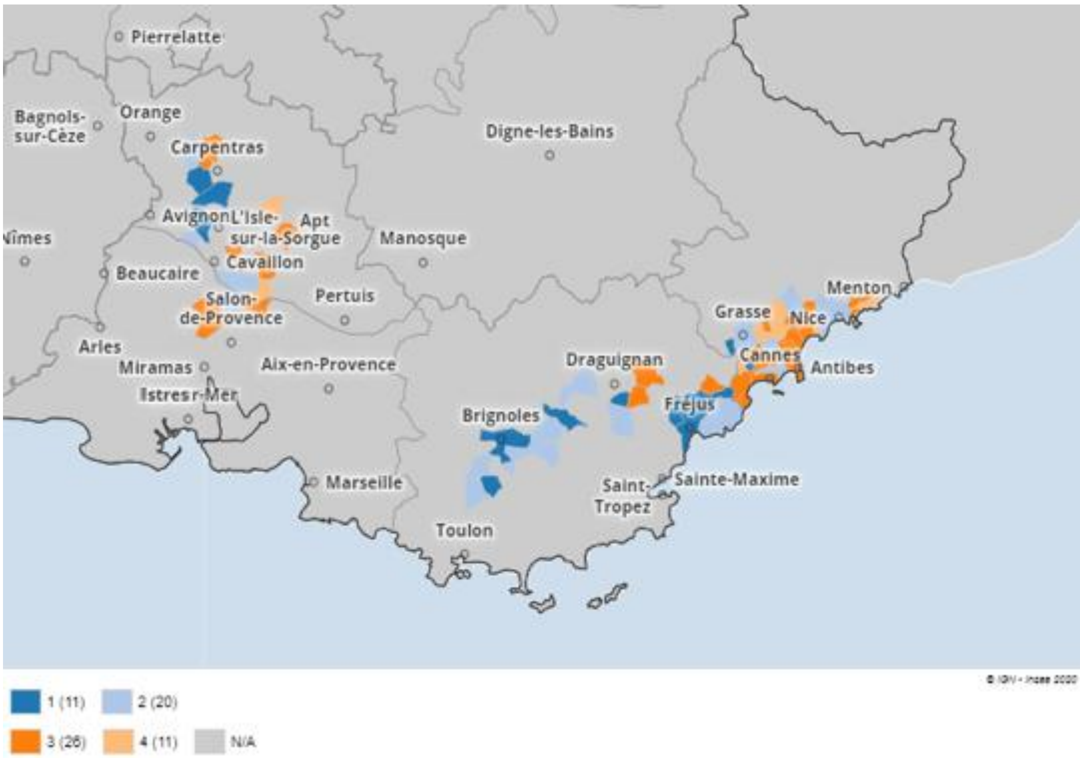

Figure 9.4 Resilience – End of 2018 map following MCDA analysis

Figure 9.5 Total resilience considering all the set of criteria used in in MCDA analysis

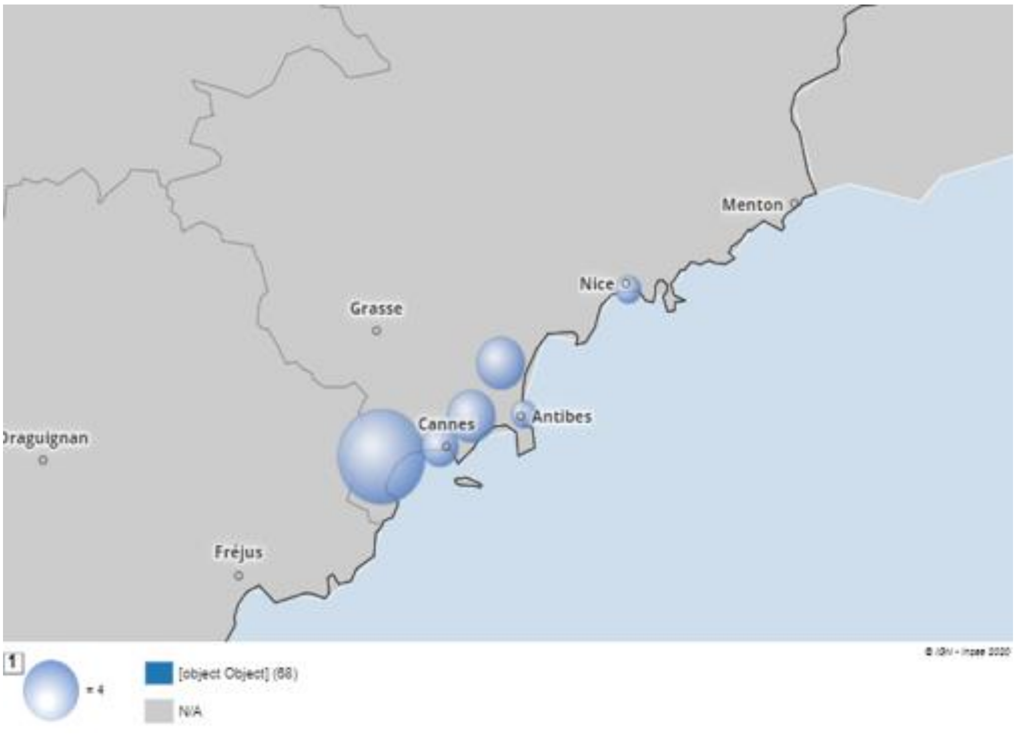

Figure 9.6 Number of death declared following the flooding

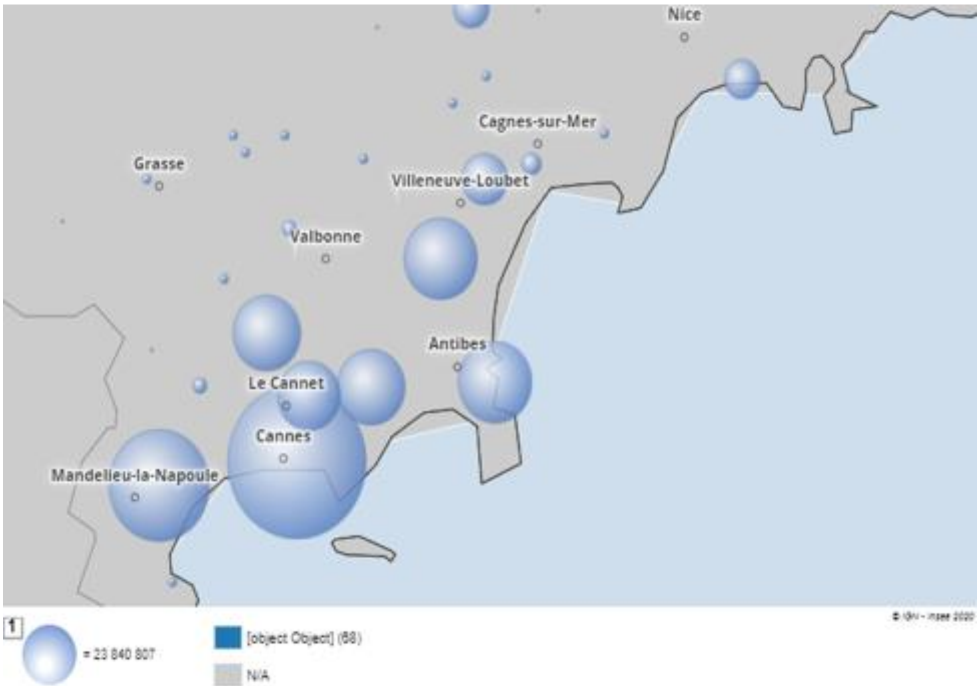

Figure 9.7 Insurance market cost based on CCR shared data

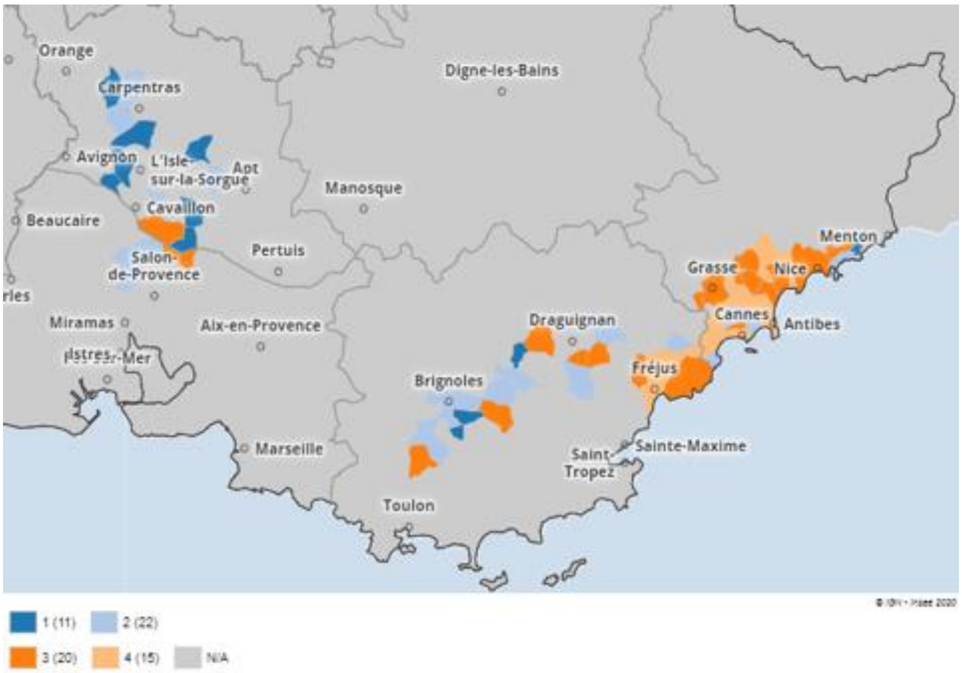

Figure 9.8 Losses map following MCDA analysis

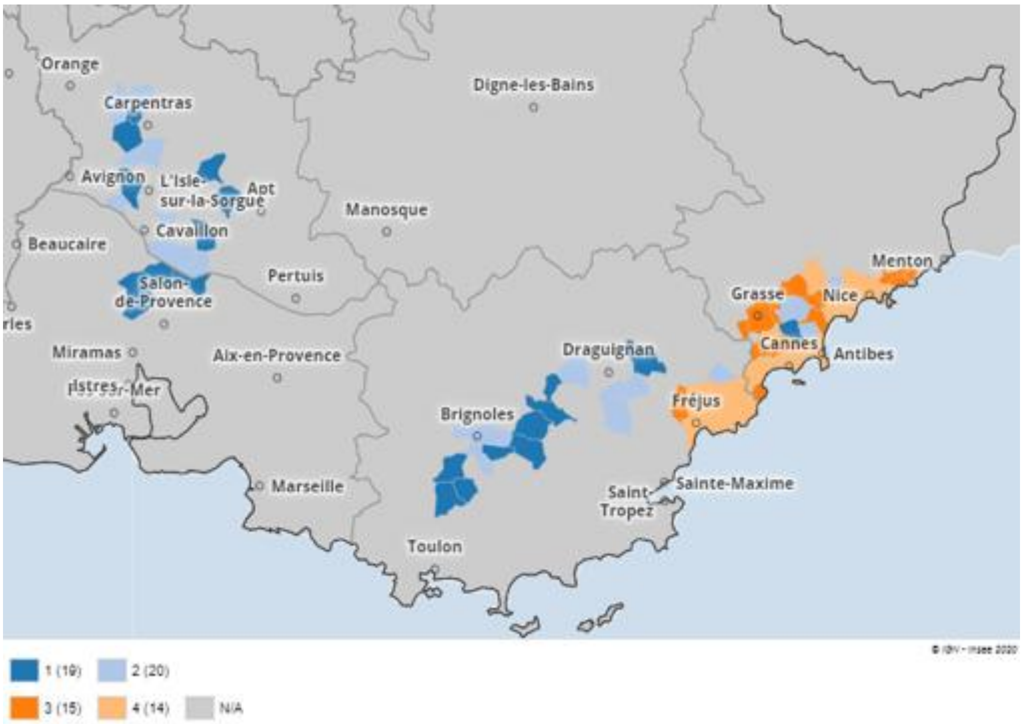

Figure 9.9 Vulnerability map following MCDA analysis

9.2.2. Additional considerations

The structuring and exploitation of databases, which the LODE project proposes to investigate and prove the feasibility of the concept, are central aspects to be taken into account for the improvement of both disaster risk prevention policies and the improvement of concepts, models, methods and tools for risk analysis and management. This will accompany the transition from "model-based" to "data-driven" risk analysis and management and governance.

In this report, we have investigated and explored the feasibility of exploiting the case of floods in the PACA region in October 2015. A multi-criteria flood decision support method was proposed and applied to the available data. This method makes it possible to establish a relative comparison of the communes impacted by the disaster by classifying them into 4 classes ranging from those that are the most resilient (class 1) to those that are at least resilient (class 4).

However, our research invites us to make the following reservations. First of all, it will be necessary to consider that more data is a chimerical quest where an illusion of precision and completeness of the database can hide from various practices such as data smoothing on "model-base". Secondly, the relationship of States and sectors of activity to confidentiality for various reasons affects the meaning of the data declared. Thus, what is declared is very often of no consequence. Thirdly and finally, although there is a need to increase the structuring of databases with quantitative data, it should be borne in mind that the quantitative can provide description where the qualitative provides more information on the organizational, social and cultural conditions of disaster risk management.

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10. THE SECCHIA FLOOD, ITALY 2014 SHOWCASE: USING POST DISASTER DAMAGE DATA TO FEED MACHINE LEARNING TECHNIQUES

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10.1 Introducing to machine learning techniques

Extreme weather events, from river flooding to droughts and tropical cyclones, pose a significant threat to communities across the world, in terms of economic losses to production and damages to physical assets, as well as wider societal losses to people and the environment (UNFCCC, 2020). The risks presented by these events are likely to become both more severe and more common in the coming years, as a result of climate change and anthropic over-exploitation of natural resources, further worsening the potential impacts (IPCC, 2018).

In the face of this rising threat, to reduce damages, policy- and decision-makers require new integrated approaches and tools to support risk management and climate adaptation pathways, particularly to understand the nuances of damages across different sectors and under multiple possible future scenarios. In terms of flood damage, sophisticated models are being introduced that can draw from expert knowledge, increased variable input, and more powerful computational methods, including those exploiting functionalities offered by Machine Learning (ML) (Amadio et al., 2016; Jongman et al., 2012; Thieken et al., 2009; Wing et al., 2020). Among these, upcoming Bayesian Network (BN) approaches (Schröter et al., 2014; Wagenaar et al., 2019, Paprotny et al., 2020), represent useful methods able to provide predictive hazard and impact assessment capabilities based on real-world training datasets.

BN are statistical approaches built in the form of qualitative structures, known as directed acyclic graphs, representing the variables of concern as nodes on the graph, with arcs to characterize the probabilistic dependencies among variables at stake in the system. Parameterization of the network then encodes marginal and conditional probabilities of the variables (Furlan et al., 2020; Sperotto et al., 2017).

BN have been noted for their ability to integrate heterogeneous data sources, that may include some inputs based on quantitative data, but also some that are classified qualitatively using expert judgement or by incorporating stakeholders' perspectives (Li et al., 2016; Sperotto et al., 2017). These methods can be designed to tackle complex environmental issues featured by non-linear behavior and hampered by large uncertainties (Sperotto et al., 2017). This flexibility also allows for the modelling of multi-faceted aspects related to hazard, exposure and vulnerability patterns, giving a more complete picture of disaster risk and damages compared to depth-damage models (Schröter et al., 2014). Overall, BN models show a notable added value in flood damage modelling, regularly outperforming both traditional models and other ML-based approaches (e.g., Random Forest). This has been applied in the majority of cases for prediction of residential damages (Schröter et al., 2014; Wagenaar et al., 2017), trained either on a local scale or to multiple case studies for checking BN performance in a transfer setting (Sairam et al., 2019; Wagenaar et al., 2018). Where others have focused solely on the residential sector, Paprotny et al. (2020) introduced a new flood damage model for the commercial sector, this representing the first of its kind in the field. However, the evaluation of the overall multi-sectoral damages within any case study still remains unclear, with minimal efforts devoted to a wider sectoral analysis that could, for instance, incorporate infrastructure, agricultural or industrial concerns as assessment endpoints.

Furthermore, where scenario analysis has been conducted, it was limited to a retrospective investigation into one of the factors that influence the experienced flood damages, such as mitigation options or early warning systems (Balbi et al., 2016; Notaro et al., 2014), and as such these models have not been used for the projection of future changes in damages.

Accordingly, this work aims to build on the state-of-the-art research in the field of ML, through the design and application of an advanced GIS-based BN approach able to capture and model multi-sectoral damages against multiple '*what-if*' scenarios, exploiting damage data collected against the 2014 Secchia river flooding event, as training dataset of the BN model.

The construction of a BN model follows a stepwise progression (Deparday et al., 2019; Furlan et al., 2020; Sperotto et al., 2017), from model conceptualization to parametrization and validation, followed by the use of the designed model for scenario and sensitivity analysis. The specific details of these developmental steps are presented in the following sections, detailing the methodological approach underpinning the BN development for the case study of concern.

10.2 The proposed methodology

10.2.1. Model design and configuration testing

The practical implementation of the BN requires a multi-stage approach, beginning with the design of the BN model and the subsequent parametrization of the variables at stake in the network. The characterization of a conceptual framework is an important step in the formalization of the issue being studied (Furlan et al., 2020). As such, a conceptual framework is built, systematically identifying pathways of interaction between environmental, physical and socio-economic damages for the exposed sectors, and the drivers of those damages. Specifically, a properly constructed conceptual framework should give a comprehensive schematic representation of the cause and effect relationships within the system, encompassing all necessary sources of data, as well as their relative interactions (Defra, 2011). With the identification of these cause-effect relationships between the system variables, a 'roadmap' is laid for the training of the BN model from the observed data (Sperotto et al., 2017).

Building on the IPCC risk framework, BN variables have been selected and classified in terms of hazard, exposure and vulnerability, through expert judgment and literature review (Merz et al., 2010; Paprotny et al., 2020), according to their potential influence on the overall flooding risk. This causal relationship has been depicted in Figure 10.1 with a box-and-arrow diagram that represents the relevant influential relationships; this graphical depiction can be used to define the BN model, incorporating all the identified variables. The boxes of the diagram correspond to the BN nodes that in turn represent the system variables, with unidirectional arrows between the boxes depicting the arcs that determine the causal relationships between variables in the model (Sperotto et al., 2019).

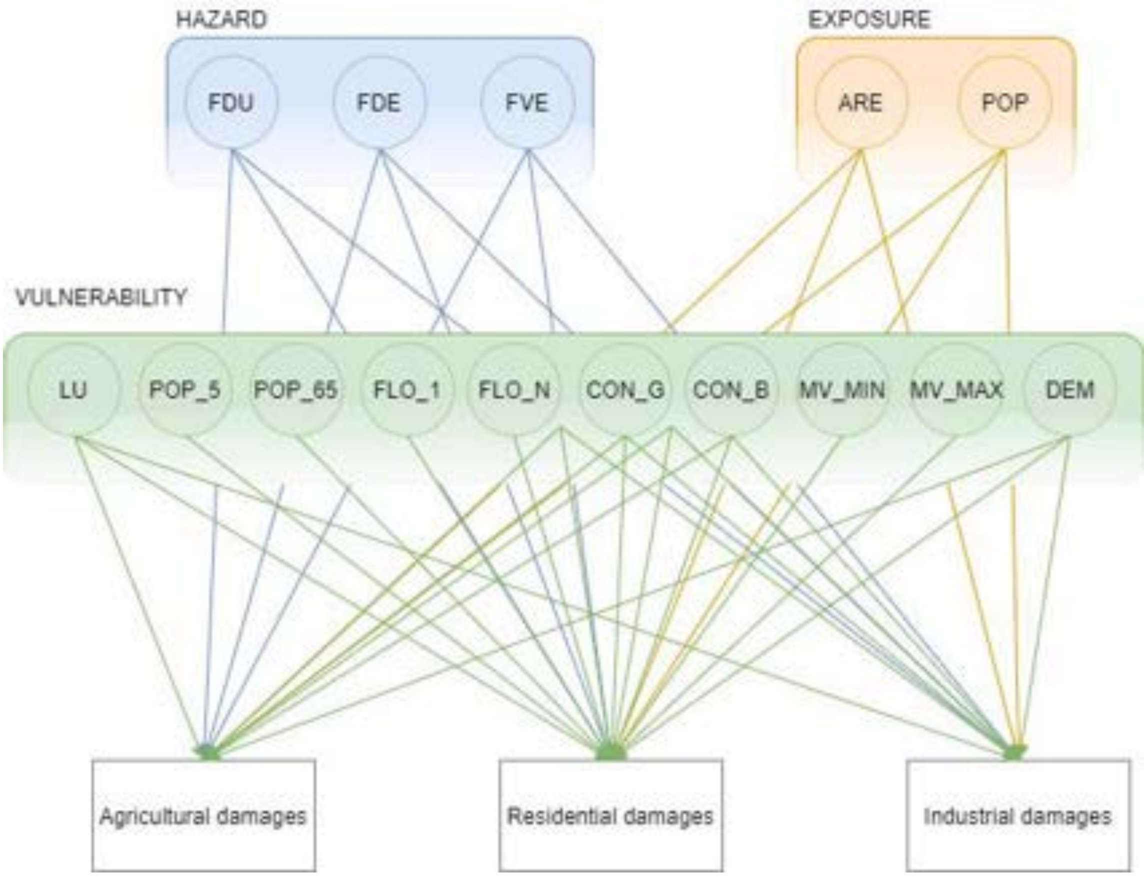


Figure 10.1 Risk-based BN Conceptual Framework. List of acronyms used for ***hazard variables****: FDU: Flood duration; FDE: Maximum flood depth; FVE: Maximum flood velocity;* ***Exposure variables****: ARE: Area of reported damage; POP: Population density;* ***Vulnerability variables****: LU: Land Use Cover; POP_5: Population under 5; POP_65: Population over 65; FLO_1: Number of houses with 1 story; FLO_N: Number of houses with greater than 1 story; CON_G: Number of houses with good conservation status; CON_B: Number of houses with bad conservation status; MV_MIN: Minimum residential market value; MV_MAX: Maximum residential market value; DEM: Digital Elevation Model*

An alternative approach to understanding the optimal model performance is by analyzing various configurations of the network, as defined through expert judgement and pertinent literature (Poelhekke et al., 2016). By setting these different configurations and observing the respective model outputs (also in terms of model prediction performance), it is possible to identify which models perform best in comparison to one another.

Within this study a two-tiered approach was developed to define and test different BN model configurations. Specifically, the first stage involves starting with a simple model that initially only integrates the core variables for training (e.g. the hazard-related characteristic linked to the Secchia river 2014 flood event), and then performing a stepwise integration of further variables one by one; in this way, it is possible to track improvements in performance of the model over time. This would be particularly useful in the case of a model constrained by limitations in the input data, where the introduction of too many variables may provide too many boundary conditions and restrict the performance of the model (Poelhekke et al., 2016). The second stage looks at reconfiguring the model (to improve its performance) by identifying, through expert judgment, new possible connections between the explanatory (parent) nodes and related child nodes, thus incorporating new layers of hierarchy within the BN structure.

Following the testing of the multiple BN configurations, for the training of the model, all the variables must each be assigned a state in the form of either a value or a condition. Specifically, these variable states can be defined in three different ways, namely i) into qualitative categories such as high, moderate or low quality, ii) as true or false states (i.e. Boolean functions), or iii) quantitatively, as a range or in discrete intervals (De Santa Olalla et al., 2005). After this input definition is complete, two computations are necessary as part of the parametrization process (Sperotto et al., 2019). Firstly, this involves the calculation of the associated prior probability of each state of the node, i.e. the relative likelihood of each possible state without any other knowledge of the variable relationships, based on the distribution of the input data. Secondly, the conditional probabilities of any child nodes must be calculated as dependent on all possible combinations of the associated parent nodes (Sperotto et al., 2017). Finally, a Conditional Probability Table (CPT) is developed to display the relative strengths of the causal relationship between all connected variables.

10.2.2. Model validation

When the predicted probabilities of each variable and the strength of their relative relationship has been calculated, the next phase of the process is to thoroughly evaluate the output of the BN model, in order to fairly assess both the accuracy and the reliability of the results. This is important to understand the potential for use of the designed BN as a predictive model for new observations under scenario analysis (Furlan et al., 2020).

Validation of the various BN model configurations can take the form of a data-based evaluation, where errors in the model output are identified through the use of a statistical test, or in relation to a set of independent observational data. Alternatively, expert judgment can be utilized to form a qualitative evaluation of the results, or similarly through comparison

of the model outputs to those of similar models found in the literature, however this is generally performed when there is insufficient data for statistical testing (Kragt, 2009).
For the estimation of the model predictive error, possible techniques range from Re-substitution and Hold-out methods, to the more complicated Bootstrap and Bolstered options (Furlan et al., 2020). One such data-based method for evaluating the accuracy of the model is the k-fold cross validation (k-cv), where the data is split into k sets (or folds) of equal size and the model is trained on all but one of these folds, with the errors then calculated for the final set of observed data. This process is then repeated with all possible combinations of k-1 folds, and the average error of these different combinations is calculated to reflect the overall accuracy of the model (Yadav & Shukla, 2016).

10.2.3 Scenario Analysis

Once the BN model has been trained and validated it can be used for scenario analysis, in which various potential scenarios are studied in order to predict their respective impacts across the variables at stake in the network. The conditions of these scenarios are simulated by 'setting' different evidence for one or more nodes (variables) within the BN model, and then propagating that information through the system, thus inferring the behaviour of the variables in order to observe changes in the posterior probability resulting from each scenario (Sperotto et al., 2017).
In order to infer this information, the direction of propagation must first be determined. A downward propagation of probability is known as prognostic inference, where the values of one or more input (or parent) nodes are set, and the impact to the posterior probabilities of the respective child nodes is observed, usually as far as the endpoints of the BN. Opposingly, the probability of a child node can be set to a fixed value as a form of diagnostic inference, where the change in probability is propagated upwards through the model towards the parent nodes (McNaught & Zagorecki, 2009).
Within this study, for the analysis of future '*what-if*' scenarios, variables were identified to reflect possible future changes in flood risk. The specific simulation of these changes was defined by setting the values of the selected variables under the following scenarios:
Scenario 1, (SC_LU): Understanding the change in damages under changing land use patterns, as determined by comparison of the 2010 land cover training dataset from the JRC LUISA model (Lavalle, 2014), against the expected land cover changes up to 2050 from the same model projection. This involves classification of the land into three main categories, these being urban fabric, industry/commercial/services, and agriculture. Specifically, the aggregated changes mostly concern a loss of agricultural land, replaced by urban areas. There are also changes in some areas to and from industrial zoning within the case study area, however the overall share of industrial land remains roughly equal.
Scenario 2, (SC_FDE): Understanding the change in damages at different flood-related return periods. The flood depth data for the BN training was obtained from a high-resolution floods

model, based on an explicit shock–capturing finite volume method for the solution of the 2D shallow-water equations (Vacondio et al., 2016). Then, to model the scenario SC_FDE, we compared the distribution of flood depth of a flood event under a 200-year return period, versus a 10-year return period flood event, comparable to that which occurred in the Secchia river in January 2014 (Shustikova et al., 2020). This comparative analysis was used to find the changes in each of the flood-depth related classes; the relative changes then being used to set evidence for the scenario related to the flood depth.

10.2.4 Sensitivity Analysis

A sensitivity analysis could then be performed on the output of the BN model, to provide information on the sensitivity of the BN assessment endpoints (i.e. damages to the residential, agricultural, and industrial sectors), in relation to changes in their various explanatory nodes. Under this analysis, the stepwise modification of individual input parameters is used to observe changes in the damage assessment endpoint probabilities, and thus determine the impacts of each parameter on the output (Kragt, 2009; Pollino et al., 2007). As such, it would be possible to interpret the relative importance of the various input nodes in determining the highest class of flood damages (Furlan et al., 2020).

Specifically, in each iteration of the sensitivity analysis, the likelihood of the highest class of each variable was in turn assigned a 100% probability, and the changes in the probability distributions were observed for the different assessment endpoint nodes.

10.3. Model Design and configurations testing in the Secchia showcase

As described in Section 11.3.1, an initial risk-based conceptual framework was established that highlighted the cause-effect relationships between the various components of disaster risk (i.e. hazard, exposure, and vulnerability), and the resulting damages.

According to the data available, this framework was then translated into an expert-based BN conceptual model, as shown in figure 2, that provided the basis for the practical BN model implementation. This was composed of a multifaceted set of explanatory (parent) nodes representing the hazard, exposure, and vulnerability characteristics of the case study as collected, each connected to their related child nodes, i.e. the multi-sectoral damages.

In order to introduce the data into the model, variable states were defined, according to the characteristics of their values (i.e. continuous, discrete, or Boolean). Specifically, all continuous variables, e.g. structure area or flood depth, were classified into three intervals with similar data frequencies. Other qualitative variables were categorized by the intrinsic characteristics of the data, such as the land use cover into urban, agriculture, and infrastructure classes, and in these cases, states were assigned to each category instead. The endpoint nodes were also classified into three separate continuous classes, representing the magnitude of monetary damages to the agricultural, industrial, and residential sectors.

Limitations in the quantity of damage data for training would constrain the ability of the model to incorporate the full set of input variables. As such, building on the risk-based conceptual framework as shown in Figure 2, a two-tiered approach to the BN model configuration was conceptualized (as also discussed in section 3.1), allowing to exploit the available training data while also incorporating a range of the collected variables to inform the model as best as possible. Beginning with a limited number of explanatory nodes, more variables were integrated step-by-step into the model until the stage at which the model performance was notably restricted. Specifically, the first iteration of this new model under the first tier of model reconfiguration (hereafter CONF_1A) utilized only the hazard variables (i.e. maximum flood depth (FDE), velocity (FVE), and duration (FDU)) as explanatory metrics of multi-sectoral damages. The impacts of the input variables showed a reliable distribution of conditional probabilities for each sector-based endpoint for flooding damages. This was most successful for the residential sector (D_RES), followed by the industrial (D_IND) and then the agricultural sectors (D_AGR), reflecting the relative volume of available observational data.

One by one, more explanatory nodes were added to further iterations of the model, with the aim of improving the model performance, i.e. reducing the classification errors of the final assessment endpoints, and then terminating the process when no significant improvement was observed in the model's performance (as discussed in the next section 4.2). Firstly, land use cover (LU) was chosen (hereafter CONF_1B), which also allowed for the planned future scenario analysis. To introduce an indicator of potential exposure, the area of reported damages (ARE) was the next selected variable (CONF_1C). Several further iterations of the model were also tested, introducing other explanatory nodes e.g. the population density (CONF_1D). However, with the introduction of each new variable, the conditional probabilities of the utility nodes tends to flatten. This evolution was particularly pronounced for the agricultural sector, again due to the data-poor condition. Accordingly, the decision was made to limit the model to five explanatory nodes (CONF_1C) so as to sufficiently balance the assessment of different variables with the performance of the model. The results of the continuous iterations of CONF_1 of the BN model are shown in Figure 10.2.

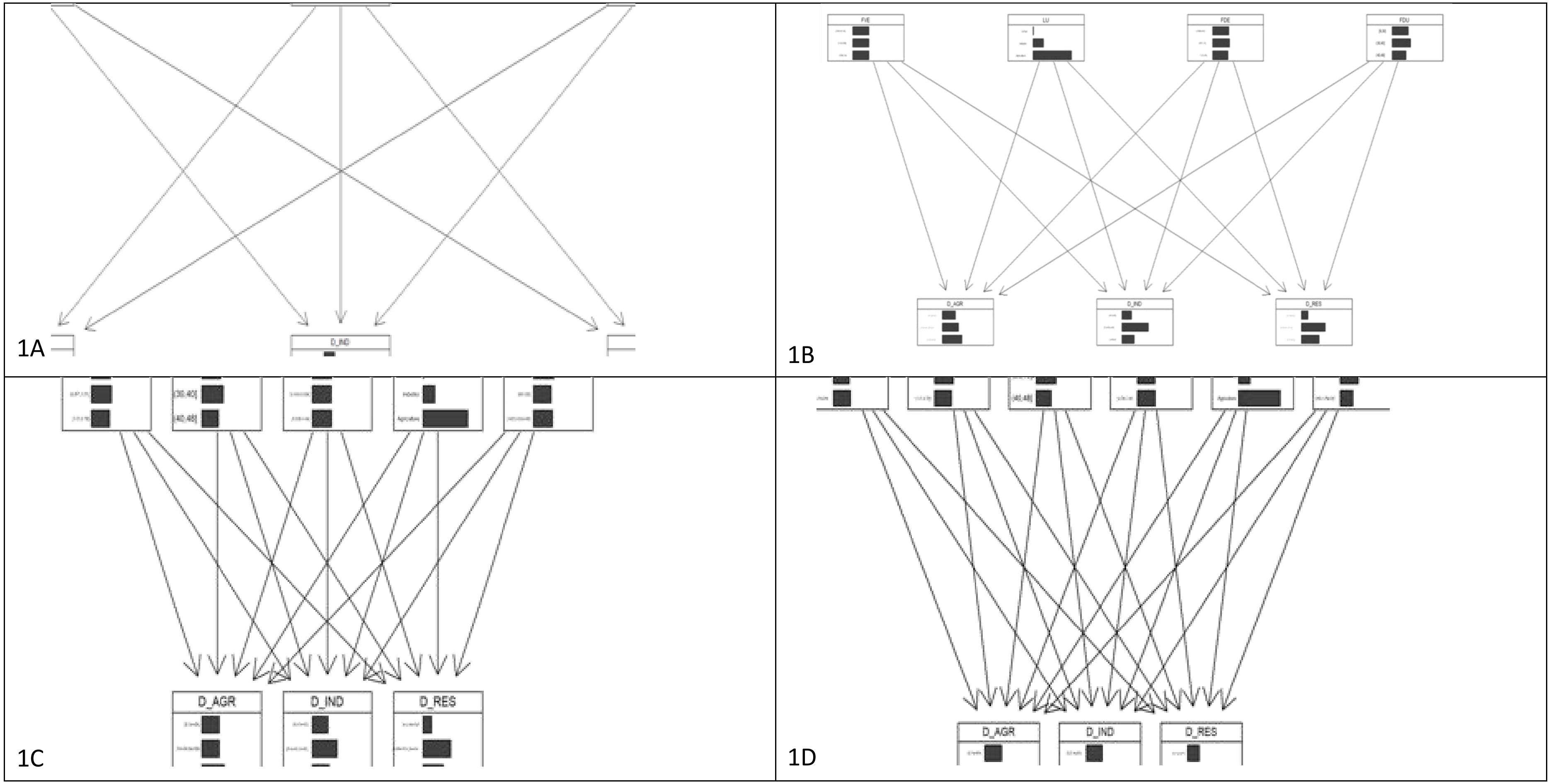


Figure 10.2 Outputs for the definition of the BN model from CONF_1A (top left) to CONF_1D. List of acronyms used for ***Explanatory nodes****: FDU: Flood duration; FDE: Maximum flood depth; FVE: Maximum flood velocity; ARE: Area of reported damage; POP: Population density; LU: Land Use Cover;* ***Damage nodes:*** *D_AGR: Agricultural; D_IND: Industrial; D_RES: Residential*

Then, the second tier of model configuration involved the investigation of the structure of the model, by rearranging the input nodes to form a new layer of hierarchy within the model (CONF_2). In this instance, it was decided to treat the variable concerning the area of reported damages as not only an exposure-related variable, but specifically to define it as a receptor of the flooding hazard. As such, instead of being connected directly to the endpoint nodes, the hazard variables (FDE, FDU, FVE) are first connected to the area node (ARE), which then leads to the multi-sectoral damages (as also developed in D Paprotny et al., 2020; Sayers et al., 2002). Figure 10.3 shows the new **CONF_2** as selected for analysis in the validation stage (Section 4.2).

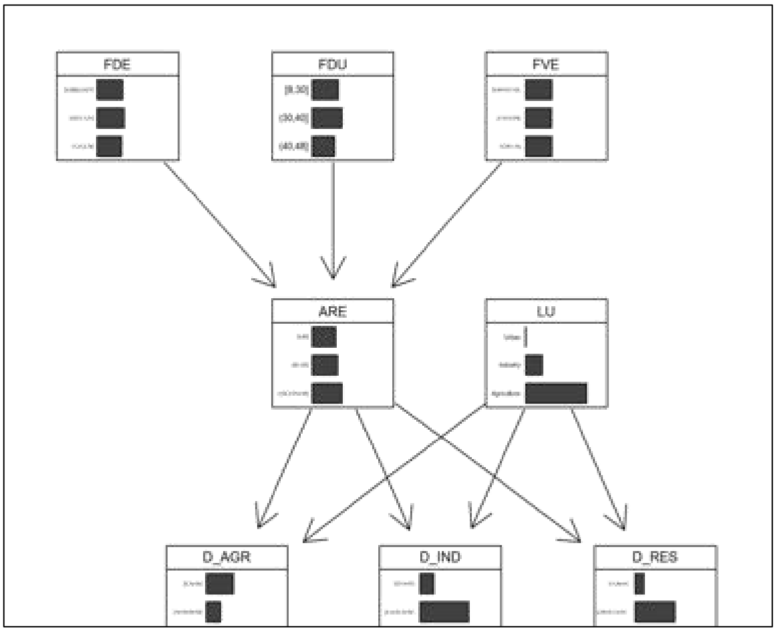


Figure 10.3 CONF_2 - BN model for multi-sectoral flooding damages assessment with associated variable marginal distributions

10.3.1. Model validation

Once the different configurations of the BN model were set, with the appropriate parametrization of the chosen variables, the models can be validated in order to give an estimation of their prediction error, and then the model with the highest performance in the estimation of multi-sectoral damages can be selected. As explained in Section 3.2, data-based validation was performed to determine the probability of observational data being misclassified in the three damage-related assessment endpoints. Specifically, the k-fold validation was applied for this analysis, and carried out through the *bn.cv* function in R with the "k-fold" method (Scutari, 2010). Due to the limited amount of observational data available for the agricultural sector, the number of folds used for the validation process was limited to five, with the results of this analysis for the most accurate model, **CONF_1C,** illustrated in Figure 10.4.

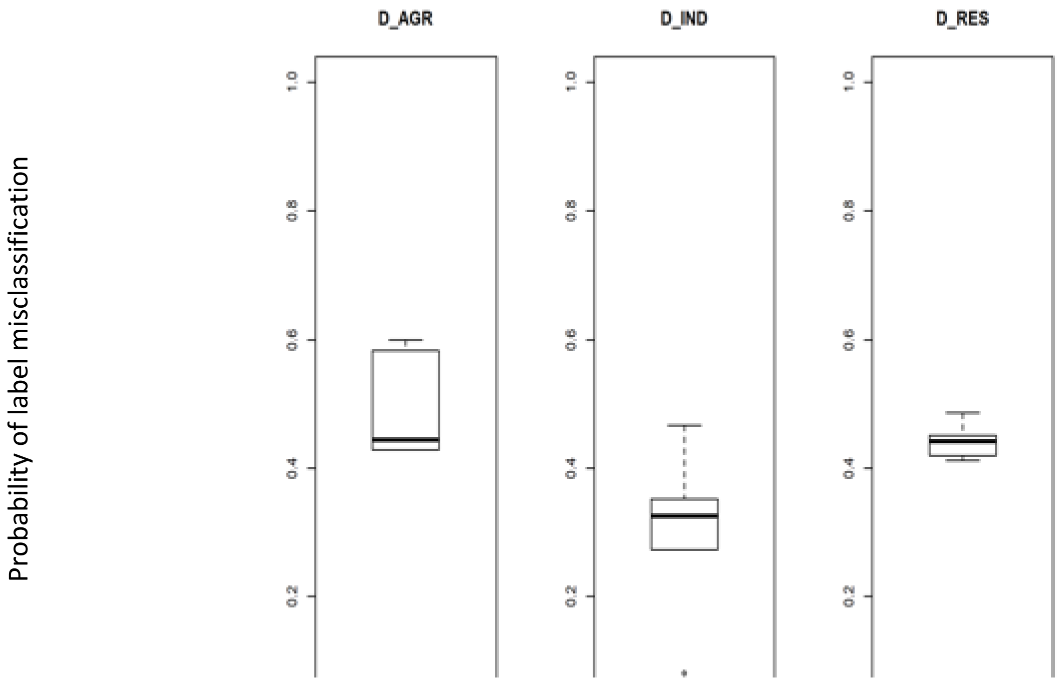


Figure 10.4 Boxplots representing the probability of damages misclassification for the i) agricultural (D_AGR), ii) industrial (D_IND), and iii) residential (D_RES) sectors under the CONF_1C of the BN model

The median classification errors were calculated as 45% for the agricultural sector, 34% for the industrial sector, and 44 % for the residential sector, showing a correctly classified output in the majority of cases. With increasing data points, the range of errors among folds narrowed, and with the most data available, error estimation showed the least uncertainty for the residential sector with less than 10% of variance.

The analysis was then repeated for **CONF_2** of the BN model in order to compare the respective predictive capability. For this new configuration the average performance of the model showed no significant improvement for any of the sectors in comparison to **CONF_1C**, and moreover the variance in the model output noticeably increased for the agricultural sector. As such, the decision was made to proceed with the **CONF_1C** as the final version of the BN model for 'what-if' scenario analysis.

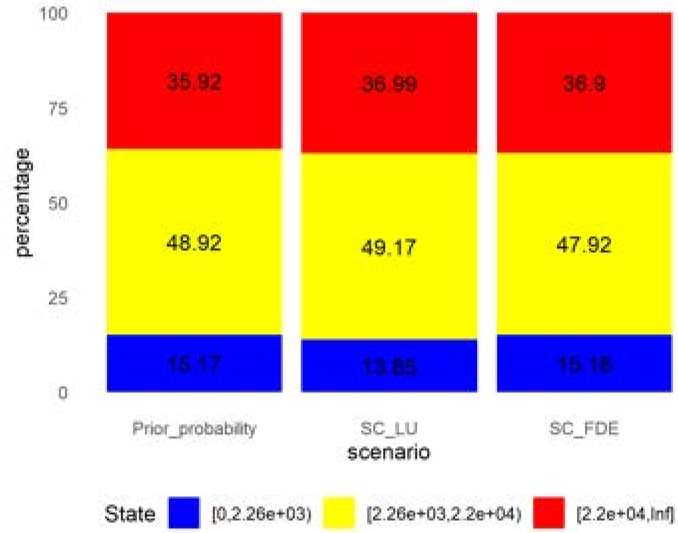
10.3.2. Scenario Analysis

After validation of the model, it was then possible to apply it for inferential purposes, including the analysis of two potential scenarios as described in Section 3.3. For each scenario, evidences were set based on the projected dataset for the variables of concern (i.e. land use/cover, flood depth, detailed in Table 1), and the changes were then propagated downward, with the output (posterior probabilities) recorded for comparison with the original conditional probabilities.

Particularly, for **Scenario 1** (SC_LU), the model was trained with the land use/cover data for the 2010 timeframe, and then compared to the 2050 scenario exploiting the JRC LUISA dataset (Lavalle, 2014). For **Scenario 2** (SC_FDE), the comparative changes in flood depth classes between the JRC LISFLOOD model 10-year and 200-year return period flooding event projections were used to build the future scenario. The impacts of these evidences were then propagated through the BN to each damage-related assessment endpoint as a form of prognostic inference.

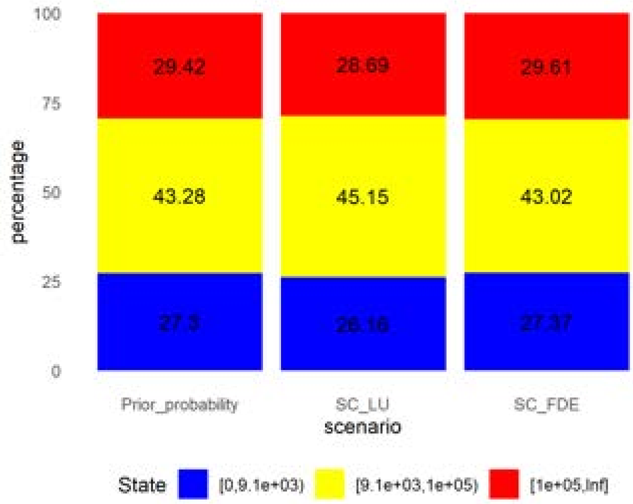
The resulting model outputs for the agricultural, industrial and residential sectors respectively are shown in Figure 11.5. Specifically, the coloured boxes represent the frequency of labels classed under the three classifications of monetary damage for the different scenarios, with the value of damages increasing from blue to red.

i)



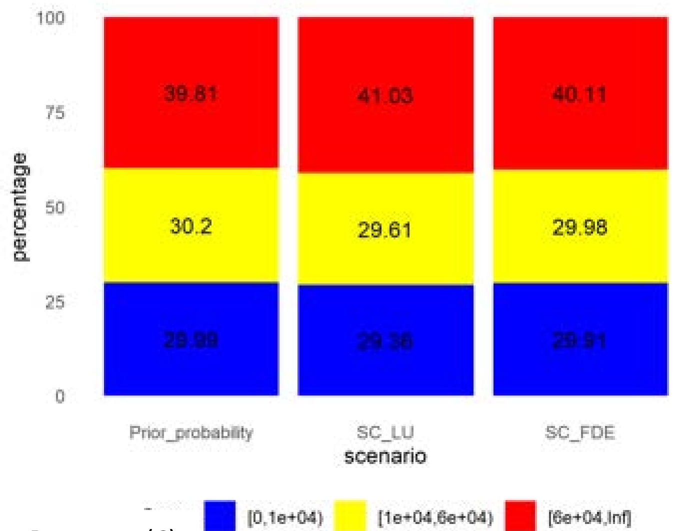
Damages (€)

ii)



Damages (€)

iii)



Damages (€)

Figure 10.5 Outputs of the BN model, comparing the prior probability of the BN model against the two simulated scenarios (SC_LU) and (SC_FDE), for the evaluation of potential damages in the i) agricultural, ii) industrial, and iii) residential sectors.

Scenario 1: Understanding the change in damages under changing land use patterns (SC_LU)
In this scenario, in comparison to the prior probability, there is a decrease in the probability of damages within the lowest class (indicated by the blue segments) for all sectors, with consequently a noticeable increase in the highest damage class for the agricultural and residential sectors (over €22,000 and €6,000 respectively). For these two sectors in particular, these results indicate that there is an expected increase in damages to be seen over the next few decades under the projected changes in the land use. The industrial sector does not conform to these patterns in the same way, mainly due to the very small potential changes in total industrial area in the case study of concern. However, while the results do show signs of changes in future damages, they are of limited magnitude; this is a result of the magnitude of change in the land cover over the 40-year period, where approximately 80% of the case study area does not change land use classification, of which the majority remains agricultural. Should there be a period of more intense development, it could be expected that the effect on flooding damages would be much more severe.

Scenario 2: Understanding the change in damages at different flood-related return periods (SC_FDE)
Similarly to the land use case, this scenario shows a limited but consistent increase in flooding damages across the multiple sectors, showing the expected impacts of more severe future river flooding events. While this effect is most pronounced for the agricultural sector, with more damages in the highest range over €22,000, the changes are smaller for the residential and industrial damages.
These limited changes are again likely a result of the input training dataset, where the flood depth does not increase too significantly between the 10-year and 200-year return periods. Specifically, there is an approximately 8% increase in the probability of the highest flood depth (specifically over 1.21m). Further, while the flood depth at different return periods has been projected, equivalent datasets for the other components of flooding hazard (i.e. duration and velocity) are not made available, limiting the scope of the analysis to solely considering the flooding depth. As such, while flooding depth is the key variable used within damage modelling and assessment, it is more difficult to capture changes in hazard characteristics, and thus the resulting effects in damages.

10.3.3 Sensitivity Analysis
As the last stage of the process, a sensitivity analysis was performed in order to provide information on the sensitivity of the assessment endpoints of the BN model (i.e. damages to the residential, agricultural, and industrial sectors), in relation to changes in their various explanatory nodes, based on the methodological approach detailed in Section 3.2.4. This was performed individually for each of the explanatory nodes in the model, by setting a 100% probability of their highest state (e.g. highest flood depth, largest area of reported damages),

while keeping all other nodes constant. In doing so, it is possible to see the relative impact of each variable in context with the other explanatory nodes.

The results of this analysis are shown in the rose charts reported in Figure 10.6, with the relative probability distributions of damage given for the simulation that changed each of the five explanatory nodes (FDU, FDE, FVE, LU, ARE), with the prior probability (PrP) shown for comparison. As with the scenario analysis, the red, yellow and blue sections represent the highest, moderate, and lowest class of damages respectively.

The results indicate that the importance of each variable in terms of contributing to the potential damages varies by sector. Specifically, changes in the posterior probability for damages compared to the prior probability indicate that for the agricultural and residential sectors, the damages are particularly sensitive to changes in the variables concerning the area of reported damages (ARE) and flood depth (FDE), in line with the results found in the corresponding key literature (Kreibich et al., 2009; Merz et al., 2010). The probability of an output in the highest damage classification increases significantly for these sectors with increasing area or flood depth, although similar results are not seen for the industrial sector. Instead these damages are more susceptible to land use changes, as well as flood duration and velocity, which may explain the particular response of the industrial sector to the identified future scenarios, relative to the agricultural and residential sectors.

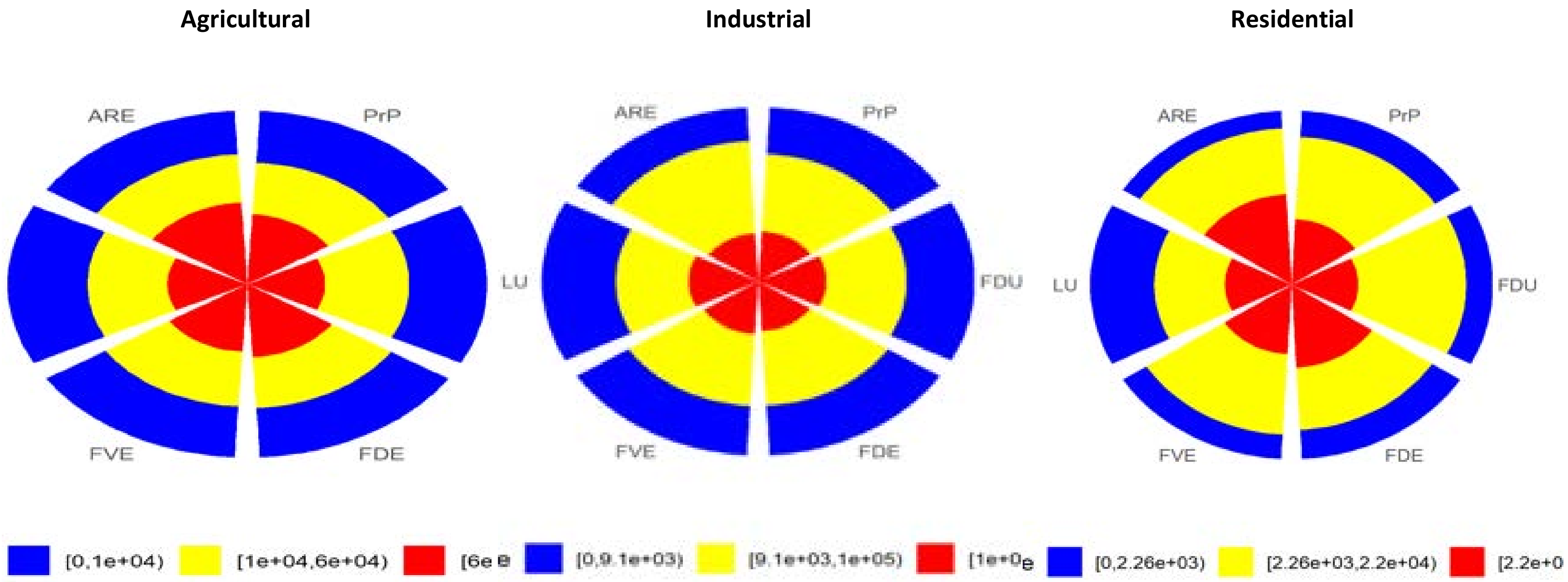


Figure 10.6 Sensitivity analysis for the explanatory nodes of the constructed BN model for the agricultural, industrial, and residential sectors respectively.

10.4. Final remarks on the potential of using post disaster damage data for advanced machine learning techniques

This work presented a GIS-based Bayesian Network (BN) approach capable of capturing and modelling multi-sectoral flooding damages, by exploiting damage data collected from the 2014 Secchia river flooding event and enhanced with hazard, vulnerability and exposure-related data for the case study area. With the aim of providing support for Disaster Risk Management and Reduction against extreme river flooding events, the developed BN-based methodology represents a novel approach for better understanding flooding damages for the agricultural, residential, and industrial sectors, and the prediction of future damages under possible changes in hazard and exposure patterns. Specifically, the methodology as presented offers a more complete picture on multi-sectoral damages by including not only residential damage prediction as an assessment endpoint, but also predictions for the industrial and agricultural sectors. Further, various approaches for the design and configuration of the BN model are deeply explored, alongside a sensitivity analysis, providing greater insight into the optimal design of BN models for multi-sectoral damage assessment. The final model, as constructed, showed promising capability for damage projection for all three sectors investigated within the case study and under two different scenarios. It also provides an analysis of two '*what-if*' scenarios for the examination of potential future damages scenarios, envisioning on one side land use/cover change in the case study area, and on the other greater flood depths resulting from more severe river flood events, and this analysis also showed the potential capacity of the BN model to better understand possible future damages. Moreover, the stepwise model configuration provided insight on how to optimize these results through both expert- and data-driven procedures, while the sensitivity analysis highlighted the relative value of the integration in the BN model of each selected explanatory variable.

These results, in combination with the inherent flexibility of the proposed BN model, allows for the potential integration of diverse heterogeneous datasets. Thus, it is possible to assimilate as much information and expert knowledge as is available during the training of the model and testing of other '*what-if*' scenarios. As such, the model also has the ability to be further improved through targeted data collection, where increasing the quality and quantity of the data will provide additional insight into the results, also improving the BN model reliability.

However, while the obtained results showed capability for damage prediction, they also highlighted some potential limitations in the methodological approach and its application, particularly where the necessary data is limited. In fact, limitations in terms of the availability of a large amount of data for the case study caused constraints on the capability of the model performance. Resultingly, the integration of many of the variables collected for training the model was not possible, and as such it was more difficult to gain insight into the full extent of the various contributing factors of flooding damages. These results stress the need for the collection of sufficient damage data post-flooding events, in order to best enable a successful model training and then scenarios analysis, particularly for the agricultural and industrial sectors where model prediction accuracy showed higher uncertainty.

As a cascading effect, the scenario analysis identified the potential impacts of expected future changes in flood depth and land use cover in the case study area, however the magnitude of these impacts was lower than might have been expected, as a result of limitations linked to the input training datasets. As highlighted under the sensitivity analysis, the difficulty in incorporating variables, such as those related to the flooding hazard, may have a large impact on the assessment of flooding damages, particularly under the consideration of their different multi-sectoral impacts.
The construction of the BN model does however allow for many possible future developments, building on strong results to either elaborate or improve upon the resulting outputs. The consideration of other possible '*what-if*' scenarios would allow for a better understanding of the likely damages of increasingly frequent and severe flooding events, and show how expected changes in hazard, exposure and vulnerability patterns will likely play into these impacts. To this aim, the integration of data concerning other flooding events occurring in the same area at different times would provide greater heterogeneity in the training dataset of the model, and thus improve the overall understanding (and then modelling under scenario analysis) of potential damages.
Moreover, a more ambitious development could involve the spatialization of the output of the model, building on the GIS-based structure of the training dataset, with the main aim of capturing damages should the flood extent increase in future events. This would allow for a larger picture on potential damages and provide further support to the management of disaster risk under changing hazard patterns, by widening the scope of the analysis to potential damages that have not yet been observed and recorded.

Overall, despite limitations inherent in the data available for the construction of the presented BN model, the results that were achieved show high promise in the prediction of multi-sectoral flooding damages, and insight into their contributing factors. Building on the previous literature, this work provides a novel approach that improves the understanding of multi-sectoral flooding damages, and in doing so, will add to the state-of-the-art knowledge in the fields of Disaster Risk Management and Climate Change Adaptation. This will provide valuable support for policy- and decision-makers who can use the results of this study to prioritize efficient collection, organization and application of post-disaster damage data, and more efficiently plan ahead for the management of potential future flooding events.

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CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

In the previous chapters the different applications to the showcases have been presented. Whilst we believe they represent a significant step forward with respect th what we didi in the past, in particular in the Idea project, it is clear that there is still the possibility to improve, and in particular to provide guidelines for future applications. At present there is a still a large variety and differences in the way the post disaster damage data have been used even within the same "label" (such as forensic or risk assessment). This is not bad per se, it actually shows the richness and the variety of usages that are possible and that constitute the added value of the effort necessary to collect damage data. What can be envisaged for the future is that once an information system is fully operational, data will be hopefully collected in a more systematic and structured way, inevitably leading to some homogeneity. The latter is certainly useful for comparison and also to design some queries that can be prepared and integrated in the system and may support the different types of uses.

For the showcases as mentioned in the introduction this was not totally possible, mainly because of the variety of formats and also the type of data that were actually provided to the partners by stakeholders and which largely mirror the present state of affair. Working in a fully consistent step by step procedure was not possible, we had to advance in parallel the development of the information system and the applications. Still we were certainly able to demonstrate that post disaster damage data can be used in large variety of ways, and that they can capiltalized by different authorities in charge of different aspects of emergency and risk management.

What can be elicited and will be done in the final deliverable relatated to the information system is al ist of queries that once applied to the an existing database could have greatly facilitated the task of carrying out the analyses, that were clearly done "manually", that is first organizing the data as shown in Deliverable 4.1 and then using them for the applications.

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