BORIS

Cross **BO**rder **RIS**k assessment for increased prevention and preparedness in Europe

D4.2

State of the art of tools for seismic risk, flood risk and multi-risk assessment

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CI3R

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1. SUMMARY

To develop next steps towards an efficient and holistic transboundary multi-risk assessments and representation with a harmonized approach, it is advantageous to gain knowledge about other previously developed risk-assessment applications. Therefore, this literature and desktop review presents some insights to the state of the art of tools that present results of seismic-, flood- and multi-risk assessments including a non-exhaustive list of tools. The idea is to support the development of the cross-border single risk-assessment methodology and risk ranking that the BORIS project aims to develop. There is a range of existing platforms, tools and projects dealing with seismic, flood, multi-hazard, or multi-risk assessments and the target group for which the results are intended can also differ. Some applications are open source and easy to understand and are intended to provide an overview for the general public, others are aimed at civil protection authorities or emergency response organisations and others can only be used with expert knowledge.

One main step forward that was made in the last years within the different methodologies and applications is from studying and displaying only (single) hazards towards Risk Assessment Tools that allow the estimation of risk as the convolution of hazard, vulnerability and exposure.

Currently there are the four different schemes for presenting the results of risk assessments and the underlying hazard and vulnerability are risk maps, risk matrices, risk curves and risk indices.

Regarding flood risk most of the methods (models) have in common that they are based on the depth-damage curves, both absolute damage curves, where damage is expressed in monetary units, and relative damage curves, where damage is expressed through the damage factor, are used. Thus, presentation of the final results differs from one tool to another, whereas the risk is visualized within the (open source) single and multi-hazard applications mainly by using colour coded risk maps.

Also, most of the seismic tools can estimate and display potential damage, either in the form of maps showing economic losses or structural damage, mostly to residential buildings. Some also estimate the number of victims/injured and the number of people who need temporary shelter, social impacts and mitigation strategies. Only some (open source) applications include a visualization of fragility curves, others, especially developed for civil protection and response organizations, provide a damage assessment of regions after an earthquake, in some cases also of infrastructure and road conditions in case of an earthquake. Regarding the input data and flexibility, a number of platforms offer the considerable option of allowing the user to create and upload different exposure/vulnerability models as well as different sets of fragility curves.

An ongoing challenge towards a multi-hazard/multi-risk view is how to compare different risks. To make the comparison of potential impacts across hazards possible, multi-risk visualization and ranking is needed. One approach to presenting multiple risks is to visualize an overall risk (combined risk scores) by using maps. Another way to display risk is through risk curves with is a data-demanding method. However, single-risk curves are often the underlying information behind risk maps, whereas the curves are not always available and used for visualization within the current open-source tools or platforms. Regarding multi-risk comparison, combined risk curves of different hazards to indicate losses are an option. Another way of presenting and ranking multi-risk is through a risk matrix. This way of presenting risk is less common among the reviewed tools, however it is often used in national risk assessments, by investigating the likelihood and intensity of the

chosen risk(-s) in combination with a “third dimension” indicating whether the disaster risk is acceptable, managed or is unacceptable.

However, the BORIS risk-assessment methodology will be performed in the of a multilayer single hazard assessment (no interactions on vulnerability level considered). Risk can be visualized not only by maps and matrixes but also through curves, as BORIS will focus on risk curves as tools for consistent quantitative assessment of the single risks towards an effective comparability of the results. Whereas the possibility of using the loss exceedance curves to compare losses derived from earthquakes and floods is being investigated (D4.1).

To conclude, open-source platforms are becoming a common tool to communicate with the interested public, and to support national and local authorities, to make the comparison of potential impacts across hazards possible. However, national hazards and risk maps that are the basis for this risk assessments often stop directly on the border, without assessing transboundary contexts. The knowledge exchanged and procedures that are developed and tested within BORIS have the potential to expand the scientific background behind tools, as presented within this report towards cross-border risk assessment (seismic and flood), as well as multi-risk comparison and ranking.

2. INTRODUCTION

The number of people affected by natural hazards is increasing, as many regions of the world are exposed to a variety of hazards. Although knowledge and opportunities of preparedness are increasing, losses due to natural hazards continue to rise. Decision-makers are challenged not only to mitigate single hazards and risks, but also to recognize multiple hazards and interactions. As the concept of multiple hazards and multi-risks is a relatively new field, there are few multi-risk models and tools available to practitioners. In contrast, there are already many more approaches and possibilities for the visualization of single hazard and single risk assessments. It is therefore an ongoing challenge in the field of Disaster Risk Reduction – addressed within the BORIS Project - to create (open source) Web platforms that perform or communicate the results of multi-risk assessments using easy-to-understand, simple tools.

This deliverable presents a literature and desktop review of existing tools for seismic risk, flood risk and multi-risk assessment developed by different organisations or within research projects to assess the overall risk and the underlying vulnerabilities and potential losses. The following chapters report on existing platforms, tools and projects dealing with seismic, flood, multi-hazard, or multi-risk assessments, briefly describing the methodology and identifying to which target groups the tool is intended. The review does not intend to be exhaustive but outlines some examples with the aim of identifying different approaches and solutions that may be applicable to the BORIS project.

In the last decade, the term "multi-risk" was still used in various contexts and especially the platforms and web tools often use terminology without defining it precisely, such as "risk", "multi-hazard" or "multi-risk". There are different ways of defining different levels and layers of risk and hazards assessments. A graphic (Figure

2.1) that attempts to capture the shift from single risk to multi-risk and the often-used definitions has been made by Zschau (2019). However, a multi-risk assessment is often meant to be more complex than a multi-hazard risk assessment and includes both multi-risk and multi-vulnerability concepts, thus taking into account possible interactions between hazards and vulnerabilities (Gallina et al. 2015).

Thus, natural hazard risk assessment tools are aiming to provide decision-makers and emergency response organisations with information on the potential impact of disasters related to natural hazards by, for example, predicting human losses, the number of victims and injured to estimate the need for medical care and shelter, or disrupting the functioning of critical infrastructure. According to the JRC Report Recommendations for National Risk Assessment for Disaster Risk Management in EU (Poljansek et al. 2019) tools for presenting the results of risk assessments and the underlying hazard and vulnerability are:

1. Risk maps, with emphasis on spatial component of risk
2. Risk matrices, which allows comparison of risks arising from different hazards
3. Risk curves with temporal component of risk
4. Risk indices to present the links between risk drives and capacities with risk components: hazard, exposure and vulnerabilities (indicator-based approaches)

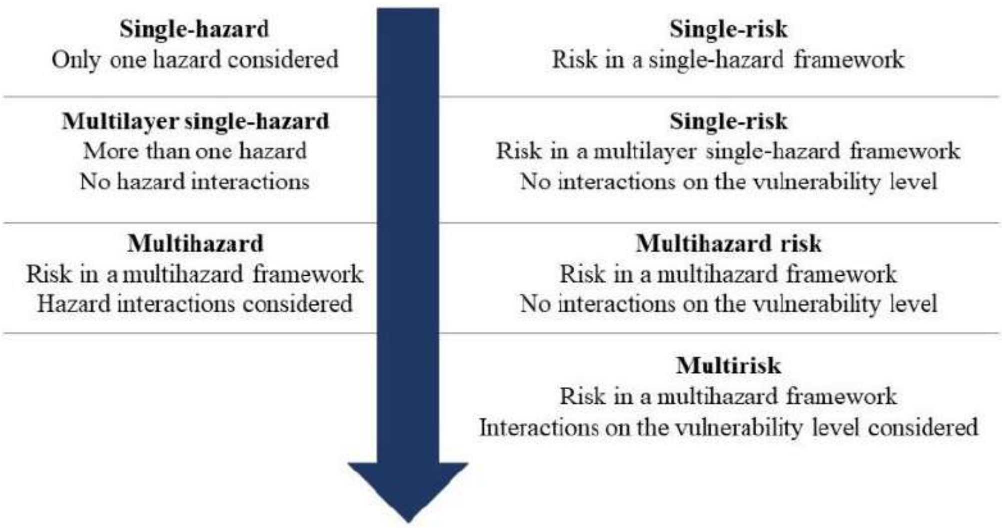


Figure 2.1: Risk terminology (according to Zschau 2019)

2.1 Risk map

A way of representing risks in relation to spatiality is to map them. It shows, often through color coding, which areas are more at risk in regards to the chosen hazard(-s). Risk maps outline the levels and natures of risk, different for each return period (or annual probability or likelihood) and hazard type (e.g., a GIS map of the potential impacts) and is therefore a way to establish the spatial extent of risk (Poljansek et al. 2019). Risk maps use different metrics to express the relation between hazard and impact, for natural hazard risk assessments at the global scale, the most commonly used risk indicator is the number of people affected, followed by the direct economic damage indicator, although many studies also use affected GDP and casualties (although rarely for flood risk) as a metric (Ward et al. 2020). To choose one example out of many the Global Earthquake Risk Map (Figure 2.2) shows the geographical distribution of the average annual loss due to earthquakes in the residential, commercial and industrial building stock, taking into account content, structural and non-structural components. Using the normalised ratio – normalised by the average construction cost of the respective country USD/m2 - it is possible to directly compare the risk between countries with very different construction costs (Silvia et al. 2018).

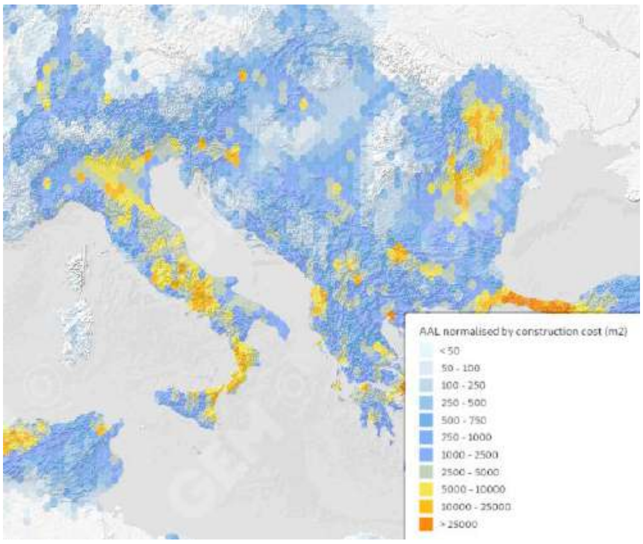


Figure 2.2: Example of a risk map that shows geographical distribution of the average annual loss due to earthquakes using colour codes (Silva et al. 2018, Global Seismic Risk Map v2018.1)

2.2 Risk matrix

Another method to represent risk is by risk matrices, which is a semi-quantitative presentation of a given risk in a matrix-system (Simmons et. al, 2017). Risk matrices are intuitive to read and can be used in a range of different ways, also as a basis for risk management decisions. They are useful when quantitative information is not available. The risk matrix is basically a simple table with approximately four to six rows and columns. The rows and columns define categories of likelihood (probability scale of an event occurring) and severity (impact of natural hazard) often with a scale from minor to catastrophic. The cells within a matrix can be assigned by numbers called "risk scores" that purport to represent a quantitative assessment of the risk: the higher the score the higher the risk, as seen in Figure 2.3, where the risk scores range from 1.0 to 4.4 (Wall, 2011). These matrices are intuitive, and individuals can easily imagine risk as a combination of likelihood and severity. For example, a highly likely event associated with catastrophic loss is ranked higher risk than an unlikely event associated with negligible loss, which is illustrated in Figure 2.3. The cells of the matrix often are color-coded to communicate this, as in the matrix below, where the cells are ranging from green (small risk or tolerable) to red (great risk or intolerable risk) (Wall, 2011; Zausch, 2019). Regarding multi-risks, risk matrices are a tool also used to compare different risks, and semi-quantitative methods are an option to visualize experts' judgments when detailed data is not available.

almost certain	2.6 [Y]	3.2 [O]	3.8 [R]	4.4 [R]
highly likely	2.2 [G]	2.8 [Y]	3.4 [O]	4.0 [R]
likely	1.8 [G]	2.4 [Y]	3.0 [O]	3.6 [O]
unlikely	1.4 [G]	2.0 [G]	2.6 [Y]	3.2 [O]
almost never	1.0 [G]	1.6 [G]	2.2 [G]	2.8 [Y]
	negligible	marginal	serious	catastrophic

Figure 2.3: Example of risk matrix with color code and risk score (Wall, 2011)

The theoretical basis of risk matrices is superficial and, despite its intuitive nature, can be misleading in practice due to a number of factors (Simmons, 2017). For a risk matrix to be effective for decision-makers, it is helpful to include another variable – not just likelihood and severity/loss. A third variable, preference/pay-off, is needed, which is usually done by color-coding and/or risk scoring to illustrate which risk(-s), displayed on the matrix are in need of mitigation/treatment (Wall, 2011). All things considered, the risk matrix remains a subjective way of assessing risks but it is a visually appealing way of illustrating risk to decision makers and laymen and it can be used as a stepping-stone or alternative to other, more quantitative, risk assessment methods.

2.3 Risk curves

A risk curve can be constructed in case of availability of quantitative data for the presentation of risk. The risk curve relates the level of impact that will be surpassed in a given time period with the actual probability. The resulting "Loss exceedance curve" (LEC) is a common output of the full probabilistic risk approach. For risk calculations the following equation can be used (Velásquez et al. 2014):

$$v(p) = \sum_{i=1}^{Events} \Pr(P > p|Event_i)\, F_A(Event_i)$$

In this equation, $v(p)$ is the exceedance rate of loss p; $F_A(Event_i)$ is the annual frequency of occurrence of the $Event_i$; Pr ($P>p$ | $Event_i$) is the probability of the loss to be greater than or equal to p, conditioned by the occurrence of the $Event_i$. The graphical representation of $v(p)$ given by the above equation in function of p is the LEC, which provides a very into depth description of risk. It displays the relation between a given loss (usually economical) and the annual frequency of occurrence of that loss or of a larger one. Figure 2.4 shows a LEC and it can be seen that it correlates an expected loss with an estimated frequency. As the frequency is the inverse of the return period, the loss can also be represented as a function of the return period (the right vertical axis) (Velásquez et al. 2014).

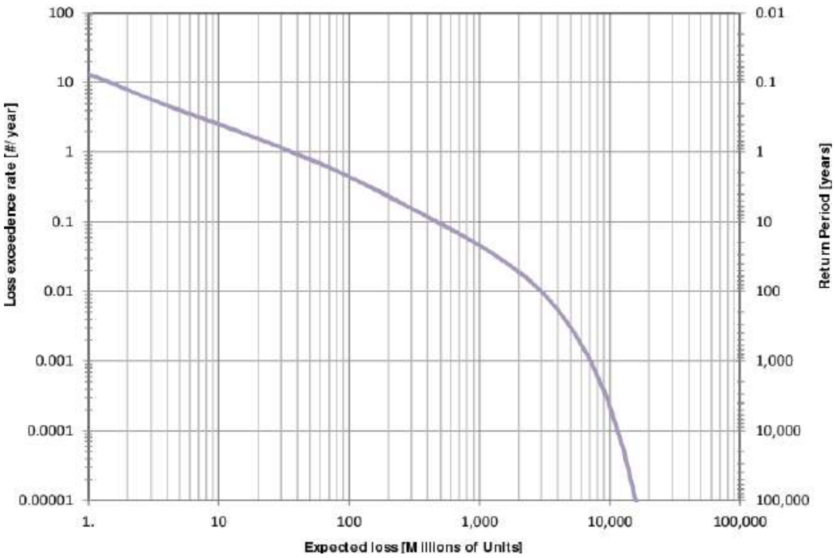


Figure 2.4: Loss exceedance curve. The left vertical axis shows the frequency while its inverse value on the right is the return period; the horizontal axis displays the expected loss (Velásquez et al. 2014).

Other important risk metrics that can be obtained are those using the annual average loss (AAL) or the probable maximum loss (PML) as indicators. The AAL is the loss expectation, that is, the weighted average of all plausible loss values; in other words, it is the value expected to be saved every year in order to cope with all the future losses. The PML is the maximum foreseeable loss for the exposed portfolio and it is usually defined for a specific return period. Both are values obtained from the LEC (Velásquez et al. 2014).

2.4 Risk indices

One other standardization scheme is to use indices also known as hazard index, vulnerability index and risk index. Using index-based approaches is also a method to achieve comparability in the multi-layered single-hazard and -risk context, combining different indicators to assess risk. Vulnerability indices are already widely used in the socio-economic domain, including in the multi-hazard context, but they are rarely hazard-specific (Zschau 2019), whereas hazard-specific vulnerability indicators exist, for example, for tsunamis or debris flows (Papathoma et al., 2003; Papathoma-Köhle et al., 2016). One prominent example is the Social Vulnerability Index, originally formulated by Cutter et al. (2003) that presents a comparative metric that represents the relative social vulnerability of an area to a range of hazards. However, risk indices will not be further focused on within this Deliverable.

3. REVIEW OF EXISTING TOOLS TO COMPUTE AND VISUALISE RISK AND LOSSES FOR SEISMIC RISK

In the last years, several research groups around the world have developed tools for seismic risk assessment in order to estimate earthquake damages and losses. One step forward was made by moving from studying and displaying only hazard towards Risk Assessment Tools that allow the estimation of risk as the convolution of hazard, vulnerability and exposure, whereas most of the tools focus on economic losses and structural damage. An indicative, non-exhaustive list of seismic (sometimes also multi-hazard) risk assessment tools is the following in alphabetic order. Some of the tools are described in more detail based on Andredakis et al. (2017).

3.1 List and description of seismic risk assessment tools

AFAD – RED (Rapid Earthquake Damage and Loss Estimation System) (Nurlu et al., 2014) has been developed by AFAD Earthquake Department in collaboration with scientists with the aim of estimating potential losses of an earthquake occurring in Turkey and also for earthquake scenarios. The event assessment is done in consecutive stages, with increasing level of sophistication as more data are obtained. The system is integrated with the National Earthquake Observation System operated by AFAD. Following an earthquake, AFAD-RED automatically receives earthquake source parameters (epicentral parameters and magnitude) from this system and provides near real-time estimation of losses in the earthquake-affected region. The system also enables to perform manual secondary analyses by revised earthquake parameters, focal mechanism solutions, strong ground motion data etc. AFAD-RED system can also be utilized to run earthquake scenarios by manual data entry. AFAD-RED uses several databases of different institutions such as administrative information (country, province, district and neighborhood boundaries), information on population, number of buildings, critical facilities, transportation systems, lifeline systems, geology (active faults), USGS Vs30 map data, Vs30 information from AFAD acceleration stations and so on. Different attenuation relationships are defined. AFAD-RED allows to choose more than one attenuation relationship and give a weight to each one. Custom-developed graphical user interfaces are used throughout to insert parameters and monitor results. As the main outputs, AFAD-RED estimates structural damage (slight, moderate, severe and complete), serviceability of critical facilities, transportation systems and lifeline systems, the number of casualties (outpatients, slightly injured, severely injured, life loss), and the number of people who need temporary shelter. It also produces estimated seismic intensity, peak ground acceleration, peak ground velocity etc. maps. The software has regularly been updated due to new calculation methods, revisions in databases, and technological developments. This tool is used by AFAD. Figure 3.1 shows main screen, event/scenario menu and an example intensity map produced by AFAD-RED.

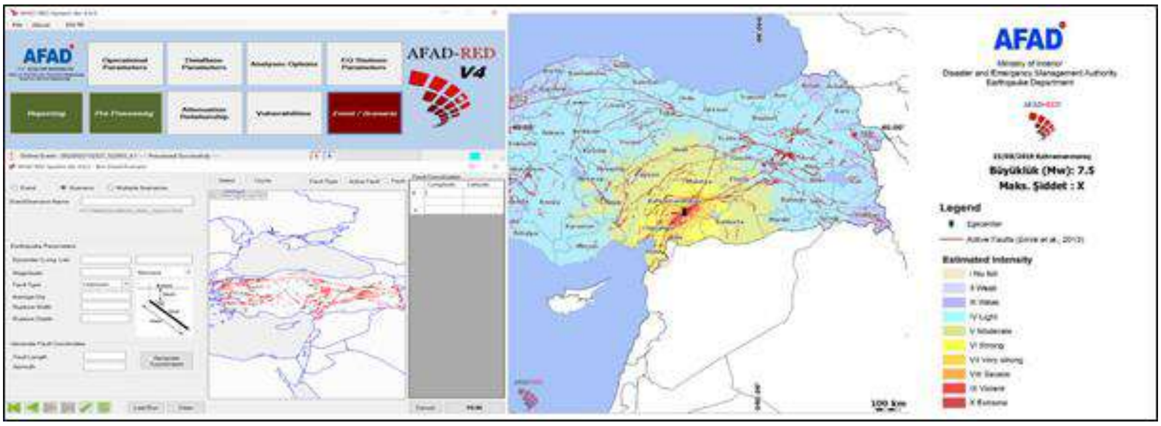


Figure 3.1 Screenshots of main and event/scenario menus of AFAD-RED (left side), an example output (right side)

ARMAGEDOM (Sedan et al. 2013) is a seismic risk analysis tool implemented by the French Geological Survey on a variety of urban seismic contexts: Bouzareah (Algeria), four provinces in Iran, the French Departments lying along the French/Spanish border and Overseas Departments in the French Antilles. The objectives and requirements of these studies differed with respect to the level of precision that was sought and the surface areas examined. In order to meet differing project targets, three levels of seismic risk assessment were defined based on the macroseismic and mechanical approaches for vulnerability and damage estimation presenting different levels of precision.

- Level N0 estimates seismic risk on a regional territorial scale based on the macroseismic approach and existing statistical data;
- Level N1 yields the seismic risk at a district level based on the macroseismic approach and on visual evaluation of the vulnerability of structures over an itinerary in the area to be analyzed;
- Level N2 also establishes the seismic risk at a district level, but the hazard description is represented by a spectrum and vulnerability is estimated based on mechanical models.

The software, with a modular design, was developed in order to optimize computation time and to automate execution of the three levels of analysis. The data of the « Tutorial » project are stored in the “catalog box” following a tree structure as presented in Figure 3.2 left. The user is always supported by a graphical interface (Figure 3.2 center and right). In Figure 3.3 an example of risk map is reported. This tool can be used by the scientific communities and civil protection authorities.

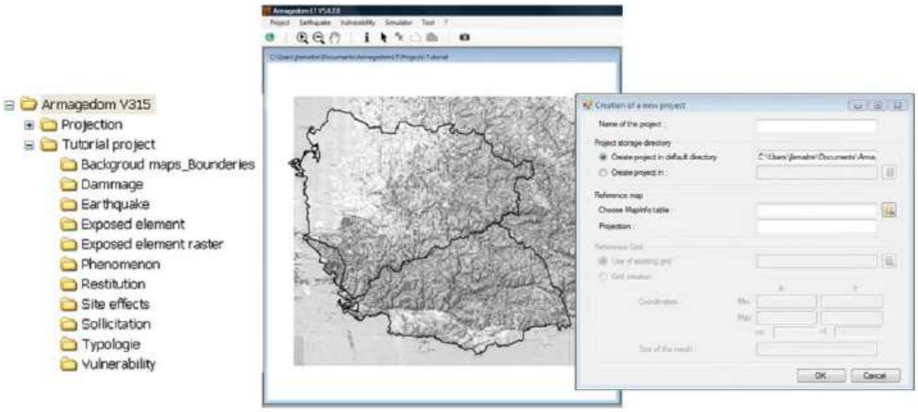


Figure 3.2: Project structure with the “catalog box” where data are loaded (left), main window (center), and the window for new project creation (right) (color figure available online) (Sedan et al. 2013)

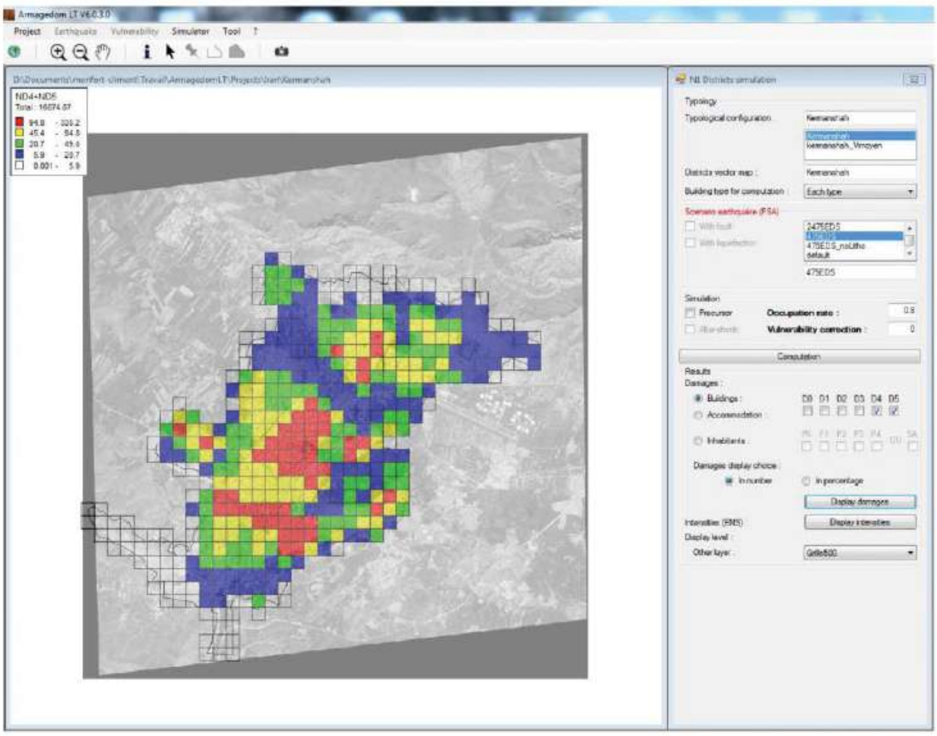


Figure 3.3: Raw results: the probability of reaching or exceeding a given damage grade for each census in studied area (Sedan et al. 2013)

CANRISK (Ploeger et al. 2016) is a tool to assess the seismic vulnerability of buildings in Canada. CanRisk models support the individual evaluation of reinforced concrete, masonry, steel, and timber-frame buildings. It quantifies an individual's risk of earthquake injury, the number of injuries, and provides an injury profile of life-threatening injuries at the building scale. In Figure 3.4 the conceptual framework of the CanRisk injury model is reported. The model uses an evidence-based and multi-disciplinary approach to identifying risk factors that affect an individual's likelihood of being injured in an earthquake. The model implements fuzzy synthetic evaluation to quantify seismic risk, combines HAZUS methodology with an own methodology to estimate number of injuries, and uses a decision matrix to generate the injury profiles. The model is designed to include the ability to test the benefits of mitigation strategies such as the retrofit of operational and functional components and the implementation of earthquake safety campaigns. This tool can be used by the scientific communities.

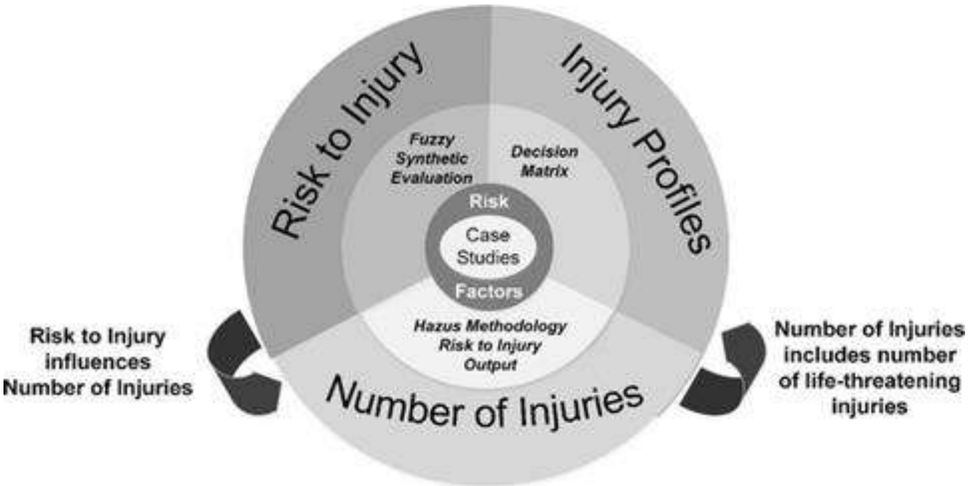


Figure 3.4: Conceptual framework of the CanRisk injury model (Ploeger et al. 2016)

CAPRA (Gill et al. 2009) is a multi-hazards software to estimate losses. It is a World Bank's initiative that aims to strengthen the institutional capacity of assessing, understanding and communicating disaster risk, with the ultimate goal of integrating disaster risk information into development policies and programs. It is a fully probabilistic and peril-agnostic risk assessment system. The CAPRA initiative aims at developing both risk assessment and communication tools to:

- guide decision-makers about the potential impact of disasters associated to natural hazards;
- formulate comprehensive disaster risk management strategies at sub-national, national and regional level;

- develop a common, open and modular methodology to assess and quantify disaster risk from multiple perils;
- provide access to state-of-the-art fully probabilistic hazard and risk assessment tools to local institutions, mainly needed in developing countries;
- develop a flexible methodology in which updates and improvements can be incorporated by universities, research centres etc.

Not only is the methodology flexible and the licence is open source, but the system can directly integrate several databases at the same time and the users can select different taxonomies to perform the fully probabilistic risk assessments. Although originally developed for disaster risk management (DRM) and disaster risk reduction (DRR) planning activities, CAPRA’s risk assessment tools can be used for rapid post-event damage and loss assessments at different scales depending on information availability, having been tested with events in Asia, Europe and Latin America. So far, the tools have been used in different DRM activities, for example seismic hazard maps for building codes in Mexico, Colombia and Spain and input data for seismic microzonations in Mexico, Colombia and Ecuador (Figure 3.5). This tool can be used by civil protection authorities.

Figure 3.5: First integrated and fully probabilistic seismic hazard and risk model for Latin America and the Caribbean (Andredakis et al. 2017)

CEDIM Risk Explorer (Müller et al. 2006) was developed by the Center for Disaster Management and Risk Reduction Technology in Potsdam, Germany. The project “Risk Map Germany” at the Center for Disaster Management and Risk Reduction Technology (CEDIM) aims at visualizing hazards, vulnerabilities and risks associated with natural and man-made hazards. CEDIM as an interdisciplinary project unified various expertise like earthquake, storm and flood disaster research. The aim was to visualize the manifold data exploration in thematic maps. The implemented Web-GIS solution “CEDIM Risk Explorer” represents the map visualizations of the different risk research. This Web-GIS integrates results from interdisciplinary work as maps of hazard, vulnerability and risk in one application and offers therefore new cognitions to the user by enabling visual comparisons. In Figure 3.6 the layout of the CEDIM Risk Explorer is reported. The potential users of “CEDIM Risk Explorer” may comprise insurance and reinsurance companies, decision makers at various administrative levels (federal, regional, communal), emergency and catastrophic management or other researchers and interested public as well.

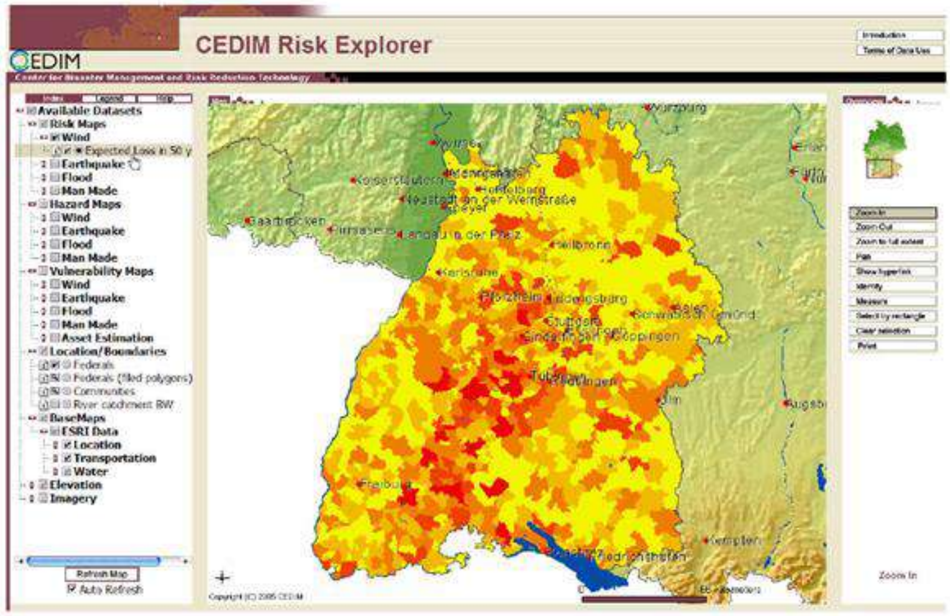


Figure 3.6: Layout of the CEDIM Risk Explorer – table of contents, map window, toolbar (Müller et al. 2006)

EQRM application (EarthQuake Risk Model) (Robinson et al. 2005) is a computer model for estimating earthquake hazard and earthquake risk. It is produced by Geoscience Australia, an Australian Government Agency, so Australia is the current geographical area of application. Modelling earthquake hazard involves assessing the probability that certain levels of ground motion will be exceeded. Modelling of earthquake risk involves estimating the probability of a building portfolio experiencing a range of earthquake induced losses. For any number of synthetic earthquakes, the EQRM application can be used to estimate:

- the ground motion and its likelihood of occurrence (earthquake hazard),
- the direct financial loss and its likelihood of occurrence (earthquake risk),
- less reliably the number of casualties and injuries and their likelihood of occurrence (earthquake risk).

The process for computing earthquake hazard can be described by the following steps:

1. the generation of a catalogue of synthetic earthquakes (or events),
2. the propagation or attenuation of the ‘seismic wave’ from each of the events in 1 to locations of interest,
3. accounting for the interactions between the propagating ‘seismic wave’ and the local geology or regolith,
4. accounting for the probability of each event and the estimation of hazard.

The process for computing earthquake risk shares the same first three steps as the earthquake hazard. The fourth step and onwards can be described as follows:

1. estimating the probability that the portfolio buildings will experience different levels of damage,
2. the computation of direct financial loss as a result of the probabilities computed in the previous step,
3. assembling the results to compute the risk.

EQRM also contains a tool to visualize the results in graphical form: Figure 3.7 shows an example of annualised loss disaggregated by distance and magnitude and Figure 3.8 an example of annualised loss disaggregated by building construction type, both for the Newcastle and Lake Macquarie region. This tool can be used by the scientific communities and practitioners.

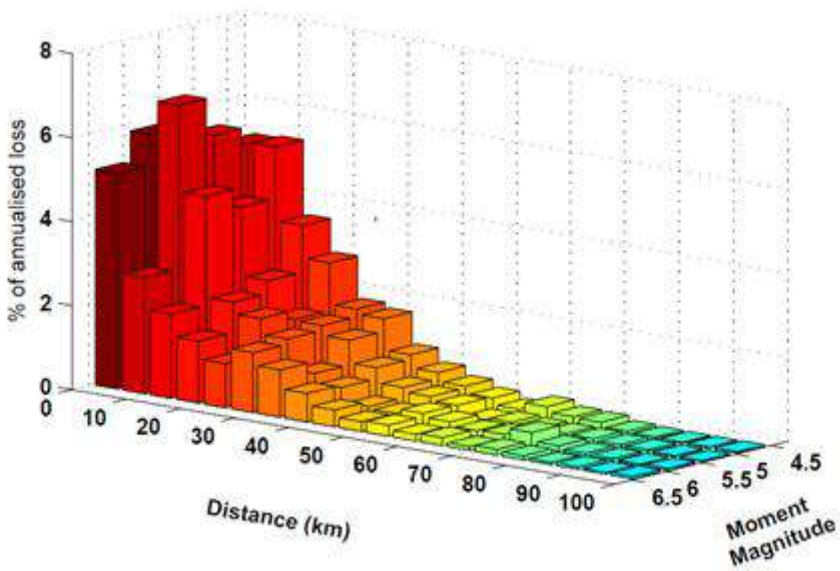


Figure 3.7: Annualised loss disaggregated by distance and magnitude for the Newcastle and Lake Macquarie region (Robinson et al. 2005)

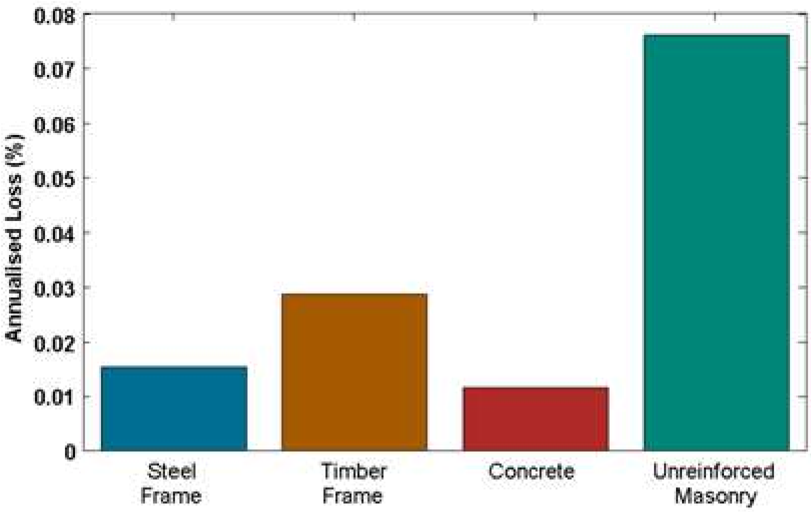


Figure 3.8: Annualised loss disaggregated by building construction type for the Newcastle and Lake Macquarie region (Robinson et al. 2005)

ELER - Earthquake Loss Estimation Routine (Hancilar et al. 2010) is a standalone application that provides rapid estimation of earthquake shaking and losses in the Euro-Mediterranean region. The multi-level methodology developed is capable of incorporating regional variability and uncertainty originating from ground motion predictions, fault finiteness, site modifications, inventory of physical and social elements subjected to earthquake hazard and the associated vulnerability relationships. The software package comprises a Hazard module and three loss estimation modules: Level 0, Level 1 and Level 2.

The Hazard module basically produces earthquake shakemaps in terms of selected ground motion parameters such as peak ground acceleration (PGA), peak ground velocity (PGV) and spectral acceleration (Sa), through region-specific ground motion prediction equations (GMPE).

Following the estimation of the spatial distribution of selected ground motion parameters, earthquake losses (damage, casualty and economic) can be estimated at different levels of sophistication, namely Level 0, 1 and 2, based on the availability of building inventory and demographic data.

The Level 0 module provides estimates of the number of casualties and their geographic distribution, either using regionally adjusted intensity-casualty or magnitude-casualty correlations and population distributions.

The Level 1 module calculates regional estimates of building damage and casualty distributions based on the EMS98 building vulnerability relationships and regional building inventory data bases and population distributions.

Level 2 type analysis corresponds to a higher sophistication level in loss estimation methodology, in which the building damage and casualty distributions are obtained using analytical vulnerability relationships and building damage-related casualty vulnerability models, respectively. The Level 2 module of ELER essentially aims at assessing the earthquake risk (building damage, consequential human casualties and macroeconomic loss quantifiers) in urban areas.

The output is represented as damage and casualty maps and the results can be exported to popular GIS platforms for further elaboration and illustration purposes. Snapshots of the main screens of ELER's GUI are presented in Figure 3.9. This tool can be used by the scientific communities.

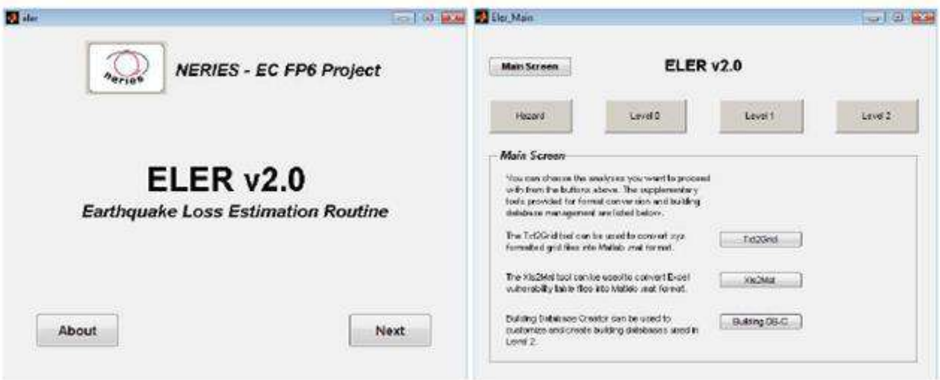


Figure 3.9: Snapshots of the main screens of ELER's GUI.

HAZUS (FEMA, 1999) is a nationally standardized risk modelling methodology. It is distributed as free GIS-based desktop software with a collection of inventory databases for every U.S. state and territory. It identifies areas with high risk for natural hazards and estimates physical, economic, and social impacts of earthquakes, hurricanes, floods, and tsunamis. It is used for mitigation, recovery, preparedness, and response. Mitigation planners, GIS specialists, and emergency managers use HAZUS to determine potential losses from disasters and to identify the most effective mitigation actions for minimizing those losses. It supports the risk assessment requirement in the mitigation planning process. Response planners use HAZUS to map potential impacts from catastrophic events and identify effective strategies for response and preparedness. HAZUS is also used during real-time response efforts to estimate impacts from incoming storms or ongoing earthquake sequences. Figure 3.10 shows the visualization of the results for California earthquakes happened in July 2019 on the HAZUS operations dashboard.

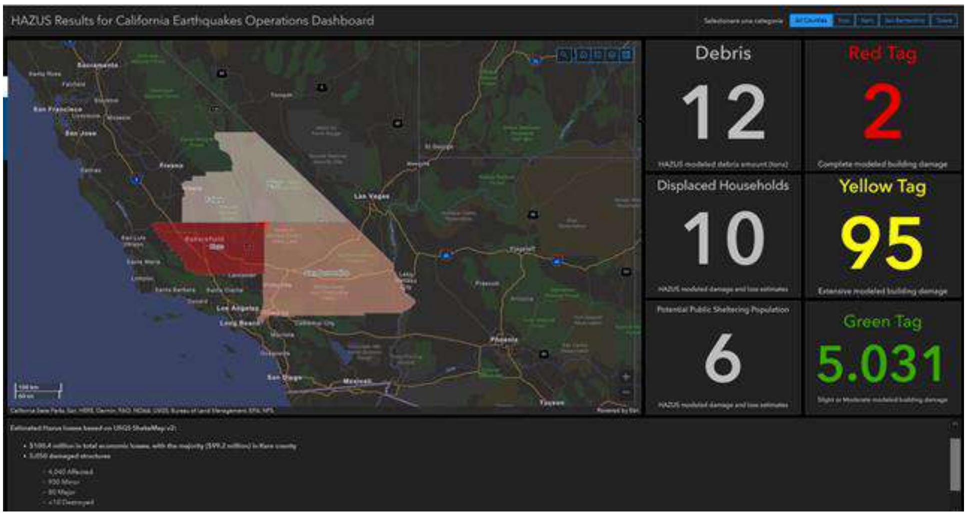


Figure 3.10: HAZUS Results for California Earthquakes in July 2019 - Operations Dashboard

HAZUS can quantify and map risk information such as:

- **Physical damage** to residential and commercial buildings, schools, critical facilities and infrastructure;
- **Economic loss**, including lost jobs, business interruptions, and repair and reconstruction costs;
- **Social impacts**, including estimates of displaced households, shelter requirements, and populations exposed to floods, earthquakes, hurricanes and tsunamis;
- **Cost-effectiveness** of common mitigation strategies, such as elevating structures in a floodplain or retrofitting unreinforced masonry buildings;

Risk analyses are categorized as Basic or Advanced (see Figure 3.11), depending on the level of effort and expertise required by the user. Advanced analyses incorporate more detailed local data about a community's population and assets to generate more accurate and applicable loss estimates. A Basic ("Level 1") analysis produces initial estimates of earthquake, flood, tsunami, or hurricane wind losses. Basic results are based on the generalized national databases and best available information included in HAZUS software. An Advanced ("Level 2" and "Level 3") analysis produces more accurate loss estimates by including information on local hazard conditions and replacing generalized national data with more accurate local inventories of buildings, essential facilities, and infrastructure. This tool is also described in section 3.1 and 4.1 in regards to flood- and multi-risk.

Figure 3.11: Levels of HAZUS Analysis

IKPIR APP (Dolšek et al., 2020) is an application developed in Matlab by the University of Ljubljana, Faculty of Civil and Geodetic Engineering, within project Seismic stress test of built environment. It involves seismic hazard databases and supports ground-motion field simulation, time-based seismic risk assessment and scenario-based seismic risk assessment. The application allows the user to consider a stochastic fragility model of the building stock and to associate risk estimates with grades indicating whether the building's seismic risk is tolerable in the short-term and in the long-term. Its capabilities were demonstrated in Seismic stress test of building stock in Slovenia. Figure 3.12 shows two on many different damage maps simulated for the same seismic scenario, which were used in the scenario-based seismic risk assessment presented in Babič et al. (2021). This tool was developed by Faculty of Civil and Geodetic Engineering, University of Ljubljana, and its use was demonstrated also for the purpose of the Seismic stress test of building stock in Slovenia (Dolšek et al. 2020) that was carried out at the micro spatial scale ordered by the Ministry of the Environment and Spatial Planning of the Republic of Slovenia.

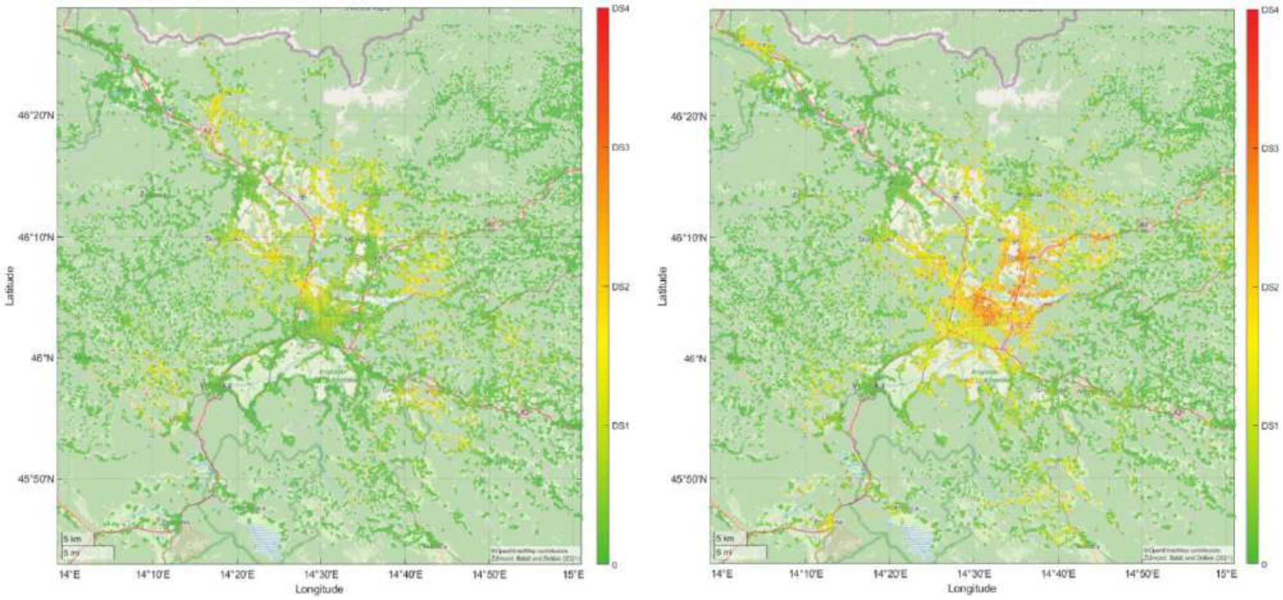


Figure 3.12: Damage maps obtained with the IKPIR APP which present the spatial distribution of the average building stock damage within cells of 0.25 × 0.25 km for two Monte Carlo based simulations of the investigated seismic scenario (Babič et al., 2021)

IRMA (Italian Risk MAps) (Borzi et al. 2021) is an IT platform developed by European centre for training and research in earthquake engineering (Eucentre) with funds of the Italian Civil Protection Department, and addressed to the scientific community. IRMA allows data sharing, methods and models aimed to evaluate the seismic risk of Italian residential buildings. IRMA uses OpenQuake, the calculation engine developed by GEM (Global Earthquake Model), to evaluate earthquake loss estimation. The hazard model used in the platform has developed by National Institute of Geophysics and Volcanology and it is actually the reference hazard map for the Italian code regulation (MPS04 – Stucchi et al. 2004,2011). Vulnerability is described by fragility curves, defined for 5 vulnerability classes (A, B, C1, C2 and D, ranked according to increasing vulnerability level) and for the five damage grades of the EMS-98 scale. Exposure data used are the Italian national census data (ISTAT 2001;2011) and the exposure/vulnerability model defines the criteria for assigning census building typologies to vulnerability classes, as also described in Dolce et al. (2021). IRMA is extremely flexible platform: the user can create and upload different exposure/vulnerability models as well as different sets of fragility curves. In Figure 3.13 the Homepage and the visualization of a set of fragility curves are showed. Therefore, by combining the different exposure databases with all the possible sets of fragility curves, the user can produce maps of conditional damage (i.e. the return period is selected) or unconditional damage (i.e. an observation time window is selected). In Figure 3.14 an example of conditional damage map is reported. Damage scenarios can also be performed by using shakemaps of seismic events as input. The shakemaps, preloaded in the platform, are those referred to the recent seismic events in Italy. IRMA was used in 2018 by the Italian Civil Protection Department to produce the National Risk Assessment document. This tool can be used by the scientific communities and civil protection authorities.

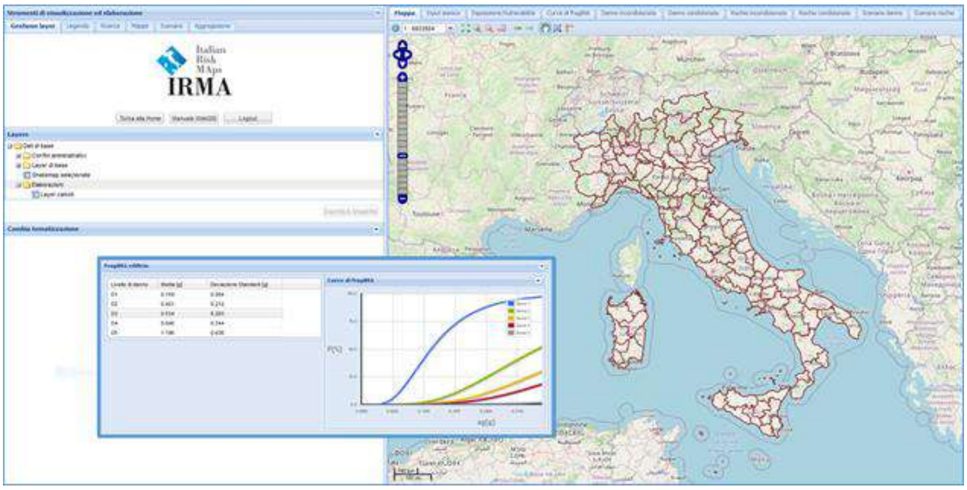


Figure 3.13: Homepage of IRMA platform and a set of fragility curves in the blue rectangle

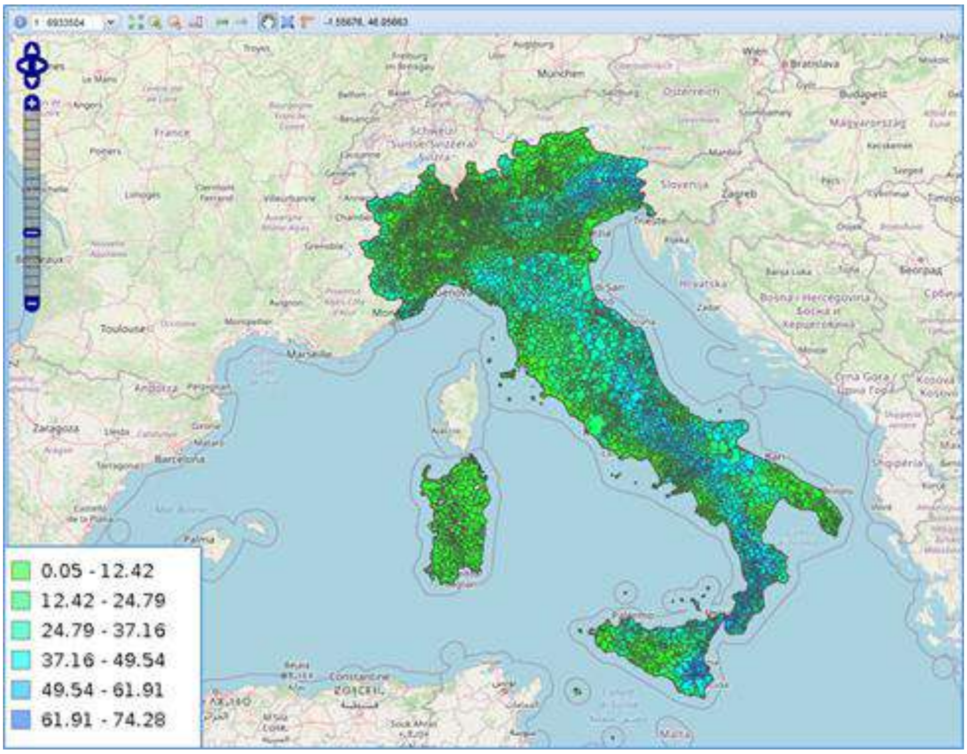


Figure 3.14: Conditional damage map for an event with a return period of 2500 years

OpenQuake (Pagani et al. 2014) is an open-source multi-purpose tool entirely written in Python developed by GEM (Global Earthquake Model). Used for the calculation of earthquake hazard and physical risk, OpenQuake (OQ) carries out both scenario hazard and event-based analyses. For scenario hazard analyses, the tool can consider spatial correlation in the ground shaking, in particular ground motion field for peak ground acceleration with or without spatial correlation. For event-based analyses, the tool generates a stochastic set of ruptures and for each rupture a scenario is calculated. Furthermore, classical probabilistic damage/loss analyses can be also done. The OpenQuake engine is used in many national and regional seismic hazard mapping programs. The use in projects at regional level allowed to develop a global fragility/vulnerability database. The outcomes for loss assessment considered the average annual economic losses at provincial level of the largest urban centres. This methodology allows flexibility as far as exposure is concerned and fragility input formats. A comprehensive database of hazard, exposure, fragility and vulnerability models is available. In Figure 3.15 the Homepage of OQ platform is reported and in Figure 3.16 an example of loss maps is showed. This tool can be used by the scientific communities and practitioners. Since OQ has no limitations in terms of geographic area and is very flexible, it could be used for seismic risk assessments within the BORIS project.

Figure 3.15: Homepage of OQ platform (Pagani et al. 2014, www.platform.openquake.org/)

Grant Agreement number: 101004882 — BORIS — UCPM-2020-PP-AG
Project co-funded by the European Union Civil Protection

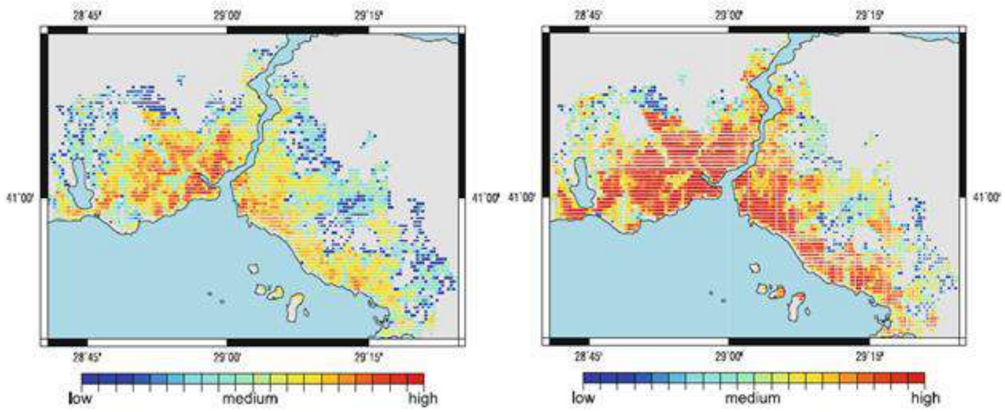
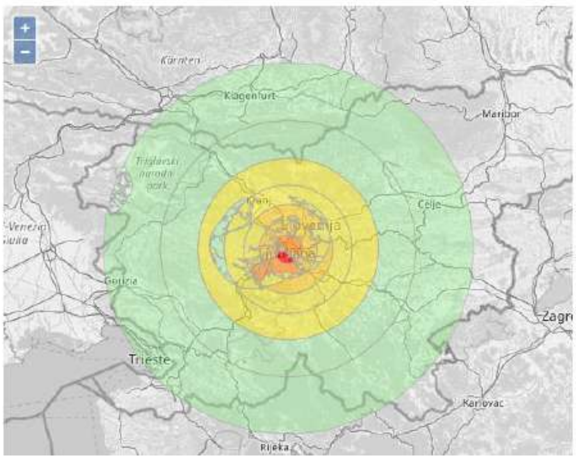


Figure 3.16: Example of loss map with a probability of exceedance of 10 % (left) and 1 % (right) in 50 years (Silva et al. 2014)

POTROG (Lutman et al., 2013) is a set of applications developed by a consortium of institutions and agencies led by the Slovenian national building and civil engineering institute. It enables a simplified seismic assessment of individual buildings, a rapid damage assessment of regions after an earthquake, an assessment of buildings occupancy and an assessment of road conditions in the case of an earthquake. Figure 3.17 shows the user interface of an online POTROG tool for the damage assessment of a region for an earthquake defined by a seismic intensity according to EMS98. This tool was developed for civil protection authorities and the general public.

Karta ocenjene intenzitete za izbrani potres.



Ocena posledic potresa - ogroženosti stavb in ljudi
Upoštevane so le stavbe na območju Republike Slovenije, ki se nahajajo v vplivnem območju (VI EMS in več) obravnavanega potresa.

Tabela | Karta rdeče | Karta rumeno | Podatki s terena (ARSO)

Celotna Slovenija

		Ocenjeno število ljudi		
Uporabnost stavb	Ocenjeno število stavb	Nočni scenarij	Dnevni scenarij med tednom *	Dnevni scenarij vikend *
Neuporabne	399 (0%)	9046 (1%)	11.570 (1%)	5205 (1%)
Začasno neuporabne	9408 (4%)	82.967 (12%)	75.577 (12%)	46.117 (13%)
Uporabne	152.086 (69%)	448.626 (66%)	299.129 (51%)	215.308 (61%)
Neocenjene	57.610 (26%)	136.384 (20%)	198.229 (33%)	81.084 (23%)
Skupaj	219.503 (100%)	677.023 (100%)	584.505 (100%)	347.714 (100%)

Figure 3.17: A screenshot of an online POTROG tool for the damage assessment of a region for an earthquake defined by intensity VIII according to the EMS98 intensity scale

SELENA (SEismic Loss EstimatioN using a logic tree Approach) (Molina et al. 2010) is an open risk tool developed by NORSAR (Norway) and the University of Alicante (Spain) with open-source code, open documentation, and freely accessible. SELENA provides a high level of versatility allowing the user to easily implement their own methodologies or input algorithms (i.e., ground-motion prediction equations, earthquake demand spectra following various international seismic building codes), choose whether site and/or topographic amplification effects shall be taken into account, or to choose between various damage computations methodologies. An important technical feature of the tool is the tripartite loss computation sequence, i.e. using deterministic earthquake scenarios, simulated ground motion shake maps, or shake maps based upon recorded ground motion data. The outputs of the computation sequence are classified as follows:

- Ground motion shakemaps (in case of deterministic computation);
- Damage probabilities and absolute damage extents;
- Debris estimation;
- Shelter estimation;
- Human loss;
- Economic loss.

Each computation output is provided on the level of the smallest geographical unit. Figure 3.18 shows an example of results for a simulation of the 1977 Vrancea earthquake. A feature of SELENA is the implemented logic tree computation scheme which allows the handling of the intrinsic uncertainties in each input parameter (i.e. focal parameters, soil conditions, fragility models, economic and human loss models, etc.). This tool can be used by the scientific communities.

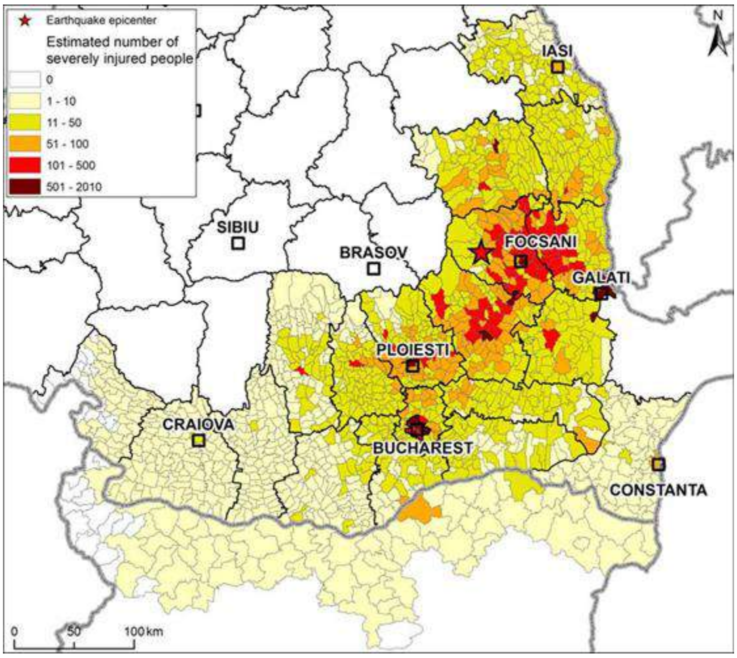


Figure 3.18: Results from SELENA for a simulation of the 1977 Vrancea earthquake (Mw 7.4) showing the estimated number of severely injured people (Toma-Danila 2014)

3.2 Maps, curves and matrices for presenting the results of seismic risk assessments

One approach to presenting seismic risk is through risk maps. In the BORIS project maps for seismic risk - with the municipality level as the minimum unit of reference - will be developed. Once known the number of buildings, dwellings, population, living area present in each municipality of the Pilot areas, fragility curves are associated to these buildings on the basis of the number of floors, structural typology and age of construction. The curves are not associated to the single building but to groups of buildings that show the same behaviour (vulnerability) towards the earthquake. To each municipality is then associated a hazard curve that defines the PGA (Peak Ground Acceleration) for different return periods, that is for different probability of occurrence. From the convolution of exposure, vulnerability (fragility curves) and hazard it is possible to calculate the risk for each municipality. On the map the risk is shown colouring the municipality according to a predefined scale. The risk value that can be displayed on the colour map could be for example the probability of reaching a level of damage. Fixed for example the time window of 1 year, the map can show the probability that the buildings present in that municipality reach the damage D5, which corresponds to the collapse. Consequence functions will then be used to move from the structural damage suffered by the buildings to the losses in terms of human and economic losses. On the map it will be possible for example to visualize throughout a colour scale, the economic losses suffered by a municipality in a time window of 50 years.

In the following figures (Dolce et al. 2021) risk maps are shown as an example, they were calculated with the IRMA tool and published in the Italian National Risk Assessment. IRMA uses OpenQuake as calculation engine. Figure 3.19 shows the average expected percentage of dwellings in each municipality affected by Damage Level D3 in a time window of 1 year. Figure 3.20 shows the average expected percentages of victims in each municipality in a time windows of 1 year. Figure 3.21 shows the percentage of unusable dwellings in each municipality in a time windows of 50 years. At last, Figure 3.22 shows the average expected economic losses for each municipality and for each region in a time window of 1 year.

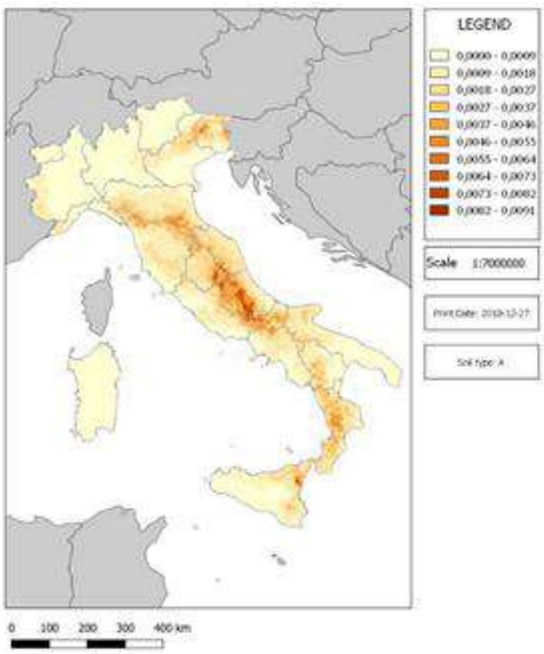


Figure 3.19: Risk in a time windows of 1 year. Average expected percentage of municipal dwellings affected by Damage Level D3 (Dolce et al. 2021)

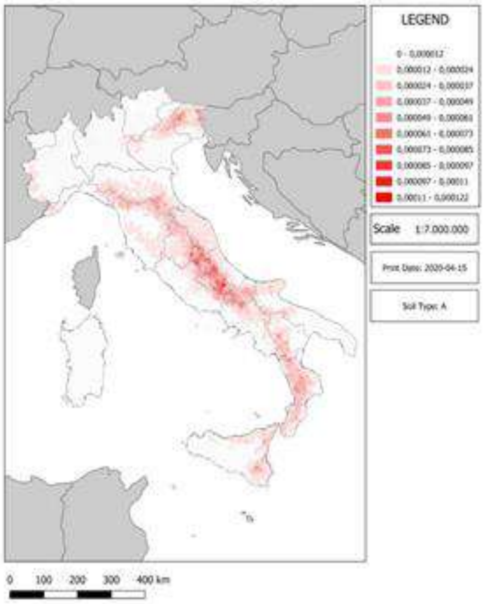


Figure 3.20: Risk in a time windows of 1 year. National maps relative to average expected percentages of victims (Dolce et al. 2021)

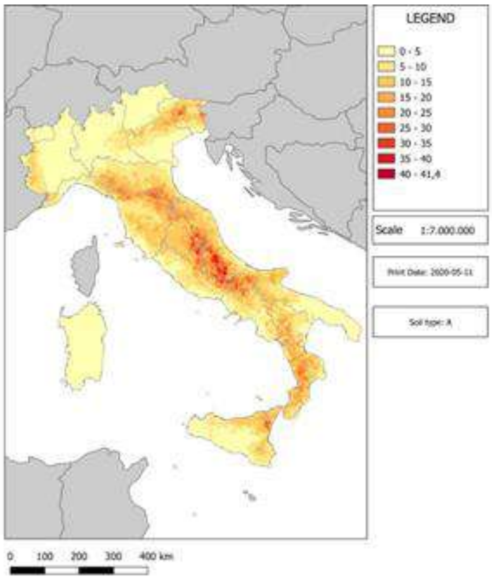
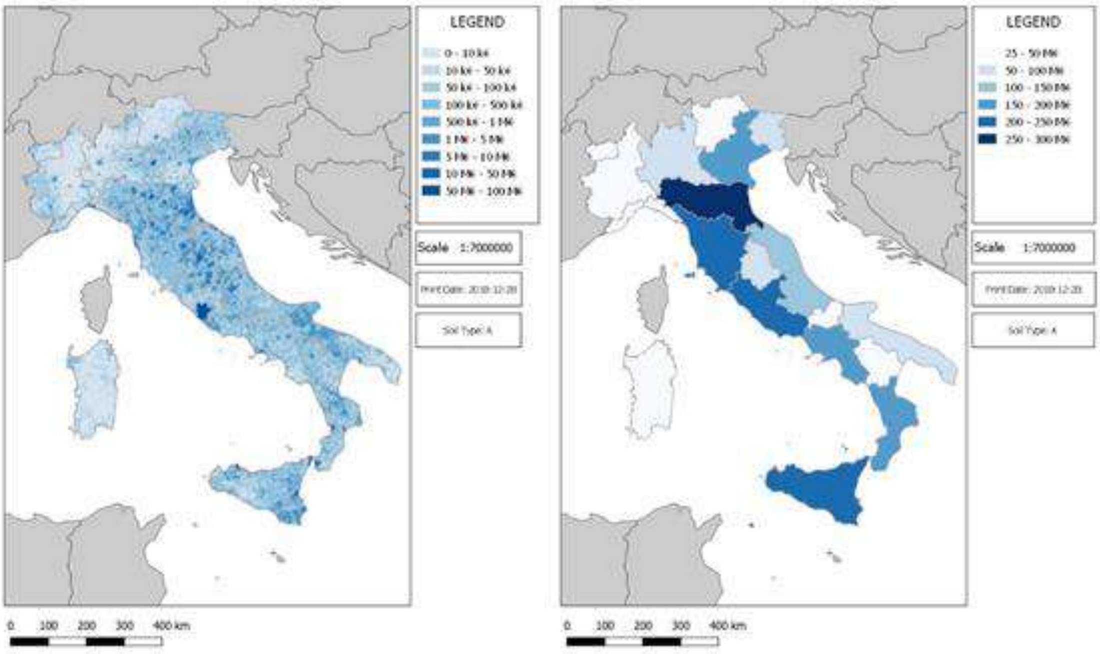


Figure 3.21 Risk in a time windows of 50 years. Percentage of unusable dwellings (Dolce et al. 2021)



(a) (b)

Figure 3.22 Risk maps in a time window of 1 year. Average expected economic losses for each municipality (a) and for each region (b) (Dolce et al. 2021)

Within the Boris project, the possibility of using the loss exceedance curves to compare losses derived from earthquakes and floods is being investigated. As mentioned in section 1.3, the seismic risk can be visualized not only by maps but also through curves denominated "Loss exceedance curves" (LEC). One of the tools able to produce seismic Loss exceedance curve is CAPRA that considers the different components of disaster risk along with their uncertainties, the characteristics of the natural phenomena, the definition and location of the exposed assets and the vulnerability of the building classes. The occurrence of the natural hazards is assumed to follow a Poisson process; accordingly, all the possible events are independent from each other. For the exposure, the CAPRA platform uses a geospatial database. The CAPRA platform includes the necessary procedures to gather the information regarding the exposed elements based on the scale of analysis; when the cadastral information of the city is not available, this information has to be generated from remote sensing or it has to be generated using proxy models. CAPRA evaluates the expected behaviour of the different assets by means of vulnerability functions which correlate a certain characteristic of the intensity of the natural phenomena (e.g. spectral acceleration of an earthquake) with the mean damage ratio. The vulnerability functions are not defined for each individual element but for a set of elements with similar characteristics; that is, a vulnerability curve has to be defined for each building or infrastructure class included in the portfolio of the exposed assets (Velásquez et al. 2014).

Another tool that can be used to calculate the LEC for earthquake is OpenQuake (OQ). OQ allows to run Classical Probabilistic Risk Calculator and Stochastic Event-Based Probabilistic Risk Calculator in order to obtain Loss exceedance curves (LEC) and average annual losses (AAL). Classical Probabilistic Risk Calculator generates LEC only for individual asset. On the other hand, aggregate loss exceedance curves are generated only by the Stochastic Event- Based Probabilistic Risk Calculator and describe the probabilities of exceedance of the total loss across the entire portfolio for a set of loss values within a given time span (or investigation interval). The calculator requires the definition of an exposure model, a vulnerability model for each loss type of interest with vulnerability functions for each taxonomy represented in the exposure model, and a Stochastic Event Set representative of the seismicity of the region over the specified time period. Loss curves can currently be calculated for five different loss types using this calculator: structural losses, non-structural losses, contents losses, downtime losses, and occupant fatalities. The main results of this calculator are Loss exceedance curves (LEC) for each asset, which describe the probabilities of exceeding a set of loss ratios or loss values, within a given time window (or investigation interval). Aggregate loss exceedance curves can also be produced using this calculator; these describe the probability of exceedance of different loss levels for all assets in the portfolio (GEM 2021).

4. REVIEW OF EXISTING TOOLS TO COMPUTE AND VISUALIZE RISK AND LOSSES FOR FLOOD RISK ASSESSMENTS

Most of the tools available to date are based on water level/depth while other influential parameters (e.g., flood duration, sediment concentration, water velocity) are rarely used (Jongman et al., 2012). Water depth is taken into account in models (tools) through damage curves that describe the relationship between expected damage and water depth. There are two types of damage curves, namely absolute damage curves where damage is expressed in monetary units, and relative damage curves where damage is expressed through the damage factor. In the following, some of the most frequently used tools for flood damage evaluation as support for flood risk assessment are briefly presented.

4.1 List and description of flood risk assessment tools

ANUFLOOD is an Australian tool mainly used to assess flood damage to residential and commercial buildings and infrastructure using empirical damage functions on micro scale (Hasanzadeh Nafari et al., 2016). Three parameters are taken into account for calculation of the expected damage: floodwater depth, size of the building and vulnerability of the building. According to Olesen et al. (2017), the model uses five values classes for residential buildings and 15 damage curves for non-residential buildings. Additionally, indirect damage is estimated as 15% and 55% of the direct residential and commercial damage, respectively.

CEDIM is a GIS-based tool developed for the flood risk assessment in a pilot area of Baden-Württember, Germany Büchele et al. (2006). Later, the results were extended to whole Germany.-The procedure of risk assessment can be divided into three steps, namely hydrological part, hydraulic part, and damage assessment at the level of area or building. Analysed area can be selected based on different spatial or administrative level, such as barrages, communities or postcodes in tables or with graphical selection in GIS tool (Figure 4.1). The software has a built-in option to select the type of function that describes the relationship between damage and water depth (e.g, linear, square-root). The authors argue that due to different and various factors influencing the absolute damage caused by floods, the user should have an option to adjust damage curve to get a meaningful damage estimation for individual building or spatial unit.

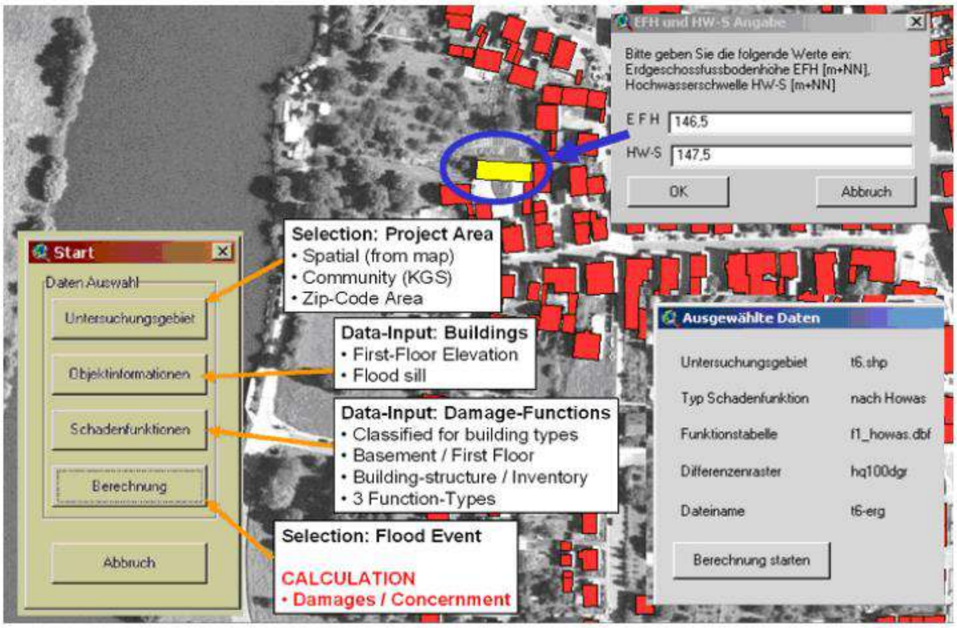


Figure 4.1: GUI of CEDIM model for flood risk assessment (adapted from Büchele et al., 2006)

Damage Scanner was developed as a simplification of **HIS-SSM model** in the Netherlands. The same depth-damage functions as in the original model are taken into account to calculate the potential damage, however land use data are aggregated. HIS-SSM model, which is extensively used by governmental agencies at the national and/or regional scale for the estimation of potential damage and for calculation of economically eligible investments (Jongman et al., 2012), requires extensive and detailed input data that cannot be predicted when considering for example population growth/decline or climate change (Bouwer et al., 2009). The basis for the flood damage assessment are flood depth-damage curves. Thirteen curves for different land uses were prepared resulting in the proportion of the highest possible damage (relative curves). The schematic presentation of the procedure for the damage assessment using HIS-SSM tool is shown in Figure 4.2.

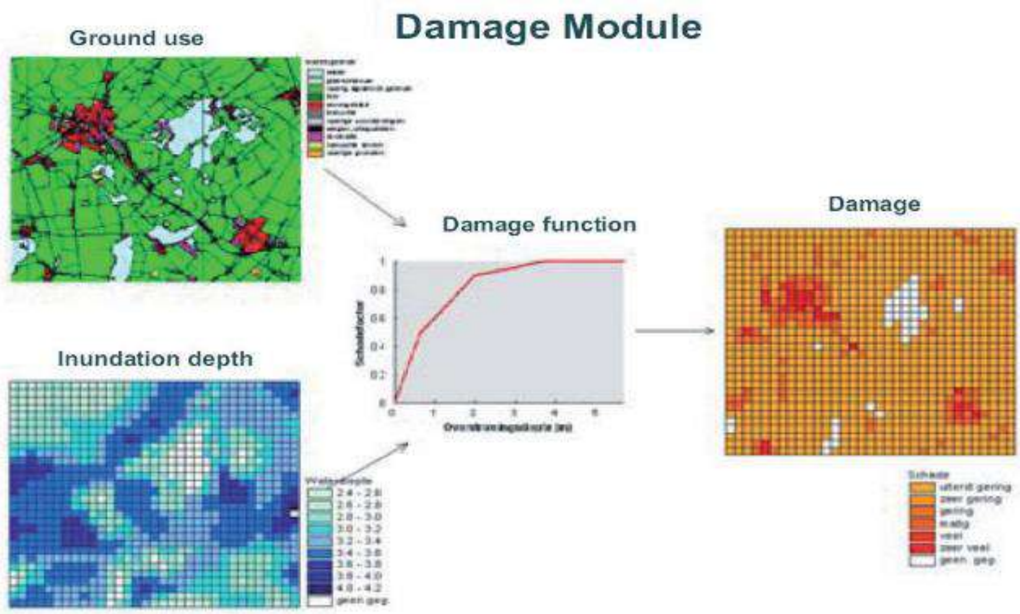


Figure 4.2: Schematic presentation of flood damage assessment in HIS-SSM model (Van Westen, 2005)

FLEMOcs and **FLEMOps** were developed in Germany for the primary purpose of scientific research of floods on local and national level. FLEMOps (Thieken et al., 2008) enables calculation of direct damages caused by floods on residential buildings using five categories of flood depth, three building types, three categories of contaminations, and three classes of private precaution, whereas FLEMOcs (Kreibich et al., 2010) calculates damage on commercial buildings and equipment using also five classes of water depth, four economic sectors, three categories of company size (number of employees), and three classes of contamination and private precaution. Both models can be used at the micro-scale level (e.g., individual building) or at the regional or national level (meso-scale level). However, in the latter case, the models were adapted according to the data on population, land use, and market values (Kreibich et al., 2010).

FLFAcs (Flood loss function for Australian commercial structures) was developed specifically for the direct flood damage assessment in business sector because as this area is rarely evaluated in detail in models and the results are consequently questionable (Hasanzadeh Nafari et al., 2016). As a dominant influencing factor, the floodwater depth was identified, while other parameters (e.g., age of building, number of storeys etc.) have been considered as vulnerability parameters. The FLFAcs model is suitable for flood management tasks as well as insurance issues. The model was calibrated according to the geographical properties of Australia. The model evaluates only structural damage.

F-RAM (Flood Rapid Appraisal Method) (URS, 2008) is a model primarily developed in California for the quick assessment of the benefits of embankments. F-RAM enables rapid and consistent evaluation of flood protection measures using cost-benefit analysis. First, it was developed for using it where spatial data sets are available, however information on the flood frequency (hazard) is limited. Later on, some modifications were made including differentiation of structural and content damage assessment for industrial and commercial buildings, HAZUS data, and possibility to assess potential and actual flood damages. It assesses damage for industrial and commercial buildings, agriculture, and roads and infrastructure (Jongman et al., 2012).

HAZUS-MH is a tool that is frequently used for potential economic, financial, and social damage. It takes into account both fluvial and coastal floods including waves, lake floods, and glacial floods. Although it was developed in USA for use by floodplain managers and other users who have the responsibility of protecting citizens and property from the damaging affects of flooding (FEMA, 2014, 2018) it is widely used all over the world. The methodology is described more in detail in chapter 2. Besides water induced hazard, the software comprises also wind and earthquakes. The most frequent use of the HAZUS-MH is at the level of the city, county or country. There are three possible levels of use, where level one uses default input data and level three requires additional information from economic and engineering studies (see Figure 3.11 in the chapter 3.1). For each CORINE land use, one function was selected and maximum damage values based on replacement values instead of depreciated values were used.

Hydrotec model also uses relative depth-damage curves to assess potential flood damage (Emschergenossenschaft and Hydrotec, 2004). The curves were developed on the basis of the German HOWAS 21 damage database. Potential damage can be assessed for residential building, business, vehicles, agriculture, forestry, and infrastructure. For the analysis, the required data are land use, values of exposed assets, and water depth. Hydrotec assesses losses to buildings together with losses to equipment.

JRC model (model of the Directorate General Joint Research Centre) is a pan-European model for flood damage assessment at the macro level of the 27 EU member states (Huizinga, 2007; Huizinga et al., 2017). The basis is CORINE land cover according to which five sectors were determined. These five sectors have been identified in more detail based on LUCAS database. This enabled evaluation of the floodwater depth for each cell and consideration in the flood damage curves. In member states where flood damage curves already existed, those existing curves were taken into the model. In member states, where vulnerability curves did not exist, an average of all existing curves was applied. Similar was done for maximum damages (for preparation of relative damage curves) with additional factor of member state GDP. JRC model is suitable for analyses on regional, national or European scale-level.

KRPAN states for the methodology for calculation of flood damage and their analyses in Slovenian language (Sapač et al., 2021; Vidmar et al. 2019a). It represents an upgraded methodology primarily developed by

IzVRS (2014) and an application that enables a set of support tools for the experts and decision makers. It is GIS-based, however, some input data such as population and number of vehicles are averaged for individual spatial areas. Types of data used for the calculation of expected annual damage can be classified into 11 categories: cultural heritage, state roads, public infrastructure, agriculture, residential buildings, the environment, personal vehicles, economic activities, watercourse, settlement cleaning, and (temporary) alternative residence. For the calculation of expected annual damage, at least three hazard maps (three different return periods) are needed. The water depth is included in the calculation if available for the analysed area, otherwise an average water depth is taken into calculation. However, the tool can give an informative insight into the vulnerability of any selected area (predefined area or drawn manually in e.g., Google Earth and then uploaded to KRPAN). Still, this tool is not suitable for assessing damage to smaller areas, such as individual building, as data is aggregated for postal districts. The main purpose of KRPAN tool is to support project designers and engineers as well as decision makers on the implementation of proposed construction and non-construction flood protection measures in the economic and financial justifications.

MCM (Multicoloured Manual) is considered to be one of the most advanced European methods for assessing flood damage. It was developed in United Kingdom (Penning-Rowsell et al., 2005). The flood damage assessment on buildings is made based on the absolute depth-damage curves. Curves are designed based on expert data and results of flood modelling for residential, industrial (separately for roads) or commercial buildings. Besides, flood damages can be assessed also for recreational areas, agriculture, and other natural areas. The input data into the model are floodwater depth, flood duration, type and age of building, and social status of inhabitants.

MEDIS model states for Methods for the Evaluation of Direct and Indirect Flood Losses and it was developed in Germany in the scope of European project of the same name (Forster et al., 2008). Similarly, as in Hydrotec model, HOWAS data (residential and business sector, agriculture, and roads) were used. Potential flood damage on buildings was assessed based on impact and resilience factors. Accordingly, five building sensitivity classes were determined with individual flood damage curve.

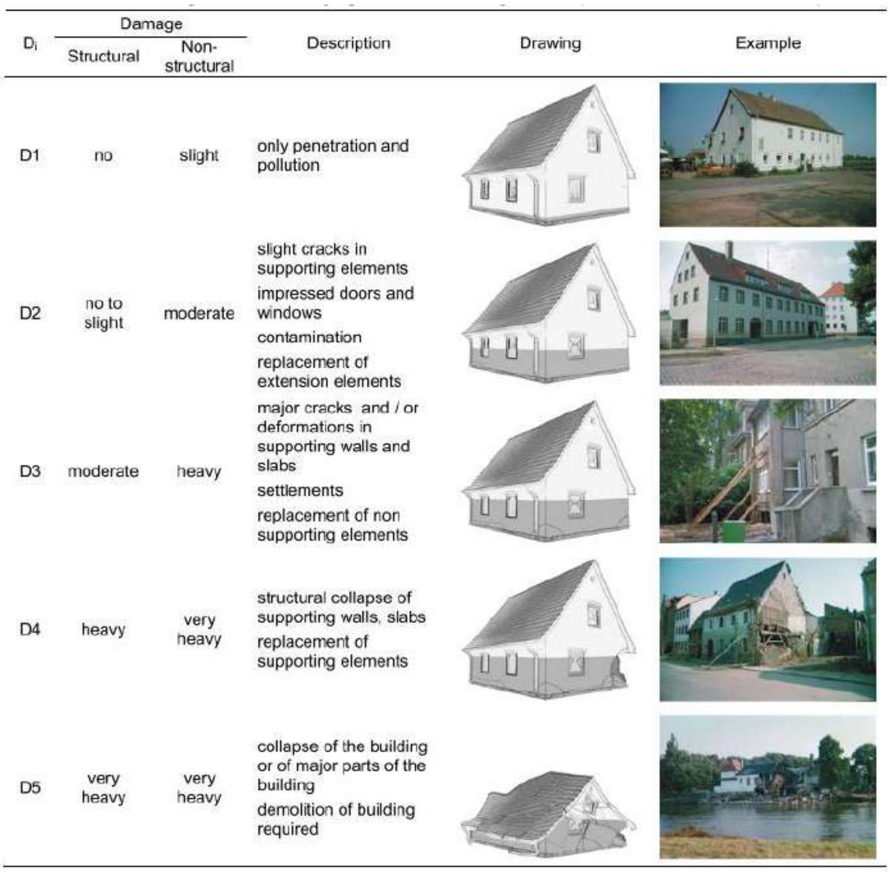
MURL was also developed in Germany but for the section of the Rhine river (MURL, 2000). Relative flood damage curves were prepared based on HOWAS database containing data of more than 6000 flood events. The damage can be assessed for residential and commercial building, infrastructure, agriculture, and forestry.

NACER model was developed for the flood damage assessment in Croatia with the purpose for using it in (Vidmar et al., 2015; Zabret et al., 2018). It is based just on publicly available data such as statistical reports, CORINE land cover, and GDP. The flood damage can be assessed for seven damage categories: buildings, industry, infrastructure, agricultural areas, forests, plantations, and other natural areas. For each category, economical/market value was determined, as well as number of elements in the area and relationship between floodwater depth and damage. The later were adapted from the existing literature but validated on the 2014 flood event data. It was developed in an open-source GIS software.

RAM (Rapid Appraisal Model) was developed in Australia for the rapid flood damage assessment purpose (Read Sturgess and Associates, 2000). In the methodology, for the development of depth-damage curves, synthetic and empirical data are used. However, the most crucial data are related to the fact if the building was flooded or not.

Rhine Atlas is a flood damage model that was developed by International Commission for the Protection of the Rhine (ICPR) involving 5 countries as well as EU (ICPR, 2001). It is a relatively simple model that includes five types of land use among which three of them represent built environment. HOWAS database was used together with some expert data for the development of depth-damage curves. It is one of the least detailed tools described in this chapter from the classification point of view (Jongman et al., 2012). More specifically, only five land use classes are defined, of which three classes represent built environment.

Schwarz-Maiwald method was developed to improve damage assessment on buildings by taking into account more realistic impact factors (Schwarz and Maiwald, 2008). Data, collected in the scope of the 2002 flood in Saxony, Germany, and data obtained with telephone interviews made in the scope of the MEDIS project were used for the development of flood damage curves. Based on the information obtained, five classes of building damage were defined. For these five classes a relation with damage on the building structure and inventory (equipment) were developed through vulnerability and damage functions. Figure 4.3 summarizes the methodology or criteria for the classification of damage on building into five classes. Comparison of observed damages with damages assessed using Schwarz-Maiwald tool is graphically presented in Figure 4.7.



D_i	Damage: Structural	Damage: Non-structural	Description	Drawing	Example
D1	no	slight	only penetration and pollution		
D2	no to slight	moderate	slight cracks in supporting elements impressed doors and windows contamination replacement of extension elements		
D3	moderate	heavy	major cracks and / or deformations in supporting walls and slabs settlements replacement of non supporting elements		
D4	heavy	very heavy	structural collapse of supporting walls, slabs replacement of supporting elements		
D5	very heavy	very heavy	collapse of the building or of major parts of the building demolition of building required		

Figure 4.3: Criteria used for the classification of damage on buildings (Schwarz and Maiwald, 2008)

4.2 Maps, curves, and matrices for presenting the results of flood risk assessments

According to EU’s Floods Directive, the Member States are obliged to prepare and revise flood hazard and flood risk maps. However, as it was shown in deliverable D2.2 and also by Nones (2017) in the scope of the HYTECH project, great differences between countries exist in the implementation of directive’s tasks. For example, different return periods of the considered scenarios for flood hazard, different number of flood risk classes, different map scales etc. Moreover, currently, there is no universal way to assess flood damage. However, most of the methods (models) have in common that they are based on the depth-damage curves (Nafari and Ngo, 2018). Jongman et al. (2012) pointed out the uncertainty regarding the use of depth-damage curves. More specifically, they emphasized that it is necessary to take into account regional differences in assets values.

Consequently, in the last decades, several tools and methods were developed for flood risk (hazard, vulnerability) assessment. In this chapter, mostly the tools, used for assessment of (potential) flood damage are presented. Due to different approaches and methodologies, also presentation of the final results differs from one tool to another. Results of the analyses of the tools listed and described in the previous chapter can be presented by one figure (e.g., Hydrotec, Anuflood, RAM) or can be more detailed, meaning that show losses to different asset types (e.g., HAZUS-MH). HAZUS-MH and MURL for example result in three figures showing loss to building structure, loss to equipment, and loss to inventory. Moreover, Multicoloured manual fragments results even more. It shows results in five figures, namely loss to building structure, loss to equipment, loss to immobile inventory, loss to mobile inventors, and loss to stock. Alternatively, it can show also total loss in one figure. KRPAN enables presentation of results of calculation in the GIS (at the asset level of detail) and/or in MS Excel (Vidmar et al., 2019b) (Figure 4.4). Colours in the figure are set according to different assets present in the analysed area. Results can be quantified both in the Google Earth (or any other GIS software) or in Excel spreadsheet which is automatically generated after the computation is done. HIS-SSM model presents results in the software window. One example of HIS-SSM results is shown on map is in Figure 4.5.

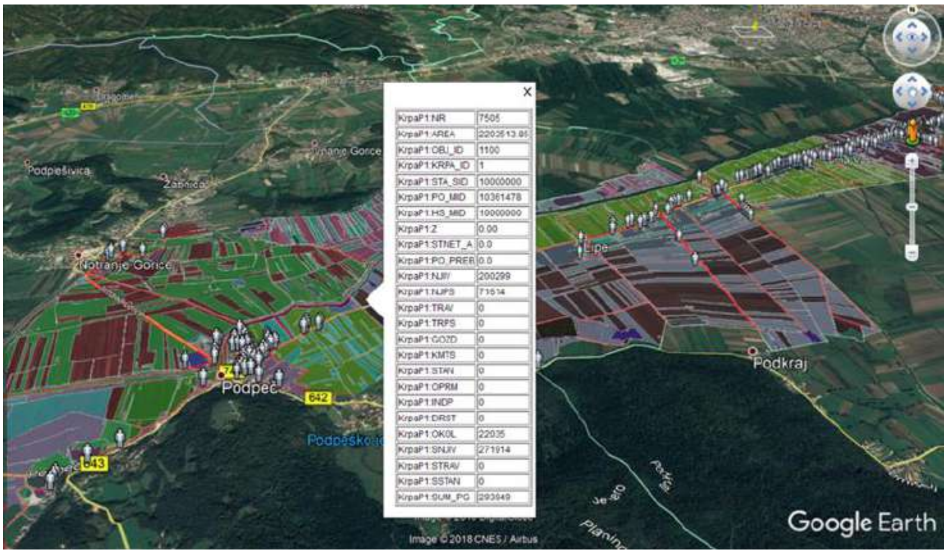


Figure 4.4: Presentation of results in Google Earth using KRPAN software (Vidmar et al. 2019a)

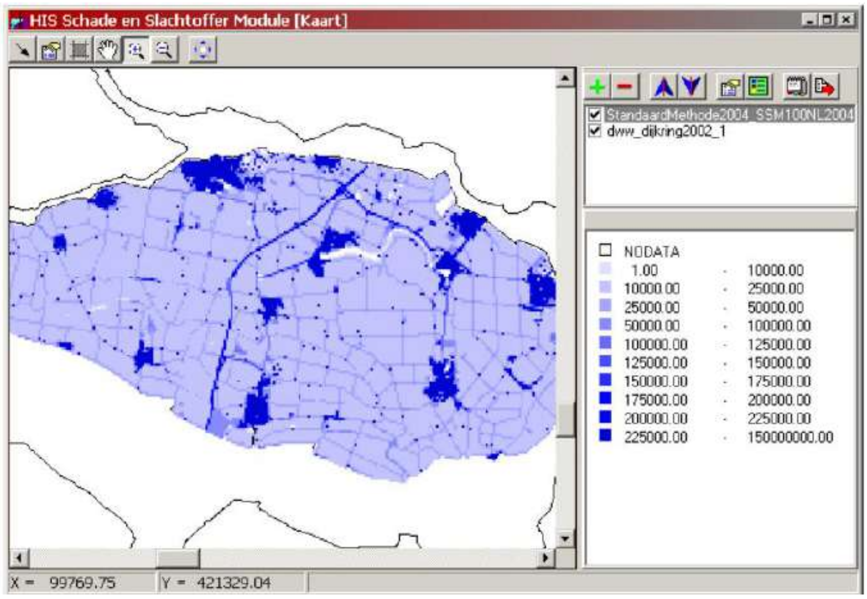


Figure 4.5: Presentation of results in HIS-SSM software (Huizinga et al., 2004)

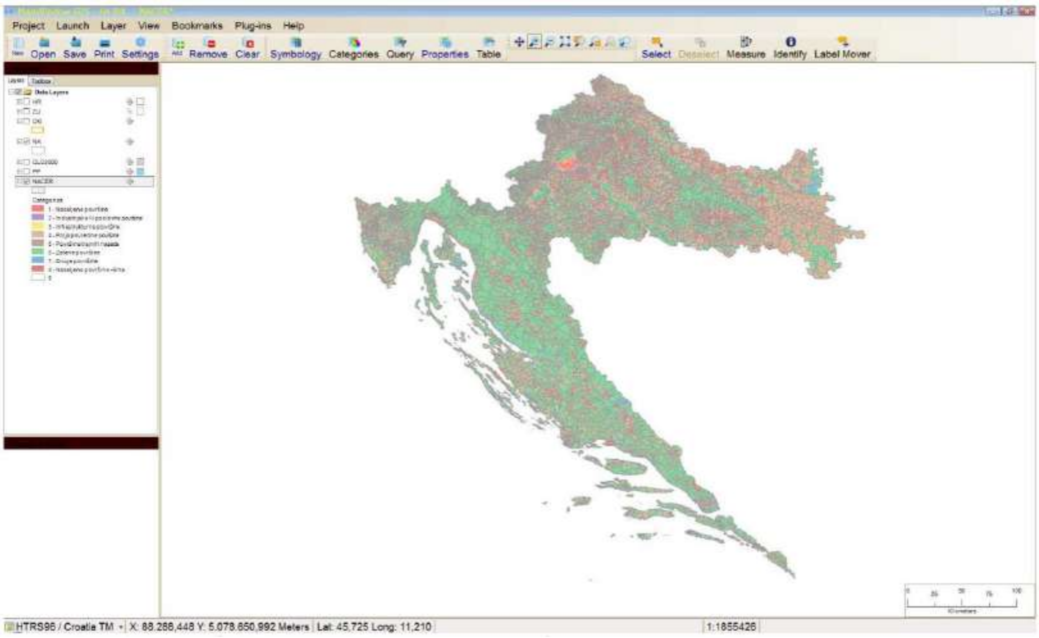


Figure 4.6: Working window of the NACER model. CORINE land use is shown in the map of Croatia (Vidmar et al., 2015)

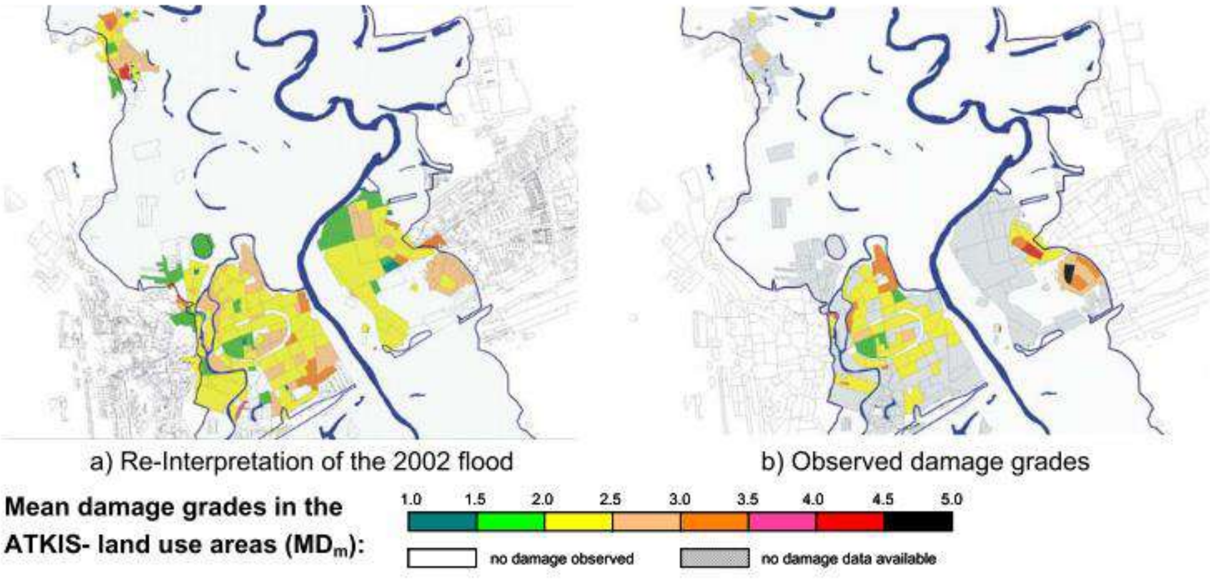


Figure 4.7: Comparison of calculated damages (left) and observed damages (right) using Schwarz and Maiwald (2008) tool

As in detail described in deliverable D2.2, already among the countries of the BORIS project partners, there are differences in flood risk assessment, regardless that assessment in all countries derives from Floods Directive. This is the case also for the flood risk matrices and damage curves. In Figure 2.2, one example of a risk matrix is presented. The matrices in different tools for flood risk assessment can have different numbers of likelihood levels as well as different number of impact levels.

Similarly, as with methodologies and matrices, for almost every of the tools described in the previous chapter, its own flood damage curves have been developed. Damage curves and loss probability curves are very important part of the flood risk analysis as well as for policy and decision makers in the flood risk management area. Below are shown examples of depth-damage curves and loss probability curves for few above-mentioned models. In Figure 4.8 six depth-damage curves used in the NACER model are presented. One can see that three of them were developed for the agricultural sector, while the other three were developed for residential buildings, industrial facilities, and vehicles.

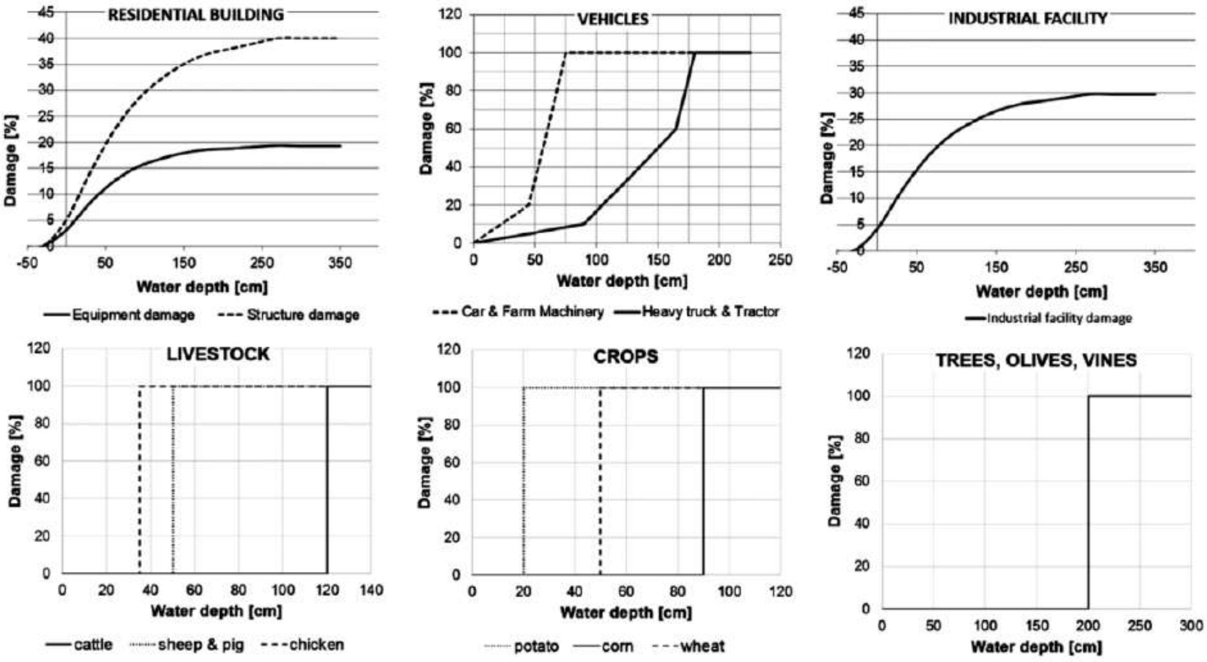


Figure 4.8: Depth-damage curves used in the NACER model (Vidmar et al., 2015).

In the Emschergenossenschaft and Hydrotec (2004) damage was also assessed for different types of assets. In Figure 4.9 seven relative depth-damage curves are shown for the following economic sectors: energy (dark blue line), and processing (red line), traffic (black line), public service (light blue line), mining (brown line), trade, accommodation, insurance, and similar (pink line), services (green line). In addition to these curves, also damage or vulnerability curves for other assets are included in the Hydrotec tool, i.e. for residential buildings, vehicles, agriculture and forestry land and infrastructure. Flood-induced damage is in HAZUS-MH tool assessed for different assets (e.g., general building stock, essential and high potential loss facilities, transportation systems, utility systems, agriculture, products, and vehicles. In addition to built-in depth-damage curves, the users have an option to create their own curves following the internal guides. In Figure 4.10 is shown one set of relative depth-damage curves for assessment of damage on residential building using HAZUM-MH model. Tool Rhine Atlas uses three sectors for which damage is assessed, namely residential areas, industry, and infrastructure. Those sectors are not divided further in detail, still, in all categories the damage is calculated for both the construction and the equipment (ICPR, 2001). The basis for the damage calculation are depth-damage curves that were developed based on the HOWAS data set and experts' knowledge.

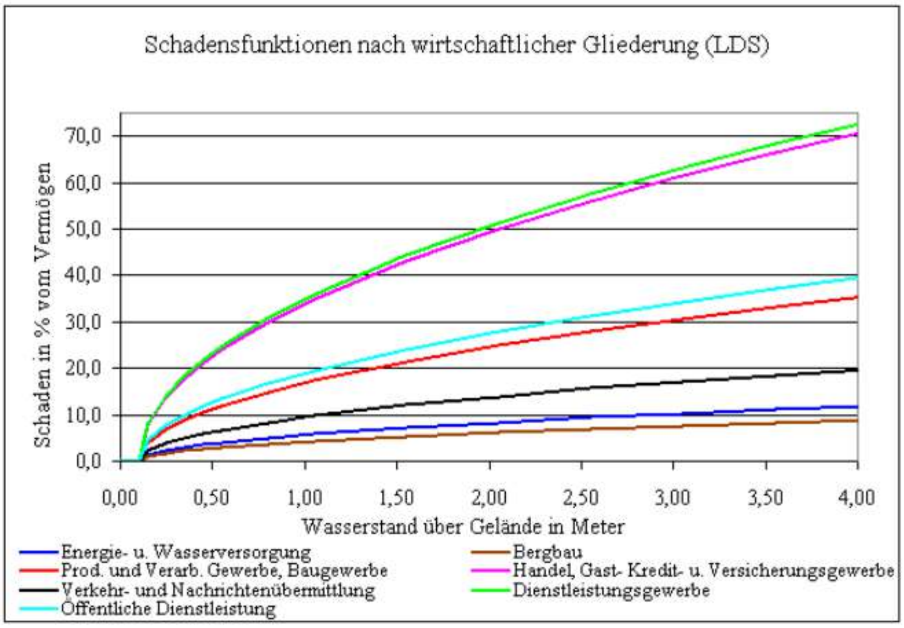


Figure 4.9: Depth-damage curves for different economic sectors used in Hydrotec model (Emschergenossenschaft and Hydrotec, 2004)

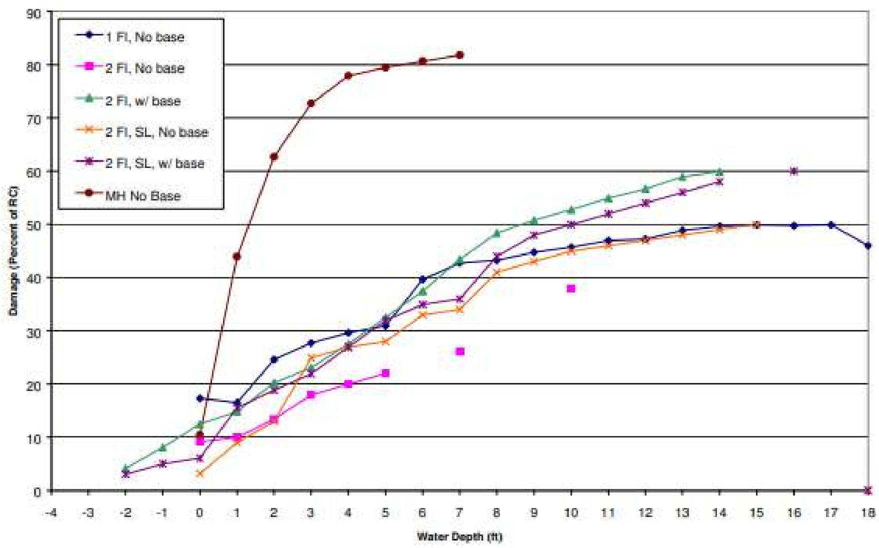


Figure 4.10: One set of depth-damage curves in HAZUM-MH model for residential buildings depending on the number of floors and presence of the basement (FEMA, 2014).

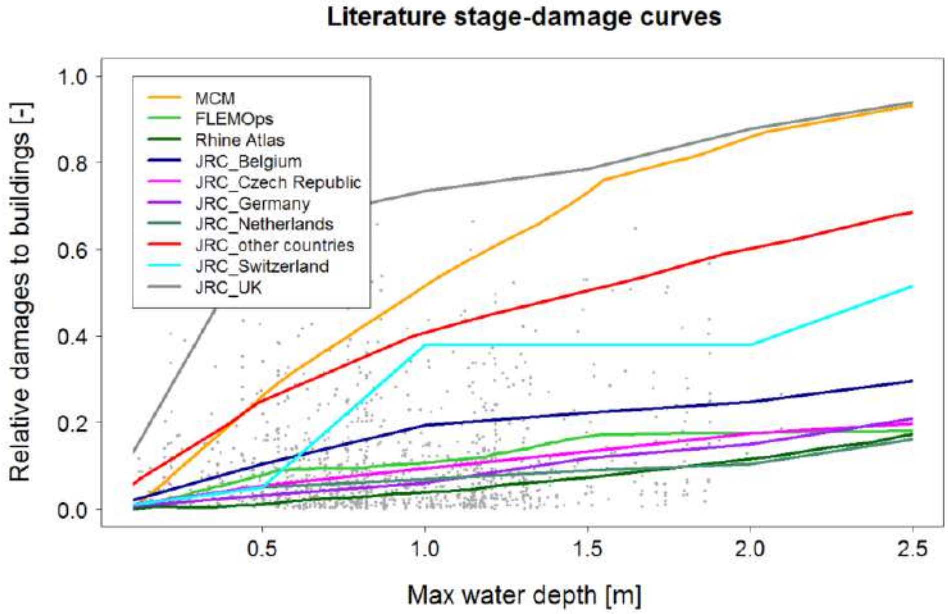


Figure 4.11: Comparison of different relative depth-damage curves (Carisi et al., 2018)

In the study of Carisi et al. (2018) the performance of a model developed on Italian dataset for the region Emilia-Romagna was assessed by comparing it with several flood damage models (e.g., JCR, MCM, FLEPOps, Rhine Atlas). A visual comparison of relative depth-damage curves is shown in Figure 4.11. One of the main conclusions of this study was a confirmation of Jongman et al. (2012) assumptions about the effects of regional differences on damage assessment, i.e. results of simpler model but with local data are significantly more accurate than results using other models from the literature.

5. REVIEW OF EXISTING TOOLS TO COMPUTE AND VISUALIZE RISK AND LOSSES FOR MULTI-RISK ASSESSMENTS

Multi-risk (multi-hazard) assessment tools have the potential to support decision-makers and can influence the perceptions about different hazards and their potential impacts. Besides national and regional studies (among others in Grünthal et al. 2006) on methods for the assessment of multi-hazards and multi-risks, a number of EU projects have been implemented since 2000 with the aim of analysing independent or also dependent events at different levels (Na.R.As.2004-2006, ARMONIA 2004-2007 and MATRIX 2010-2013, CLUVA 2010-2013, CRISMA 2012-2015), whereby especially the latter also had a focus on crisis scenarios (Zschau, 2019, BORIS 2021). Also, on the global level tools have been developed to visualise different data and single hazard layers and to rank towards a multi-risk view. Below is a non-exhaustive list of tools that are assessing more than one risk and are of relevance to the BORIS project.

5.1 List and description of multi risk assessment tools

CAPRA (Probabilistic Risk Assessment) Platform Universidad des los Andes Colombia aims to strengthen the institutional capacity for assessing, understanding and communicating disaster risk, with the goal of integrating disaster risk information into development policies and programs. The risk assessment module of CAPRA includes the software CAPRA-GIS, which uses probabilistic risk calculations (CAPRA, N.D). The software assesses hazards, exposure, and vulnerability on a spatial level by a standard format for exposure of different components of infrastructure, a vulnerability module with a library of vulnerability curves and an exposure, hazard and risk mapping geographic information system and has the ability to calculate multi-hazard risks (or multi-risk) (Ordaz & Salgado, 2017). The results are presented through risk metrics such as a probable maximum loss for any given return period or as an average annual loss. The target audience for CAPRA are local institutions, mainly in developing countries, and for those guiding decision-makers about the potential impact of disasters associated with natural hazards (Ordaz & Salgado, 2017). An example of the visualisation of risks in CAPRA is seen in Figure 5.1 below, where the level of risk is colour coded and categorised to the left.

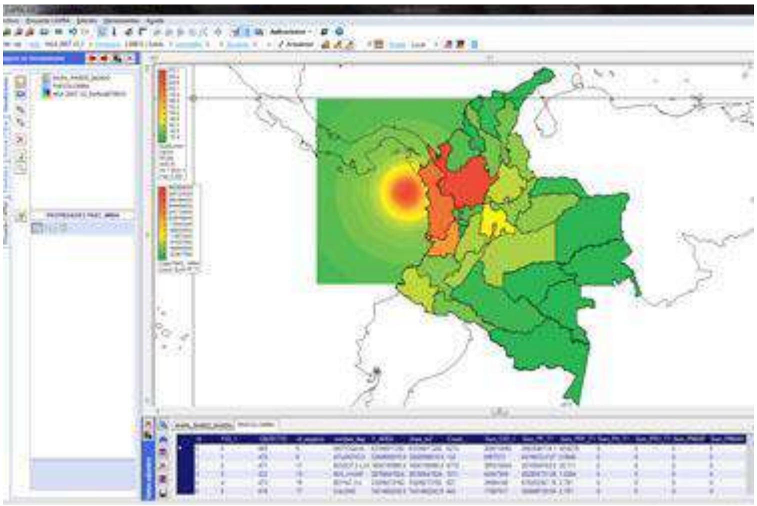


Figure 5.1: Risk assessment in CAPRA (OASIS, N.D).

myDEWETRATool (Pagliara et. al 2011) is an integrated system of the Functional Center of the Civil Protection Department, entirely developed by CIMA Research Foundation and Acrotec Foundation to provide real-time forecasting and monitoring regarding flood and forest fires risks, to which the national territory is exposed. The system is developed with the most modern technologies and compliant with international standards. Its interface automatically responds and adapts to different devices; data and functionalities are grouped together in a package of user applications.

Figure 5.2: Flooded area in the Bomporto (Modena) by the Secchia river. Images captured by Cosmo-SkyMed on 21/01/2014 and elaborated by CIMA Research Foundation and show within myDEWETRA.

Some of the activities possible with myDEWETRA are: the visualization of thematic predictions and observation maps, the contextual analysis of the monitoring data of the phenomena in progress, the evaluation of the possible impacts to these consequents and the drafting and diffusion of the criticality bulletins (Figure 5.2). myDEWETRA is moreover designed to have a high simplicity of use. The scientific know-how and usability possible to the various functional centres using myDEWETRA daily make it a technically certified tool for operational use, even during emergency phases. New technologies, gradually introduced to meet the needs of the operators, make it in fact a shared platform in continuous transformation and development. my DEWETRA's versatility has also allowed its easy implementation in numerous international civil protection cooperation actions, worldwide.

DRMKC Risk Data Hub's Risk Analysis is a GIS-based open-source web-platform where different hazards and their possible consequences on different types of assets can be mapped, ranked and matrixed. It is focused on the risk evaluation of European countries (Figure 5.3). The categories of assets implemented are population, buildings, critical services, and environment. Each of these categories has subcategories, so the user can look at exactly which kind of consequence(-s) to which hazard(-s) they need compared/assessed. It is possible to choose as many or as few hazards and assets as wanted - making it applicable for a multi-hazard view. The user can choose a timeframe ranging from 1 to 25 years to see how exposure and risk may change in each number of years, if no actions are taken. The mapped risk is determined probabilistically as a function of hazard, exposure, and vulnerability. The result is weighed on a scale of 0-10 and color coded for convenience of the user (Salvi et. al, 2022) - an example of this is demonstrated in Figure 5.3. The data used in the Risk Data Hub stems from different databases e.g., EM-DAT, DFO, and SHARE (DRMKC, N.D). Additionally, the program gives the user the possibility of downloading a report of the calculated exposure, vulnerability, and risks. Additional information about this web-platform can be found in the technical report "The DRMKC RDH Users' Guide: A tutorial for external users on the use of the DRMKC RDH" by Salvi et. al. (2022).

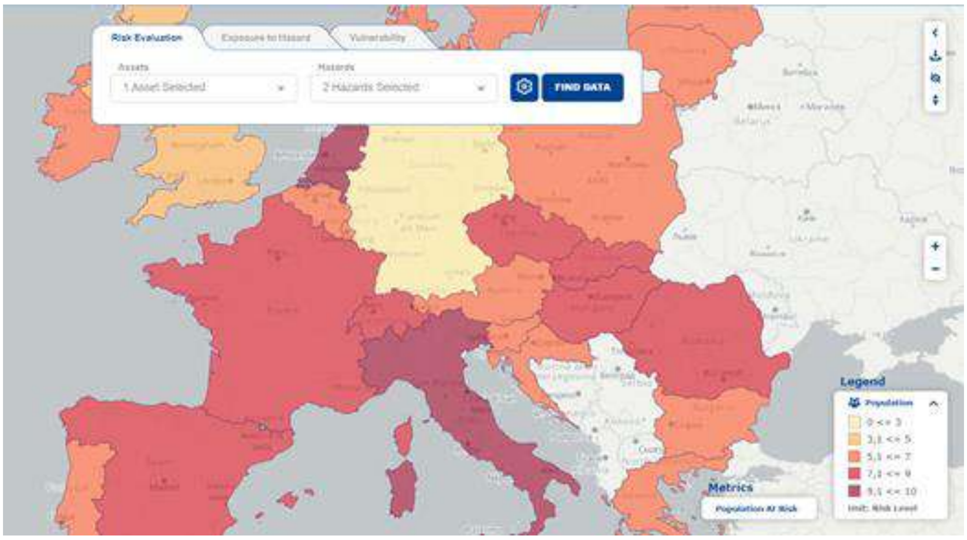


Figure 5.3: Screenshot of Risk Evaluation in Risk Data Hub for the asset “Population at Risk” and the hazards “Earthquake” and “River Flood” in a 1-year timeframe (DRMKC, N.D).

HAZUS-MH program and methodology is developed and distributed by the US Federal Emergency Management Agency (FEMA, 1999). HAZUS provides standardized tools and data for estimating risk from earthquakes, floods, tsunamis, and hurricanes. HAZUS can quantify and map risk information such as physical damage to infrastructure, economic loss, social impacts, and cost-effectiveness. It allows to identify vulnerable areas and to assess the level of readiness and preparedness to deal with a disaster. The study area can be a region, a community, a neighbourhood, or an individual site, it is limited more by the available data then by the scale. The nationwide databases included are non-proprietary and therefore can be easily shared. HAZUS-MH has been designed with an open framework that allows additional local datasets to be easily merged into the existing databases, allowing customization of the databases to produce more accurate results. The software is distributed as a GIS-based desktop application with a growing collection of simplified open-source tools that provides three levels of analysis: A Level One analysis is a rough estimation based on the nationwide database. A Level Two analysis requires the input of refined data, hazard maps and knowledge of local experts to get more accurate risk and loss estimations. To support this refinement three data input tools are available: the Inventory Collection and Survey Tool, the Building data Input Tool and the Flood Information Tool. Level three shows the most accurate estimate of damage and usually requires the involvement of technical experts who can modify the damage parameters based on the specific characteristics of a community. As mentioned before to conduct a Level one and two assessment local knowledge and access to an ArcGIS software is needed and therefore can be carried out by the scientific communities, practitioners as for example local government and planners and technical experts, emergency response personnel and civil protection authorities. However, the GIS-based environment allows users to easily create graphics (risk maps, bar charts) to help communities visualize and understand their hazard risks and solutions to prepare, recover and mitigate.

Location Risk Intelligence Platform (Natural Hazard Edition) is a software tool from the reinsurance company MunichRe's to analyse and to manage physical risks of natural hazards and climate change that aims at focusing on both the local and cross-border context. This modular solution combines different complementary assessment models to generate results based on data from past events (NatCatservice) and future oriented assessments that consider climate change scenarios. The Natural Hazards Edition is available as an on-demand version focuses on different hazards: earthquake, volcano, tsunami, tropical cyclone, extratropical storm, storm surge, tornado, hail, lightning, wildfire, river flood, flash flood. The individual modules have different levels of functionality and features, as for example the flood module includes Natural Hazards Defended (for Netherlands and Belgium only) and allows the integration of additional data sources (Germany and England only). Some modules include the NATHAN risk scores (see Fig.4.5) describing the vulnerability, i.e. the magnitude of potential financial damages. Users can search for locations visualise risk scores and download them as comprehensive reports (MunichRe, 2021)

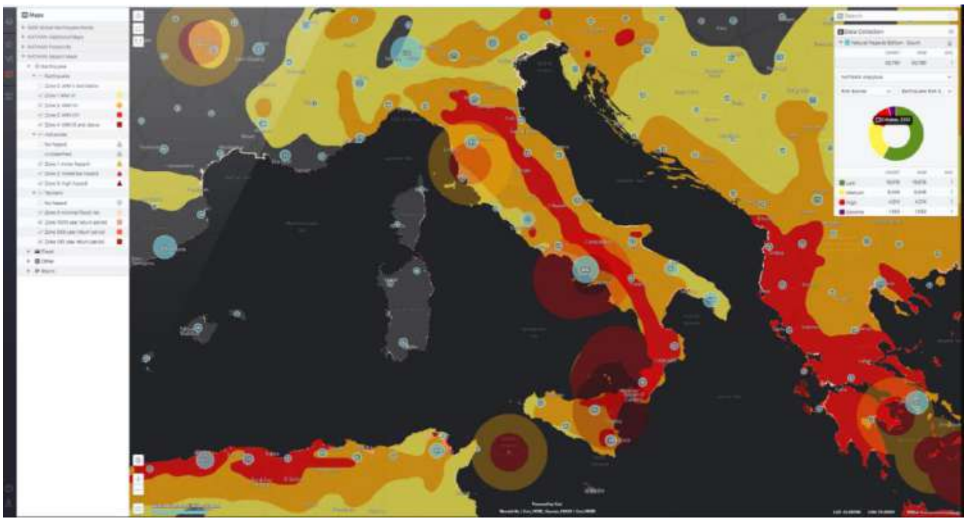


Figure 5.4: Example of visualization of Risk Scores for earthquake risk (low=green to extreme = violet) (, 2021)

MATRIX - The EU FP7 project Multi-HAzard and MulTi-RIsK Assessment MethodS for Europe has investigated between 2010 and 2013 innovative solutions assessing multiple natural hazards and risks as a step towards dealing comprehensively with disasters. It integrated new methods for multi-type assessment, accounting for risk comparability, cascading hazards, and time-dependent vulnerability. Three test sites were considered during the project: Naples, Cologne, and the French West Indies. A test software platform, the MATRIX-Common IT system, was developed to allow the evaluation of characteristic multi-hazard and risk scenarios in comparison to single-type analyses. (Aspinall et al. 2014, Nadim et al. 2013)

National Risk Index (NRI) is another tool developed by the FEMA for assessing risks in the USA. NRI is completely open source and is intended for both experts and interested individuals without prior experience (FEMA, 2021). NRI's method of assessing different risks is by a calculation containing three variables; expected annual loss, social vulnerability, and community resilience (FEMA, 2021). The data source for the Vulnerability variable is University of South Carolina (UofSC) HVRI's Social Vulnerability Index (SVI), where 29 socioeconomic quantitative factors are compared (FEMA, 2021). The data source for the Resilience variable is from UofSC HVRI's Baseline Resilience Indicators for Communities (BRIC), which provides a methodology for quantifying community resilience by identifying the ability of a community to prepare and plan for, absorb, recover from, and adapt to the impacts of natural hazards (FEMA, 2021). The Expected Annual Loss is calculated based on the consequence-, likelihood risk factors of natural hazard exposure, and Natural Hazard Historic Loss Ratio (HLR) (FEMA, 2021). The source of HLR is Arizona State University's Spatial Hazard Events and Losses Database of the U.S (SHELDUS). The impact/consequence of any natural hazard is categorised into three types; buildings, population, and agriculture. NRI provides the user with either a single risk assessment, or a multi risk assessment of all hazards, of a given territory. Using this tool, it is possible either to display the overall risk for all hazards combined or for every hazard separately, though an individual selection and combination of the single hazards is not possible. Figure 5.5 shows for example a map with the risk index for "all hazards" This includes floods, earthquakes, avalanches, hurricanes, winter weather etc combined, and the legend (to the left) the categorisation of the level of risk. It is possible to change between county view and census tract view, which is more detailed.

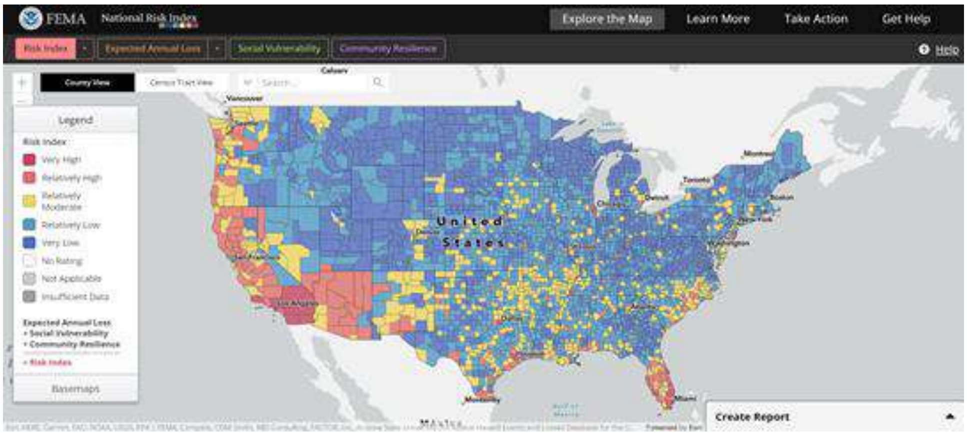


Figure 5.5: National Risk Index in "County View" for all hazards (FEMA, 2021).

RiskScape is an open access software tool that enables users to assess risk to buildings, infrastructure and people from natural hazards such as earthquakes, tsunamis, volcanic ash fall, windstorm and floods. The model to assess multi-risks was developed in the project `Regional RiskScape' at the Research Organization GNS Science and the National Institute of Water and Atmospheric Research Ltd. (NIWA) in New Zealand. The loss modeling tool combines hazard, asset and vulnerability layers, through a data selection process, to quantify a range of economic and social consequences. It has been developed for a range of end-users and tasks including land-use planning, emergency management contingency planning, cost-benefit analysis, and hazard research. The aim is to support practitioners to decisions on natural hazard management activities. RiskScape currently provides for nine asset types: agriculture, buildings, electricity cables, network junction points, open space, pipelines, roads, telecommunications cables and waterways. (Thomas et al. 2020)

5.2 Maps, curves and matrices for presenting the results of multi-risk assessments

One approach to presenting multiple risks is through risk mapping. Risk maps are described in detail in paragraph 1.1. All of the tools reviewed in the chapter 5.1 are able to display both single- and the combined overall risk (multi-risk) by using maps. One of the tools that display multi hazard risk assessment results this way is DRMKC Risk Data Hub's Risk Analysis, as seen in Figure 5.3. Risk Dats Hub intents to provide a tool to support national and local authorities, to make the comparison of potential impacts across hazards possible. However, national hazards that are the basis for this risk assessments often stop directly on the border, without assessing transboundary contexts. The knowledge exchanged and procedures that are developed and tested within BORIS expand the scientific background behind tools, as presented within this report towards cross-border risk assessment (seismic and flood), as well as multi-risk comparison and ranking. Risk maps offer the advantage of being simple to understand, but it is still important to have an accurate legend and the opportunity to obtain background information on how risk was calculated. Another way of presenting and ranking multi-risk is through a risk matrix. Risk matrixes are described in detail in paragraph 1.2. This way of presenting risk is less common among the listed tools above. However, DRMKC Risk Data Hub's Risk Analysis platform has the ability to show the user the average expected likelihood and intensity of the chosen risk(-s) in combination with a "third dimension" indicating whether the disaster risk is acceptable, managed or is unacceptable. The blue dot in Figure 5.6 represents the risk of river flood, while the brown dot represents earthquake risk – in this example the two risks both have a high likelihood of occurrence, but the earthquake has slightly higher intensity, and are therefore both categorised as acceptable Disaster Risk /Low risk).

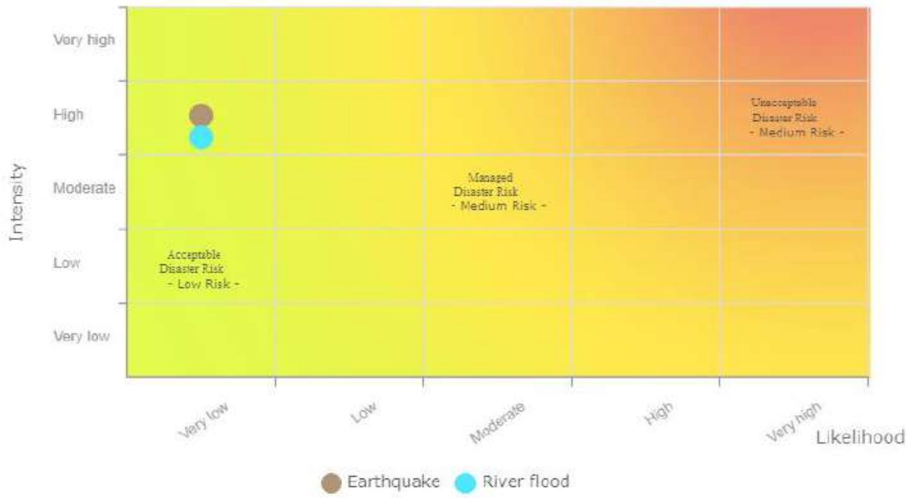


Figure 5.6: Risk matrix of the expected impacts of earthquakes and river floods for Austria for the next 1 year (DRMKC, N.D.).

Another way to display risk is through risk curves, described in detail in chapter 1.3. A risk curve is a completely quantitative way of displaying risk and can effectively be used in various analysis methods and presents clear relationships between selected metrics (see also D4.1). Risk curves are often the underlying methodology / information behind risk maps, whereas the curves are rarely available within the open-source tools or platforms. To create risk-curves is a very data-demanding method, and it does not take in account all spatial differences (Van Westen, N.D.). None of the multi-risk tools above exclusively use risk curves, however, tools like HAZUS can create both risk curves, other quantitative analysis methods and risk maps (Sevieri et. al, 2020). As seen in Figure 5.7, it is possible to develop different kinds of risk curves in HAZUS to depict vulnerability with regards to different variables. In this case HAZUS, however, depicts two separate single risks, instead of a compared multi-risk curve, where interactions are considered. An ongoing challenge towards a multi hazard / multi risk view is how to compare different risks, Figure 5.8. shows an example of combined risk curves of different hazards to indicate losses of buildings and content (Grünthal et al., 2006)

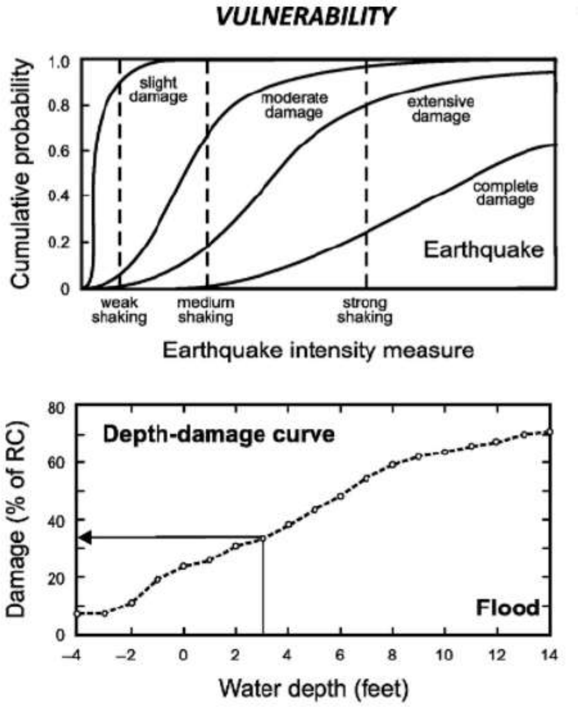


Figure 5.7: (Top) Vulnerability curve presenting earthquake intensity compared to the cumulative probability. (Bottom) Vulnerability curve presenting flood water depth compared to damage. (Nastev & Todorov, 2013)

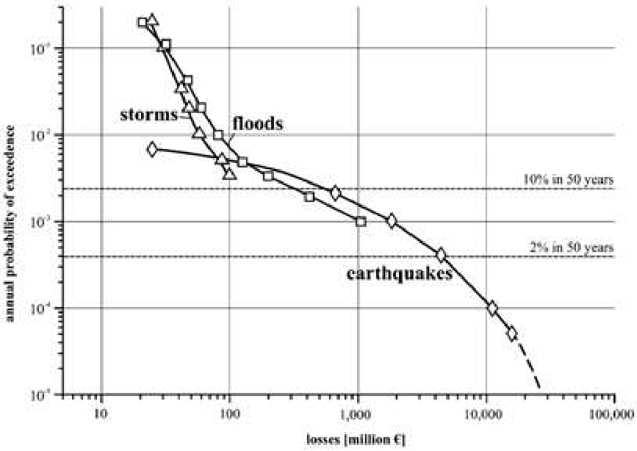


Figure 5.8: Combined Risk curves of the different hazards and losses concerning buildings and contents for the city of Cologne (Grünthal et al., 2006).

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