EFLIP

Economic impacts of
Flood risk in Lombardy
and Innovative
risk mitigation Policy

D2.1 Prototype of the flood vulnerability and impact database with gaps filled

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Executive summary

Natural hazard risks are essentially dynamic, depending on climate variability as well as on changes in vulnerability patterns (IPCC, 2012). Climate change and socioeconomic developments strongly affect such natural dynamics which include changes in the probabilities or intensities of hazards (Elmer et al., 2012; Cammerer et al., 2012; Cammerer and Thieken, 2013). Flooding regimes associated with human-induced environmental alteration and new climate change-related hazards are examples of such socio-natural hazards. Socioeconomic development includes land use changes, demographic and asset values at risk changes, and consequently changes in the vulnerability of elements at risk and the communities' adaptive capacity (Hufschmidt et al., 2005; Bouwer et al., 2011; Przyluski and Hallegatte, 2011). Therefore, vulnerability can be described as 1) multi-dimensional (e.g., physical, social-cultural, socio-economic, and environmental); 2) dynamic (vulnerability changes over time); 3) scale-dependent (vulnerability can be expressed at different scales); 4) site-specific (each location might need its own approach). Since both vulnerability and hazard are non-stationary, risk changes in time (Merz et al., 2010), the integration of both climate change scenarios and socioeconomic change scenarios are fundamental to extrapolate the risk situation and damage assessment into the future.

A key part of risk assessment studies consists in the estimation of the vulnerability of flood-prone areas, that is, the consequences that could be caused, in terms of damage and loss, by flood events of different magnitudes. Therefore, knowledge about vulnerability of elements at risk is necessary as a key concept for both disaster risk and climate change adaptation, for identifying appropriate risk reduction measures (Merz et al., 2010).

In the first part, this document describes the design, development and application of a conceptual foundation for a quantitative integrated vulnerability assessment as a fundamental component of risk assessment, using the Source-Pathway-Receptor-Consequence (SPRC) model and a GIS-based approach. Integration of all the available information into geodatabases and their implementation are considered as crucial stages in the methodological steps for vulnerability assessment.

The second part of the document focuses on impact database. Recording disaster loss data is equally important as their gaps identification. Here, the aim is to collect and rehabilitate the scattered data on the economic impact of selected past flood events in Lombardy, including the indemnities paid to insurance policy holders, compensations paid for uninsured residential flood damage and state aid provided to economic entities to foster recovery. Here, a preliminary and fragmented catalog of damages and losses data has been created for the selected past event occurred in Lombardy between 2014 and 2019 for which a National state of emergency have been declared by the Government. Next steps will consist of the collection of a comprehensive dataset through the access to the RASDA archive, with gaps filled related to the selected significant past flood events occurred in Lombardy Region.

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1. Prototype of the flood vulnerability

Vulnerability is a key component of risk assessment: $R_{isk}=H_{azard}xE_{xposure}xV_{ulnerability}$. Recently Poljanšek at al., 2017 have related to vulnerability as "*the susceptibility of assets such as objects, systems (or part thereof) and populations exposed to disturbances, stressors or shocks as well as to the lack of capacity to cope with and to adapt to these adverse conditions. Vulnerability is dynamic, multifaceted and composed of various dimensions, all of which have to be considered within a holistic vulnerability assessment*." Furthermore the the United Nations General Assembly (UNGA) considers the vulnerability as '*The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards*' (UNGA, 2015).

Vulnerability to meteo-hydro-geologic hazards of the exposed elements can be assessed at different dimensions (Birkmann, 2006): (1) physical, (2) social-cultural, (3) socio-economic, and (4) environmental dimension, through the development of vulnerability indicators or damage functions. In any case, vulnerability represents the system's or the community's physical (structural, including the built environment), social, and economic susceptibility to damage and it is heavily influenced by the lack of capacity to cope, recover and adapt in the face of disaster risks.

In EFLIP project the vulnerability assessment as fundamental component of risk assessment will be based on the Source-Pathway-Receptor Consequence concept (SPRC) and the methodology is completely GIS-based (ICE, 2001; Schanze et al., 2006) (Figure 1).

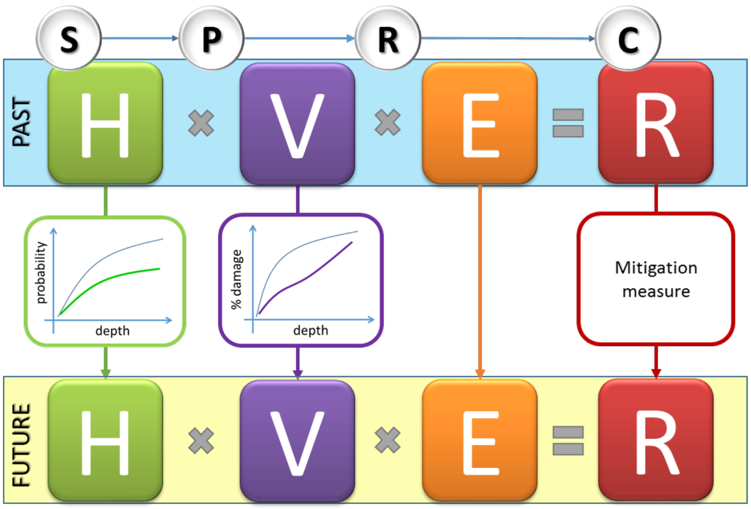

Figure 1 SPRC conceptual model for risk assessment

The SPRC model describes the hazards in terms of the process of event propagation, the initiation of a hazard and its propagation through a pathway to a receptor with certain consequences (usually negative) (ICE, 2001; Taramelli et al., 2014). For a risk to arise, there must be hazard that consists of 'the source', an individual or object that

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could be damaged 'the receptor'; and a 'pathway' between the source and the receptor (Horrilo-Caraballo et al., 2013). Essentially, the system is defined by identifying known route for Pathway between their Source and impacts. Once the Source-Pathway-Receptor is identified, the consequences that could be caused, in terms of damage and loss, by flood events of different magnitudes can be evaluated (related to Vulnerability).

On the base of data availability, data accuracy, and scale of study measuring physical vulnerability is a complicated process, and can be done using three approaches:

a) *empirical*, involving a complete analysis of the observed past events in the study areas. The purpose is to obtain relationships between the physical features of the damaging events and the degree of loss of the impacted elements. The result is either a damage probability matrix or a vulnerability curve. Different curves for different structural characteristics of the involved elements can be performed;

b) *analytical*, studying the behavior of buildings and structures based on engineering design criteria using numerical models and computer simulation techniques to estimate the reliability of a structure and calculate its probability of failure techniques and focusing on the assessment of the degree of loss by vulnerability index calculation;

c) *theoretical*, estimating the damage state probability according to the possibility to describe a structure in terms of its likelihood (probability) of exceeding a certain limit state at a specified stress condition.

Elements at risk have a certain level of vulnerability, which can be defined in a number of different ways. Many studies exist applying a multi-elements approach over large areas (Meyer and Messner, 2005). Only a few numbers of approaches exist for single elements (Léone et al. 1996; Faella and Nigro, 2003; Roberds, 2005) given the lack of data related to the physical/mechanical parameters of the damaging events as well as the degree of loss experienced by vulnerable elements in the past. When considering physical vulnerability only, it can be defined as the degree of damage to an object (usually expressed on a scale from 0 meaning no damage, to 1 meaning total loss) exposed to a given level of hazard intensity (e.g., water depth). Vulnerability data is often collected in the form of vulnerability curves, damage curves or vulnerability matrices, which indicate the relationship between the levels of damage to a particular type of element at risk given intensity levels of the flood hazard. Generation of vulnerability curves is a complicated issue, as they can be generated empirically from past damage event for which intensity and damage is available for many elements at risk, or through numerical modelling (Roberts et al., 2009). Akbas et al., 2009 developed specific vulnerability indicators for every element at risk using the concept of probabilistic damage functions and appropriate definition of relevant damage states for every element at risk, including sources of uncertainties related to the temporal probability and the probability of spatial impact. Damage functions (and associated damage estimation for several intensities of hazardous events) are very rare in the

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scientific and engineering community and are a necessary step forward in quantitative risk assessment.

Some aspects have to be addressed with specific methods and modelling approaches. The physical and economic dimension of vulnerability will be addressed using probabilistic and deterministic approaches associated with damage scenarios and potential economic impacts. Social vulnerability will be assessed with reference to demographic, institutional and cultural aspects defined by indicators, population data, statistics and qualitative judgments.
In this task, the physical vulnerability of the different elements at risk will be investigated by evaluating existing information (also from outside the study area). The database of past events will be used to obtain relationships between the physical features of the damaging events and the structural characteristics of the impacted elements (Akbas et al., 2009). First, we obtain the "inundation map", which provides flood depth extension and flow velocity for the inundated zones of the study area for the considered past event. Second, we construct consistent "land use maps" for the maximum inundated area. Third, we will do the exposure analysis and asset assessment by describing the number and type of elements at risk and by estimating their asset value. Fourth, in regard of vulnerability identification, elements which are exposed to hazard will be categorized into homogenous classes (Hasanzadeh et al., 2015). Naturally, the responses of the impacted elements are not deterministic. They invariably have a measure of both randomness and uncertainty associated with them due to the variability of the structural characteristics and construction technique. It is very probable that the data compiled from the past events will not be enough to estimate this uncertainty. Therefore, a theoretical approach should also be used to complement the whole process, by defining damage curves. By means of input data related to the stage of the Hazard (i.e., water depth and velocity), Vulnerability (i.e., number of story's, building type, surface area, presence of basement, construction materials, quality of building, etc.), Exposure and with the help of damage curves, ex-ante direct damages will be assessed in relative or absolute values. Therefore, once source-path-receptor is identified, such a model may be used to characterise any flood event that falls within the defined boundaries of the study at any resolution, and an impact can be evaluated as a consequence, in terms of expected losses (in a given area as a result of a given hazard scenario).

As a result, the vulnerability contribution is to map and define the **Structural Vulnerability**, that is the potential of a particular class of buildings or infrastructure facilities to be affected or damaged under a given flood intensity. Here general building stock, specifically residential and critical facilities are considered in the Structural Vulnerability assessment.

The flood hazard and vulnerability assessment can be summarized in a step by step procedure as follows (Figure 2): 1) Hazard scenarios definition (including flood extent, depth, duration and flow velocity); 2) Elements at risk characterization (type, location, structural and architectural features) and exposure of elements at risk to hazards

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(assessment of the elements at risk potentially affected by flood) and 3) Vulnerability assessment and loss estimation.

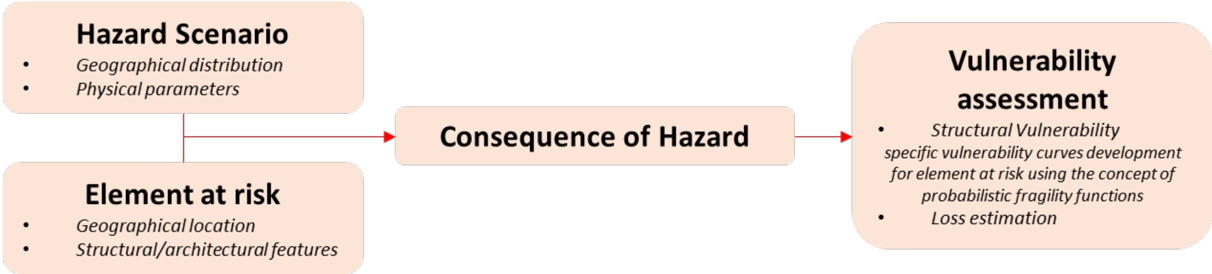

Figure 2 Methodology overview

1.1 Vulnerability Assessment

1.1.1 Hazard scenarios definition: source estimation

Hazard is obtained by reconstructing the delimitation of the flood affected area and replicate the flood characteristics (i.e., depth of flood water, and velocity and flood duration if possible) using state-of-the-art hydrological and hydraulic models, and remote sensing data for selected, significant flood events in Lombardy.

1.1.2 Elements at risk identification: pathway and receptor estimation

The proposed methodology in vulnerability assessment looks at the land parcel in order to generate an up and downscaling process that allow the integration of each considered building result into a local scale assessment, and in view of the capacity building objective, into a regional scale. In order to propose the best methodology to guarantee the self-application for a self-assessment of vulnerability a hierarchical and replicable structure of the database will be assessed on the base of data availability (Taramelli et al., 2010; Taramelli et al., 2014).

All assets have a “value”, which can be expressed in monetary terms, in number of persons affected or in less quantifiable units such as cultural importance or environmental quality. Assets can be identifiable objects such as persons, buildings, cars, etc. but also include systems and services such as a community, utilities and the economy. It is therefore important to have a good inventory of the assets in a given area. It is also important to map locations of special interest such as cultural heritage sites, factories with dangerous materials and potential critical facilities such as schools, hospitals and retirement homes. An element at risk is about exposure to the hazard. What is there that can be damaged or destroyed, injured or killed, hampered or interrupted. The degree to which this is effectuated depends on the intensity of the hazard and the intrinsic quality of each element at risk to suffer loss due that particular hazard with that particular intensity. This intrinsic quality is called the “vulnerability”. Elements at risk assessment should be done based on certain basic spatial units. In the proposed vulnerability prototype, an exposed asset is firstly defined at mesoscale, based on spatial aggregation units (aggregation units are define based on relevant

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impacted land use categories and imperviousness degree). Then, at microscale the purpose of a building inventory classification system for residential buildings stock and critical facilities is to group buildings with similar characteristics into a set of pre-defined building classes that could be affected by analogous damage/loss. Specifically, critical facilities consists of the physical structures, facilities, networks and other assets which provide services that are essential to the social and economic functioning of a community or society (UNGA, 2016), such as hospitals, healthcare facilities, and schools. These sites, if affected by an emergency, may enlarge the scope of impact by exacerbating the problem by reducing ability to respond or presenting a secondary problem greater than the primary one.

Therefore, the Pathway estimation is evaluated by overlapping obtained hazard maps with elements at risk distribution map, and a corresponding hazard class is assigned to each building class (Taramelli et al., 2014). This represents the Pathway estimation and it is done in order to define the magnitude of different damaging flood related events assigned to each element at risk (representing the Receptor estimation).

1.1.3 Vulnerability assessment: consequences estimation

The main aim is to analyse patterns of vulnerability, speed of recovery of disrupted production, and improve the parameterisation of the flood damage assessment models developing specific vulnerability curves for element at risk based on flood damage curve (i.e., probabilistic damage functions) for the assessment of the macro-economic impacts of selected past events and future flooding events in Lombardy.

In order to assess vulnerability from flooding hazards there is a need to integrate hazard analysis results into vulnerability assessments. Vulnerability assessment needs to be fed by the amount of "social, economic or ecological units or systems which are at risk of being affected regarding the relevant kinds of hazard in a specific area, e.g. persons, households, firms, economic production, private and public buildings, public infrastructure, cultural assets, ecological species and landscapes located in a hazardous area or connected to it" (Messner and Mayer 2006).

Depending on the spatial extent of the investigated area and the study degree of detail of the damage assessment, a wide number of elements at risk have to be considered as described in the sub-paragraph 1.1.2. Generally, damage assessment for each single object is not possible due to a lack of information on the damage behavior of each object and/or because such a detailed assessment would require a huge effort. Thus, elements at risk are usually pooled into classes, and the damage assessment is performed for the different classes, whereas all elements within one class are treated in the same way (Merz et al., 2010).

In most cases, the classification is based on economic sectors, based on the understanding that different economic sectors show different characteristics concerning assets and susceptibility (e.g., private households, companies, infrastructure, with a further division into subclasses) (Merz et al., 2010).

The physical parameters of the flood damaging events (water depth and velocity) will be related to indicators of structural, social and economic units and systems. These sets of indicators refer to preparedness, coping and recovery capabilities and

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strategies of individuals and social systems, and measure how sensitively an element at risk behaves when face with some kinds of hazard (Messner and Mayer, 2006). According to Messner and Mayer (2006), awareness and preparedness indicators for individuals and communities include for instance: the number of households protected against hazard impacts by means of technical measures, the number of people with insurance against damage, participation in evacuation plans and number of people affected. It should be noted that socio-economic element at risk indicators could be a function of: (i) location (ii) socio-economic indicators as defined above (iii) and type of residence. The empirical vulnerability functions allow for an estimation of expected direct losses as a result of considered hazard scenarios, which are based on a spatially explicit representation of process patterns, and elements at risk categorized into defined typological categories as describe above (Mazzonara et al., 2014). Each vulnerability graph will express the relationships between physical damage and degree of hazard for diverse classes of building. Finally, vulnerability will be expressed or presented through: 1) damage curves providing the probability for a particular group of element at risk to be in or exceeding a certain damage state under a given hazard intensity; 2) vulnerability curves displaying the relation between hazard intensity and degree of damage for a group of elements at risk (e.g. a certain building type) ranging from 0 to 1. Vulnerability curves can be relative curves (showing the percentage of property value damaged) or absolute (show the absolute amount of damage); and 3) damage probability matrix that indicates the probability that a given structural typology will be in a given damage state for a given intensity.

1.2 GIS-based approach

All components of the risk are spatially varying. To be able to evaluate these components we need to have spatially distributed information. Computerized systems for the collection, management, analysis and dissemination of spatial information, so-called Geographic Information Systems (GIS) are used to generate the data on the hazard and vulnerability components. GIS-based approach allows homogenization and integration of all the available information into geodatabases, a standardized access to data, the generation of thematic cartography and spatial and geostatistical analysis. Once the data are defined, they are collected, validated and stored in a database using a GIS system.

The design of the element at risk GIS model seeks to automate the assessment process because it facilitates the conduct of spatial and tabular analysis to calculate the area and population estimation scores (Santini et al., 2010). In each hazard area, the hazard boundaries will be used to perform a 'tabulate' analysis in each available "elements at risk" datasets. So that, the 'tabulate' function will be used to compute the estimation score using the hazards classes as polygon masks. On the basis of the different hazard entities determined, a table will be created: floods estimated element at risk. Then, once a set of grids has been created on the basis of the table it is possible to calculate link-by-link statistics with the ZONALSTATS command. The output will be an attribute table, which has an entry for every zone. In this task the zone will be a grid referring to the flood hazard values and will include the equation for a population table, the land

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covers areas tables, and the elements at risk table. In order to finally calculate the estimate of the element at risk we look at the population living in the potentially affected areas, comparing the data with the land cover and the elements at risk. Special emphasis could be also put on social vulnerability indicators subject to data availability.

1.3 Geodatabase (GDB) Implementation

The aim is to collect a large empirical data set from the meso-scale (i.e., impacted land use categories) to the micro-scale (i.e., impacted individual buildings and critical facilities), which includes hazard and exposure variables for three significant past flood events in Lombardy.

The geodatabases implemented in GIS system are used in the methodological steps for vulnerability assessment as described in paragraph 1.1 and the information needed for implementing Geodatabases have been collected from a variety of sources (Table 1) and then spatially projected to get a georeferenced data set for each study case.

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Data	*Data Format*	*Spatial resolution*	*Coverage*	*Coordinate System*	*Reference years*	*Description*	*Source*	*Link*	*Access*
Flood hazard (Source)									
Directive 2007/60/CE	Vector	1:10000	Lombardy Region	WGS84/UTM32	2019	This map service shows Hazard and risk mapping, consisted of a preliminary flood risk assessment, which involved the identification of significant historical events (both in terms of the phenomenon severity and the caused damage) and delimitation of areas with significant potential flood risk. The specific requirements refer to the mapping of the areas or river sectors affected by historical floods and their consequences on human health, environment, cultural heritage and economic activity.	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Digital Elevation Model	Raster	5 m	Lombardy Region	WGS84/UTM32	2015	The main input data used to create the DTM are: 1. the regional topographical database for about 80% of the territory (in particular the information layers concerning morphology: contour lines, quoted points and break lines); 2. the Lidar of 1 mx 1 m resolution along the watercourse rods and, for limited portions where the data were not available, with altimetric data from the previous edition of the regional DTM 20 mx 20, from the Regional Technical Charter scale 1: 10,000 edition 1982-1994.	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Global flood model	Model	NA	Global	EPSG:4326 - WGS84	NA	GLOFRIS can assess changes in flood risk at the global scale under a wide range of climate and socioeconomic scenarios. Fluvial flood inundation layers from the GLOFRIS global flood model. Flood inundation maps were provided for 8 return periods between 5yr and 1000yr. The unit of the data is inundation depth in meters. The data resolution is 30 arc seconds (approximately 1km at the equator). The data are provided in GeoTIFF raster file format '.tif'	GLOFRIS	https://www.geonode-gfdrrlab.org/people/profile/GLOFRIS/?limit=20&offset=0	open
Hydrological rainfall-runoff model	Model	NA	Europe	NA	NA	The LISFLOOD model is a hydrological rainfall-runoff model that is capable of simulating the hydrological processes that occur in a catchment. LISFLOOD has been developed by the floods group of the Natural Hazards Project of the Joint Research Centre (JRC) of the European Commission.	LISFLOOD	https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/lisflood-distributed-water-balance-and-flood-simulation-model-revised-user-manual-2013	open
Hydrological and hydraulic data	Report, Tabular, Vector, Raster, WMS, WFS	NA	Lombardy Region	GAUSS-BOAGA MONTE MARIO / ITALY ZONE 1 (EPSG: 3003)	NA	Regional Environmental Protection Agency: -Cumulated precipitations; -daily precipitations; -CN number ; -Historical precipitation, Temperature and water level data; -rainfall depth (mm) 1-24h and return period (2,5,10,20, 50, 100 E 200 yrs) 1.5X1.5 Km ; -water balance	ARPA	http://idro.arpalombardia.it/pmapper-4.0/map.phtml	open

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Global Active Archive of Large Flood Events	Tabular, Report, Vector, WMS	NA	Global	NA	1985-present	Flooded area location, flood duration, flood triggering factors, surface of flooded area, flood severity and magnitude. Global The Active Archive of Large Flood Events information is derived from news, governmental, instrumental, and remote sensing sources. Each entry in the table and related "area affected" map outline represents a discrete flood event. However, repeat flooding in some regions is a complex phenomenon and may require a compromise between aggregating and dividing such events. The Archive includes: 1) an online .html table of recent events, only; 2) Excel .xlsx and .xml files for all events, 1985-present, updated as the recent events html is updated; and 3) Zip-compressed GIS MapInfo format and Shp format files, each providing flood catalog numbers, centroids, area affected outlines, and other attribute information and updated as the recent events html is updated.	Dartmouth Flood Observatory (DFO)	http://floodobservatory.colorado.edu/	open
European past floods	Tabular, Report	NA	Europe	NA	1985-present	Dataset contains information on past floods in Europe since 1980, based on the reporting of EU Member States for the EU Floods Directive (2007/60/EC) and combined with information provided by relevant national authorities and global databases on natural hazards. Reported data have been assessed and processed by the ETC-ICM and the EEA.	European Environmental Agency EEA	https://www.eea.europa.eu/data-and-maps/data/european-past-floods	open
Land Cover/Land Use (Pathway)									
Administrative Limits	Vector	1:10000	Lombardy Region	WGS84/UTM32	2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, present	The database contains the administrative, provincial and mountain communities boundaries of the Lombardy Region.	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Agricultural and Forestry Land Cover/Land Use	Vector	1:10000	Lombardy Region	WGS84/UTM32	2012, 2015, 2018	DUSAF (Destinazione d'Uso dei Suoli Agricoli e Forestali) is a detailed geographical database of agricultural and forestry land use. Orthophotos (taken by AGEA, 1 pixel = 0.2m to the ground) were used, with color aerial photos taken in 2018 and satellite images SPOT6 / 7 2018 (1 pixel = 1.5m to the ground).	DUSAF Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open

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Urban Atlas	Vector	10 m	Varese, Como, Bergamo, Brescia, Milano città Metropolitana, Lecco, Vigevano, Pavia, Cremona	ETRS_1989_LAEA	2012	Urban Atlas provides detailed land cover and land use information over major EU city areas for year 2015, covering a number of Functional Urban Areas (FUA). In 2012, an additional layer (Street Tree Layer - STL) was produced for a selection of FUAs. It includes contiguous rows or a patches of trees covering 500 m² or more and with a minimum width of 10 meter over "Artificial surfaces" (nomenclature class 1) inside FUA (i.e. rows of trees along the road network outside urban areas or forest adjacent to urban areas should not be included). 2012 Urban atlas contains population estimates for each polygon.	Local - CLMS	https://land.copernicus.eu/local/urban-atlas	open
Land Cover/Land Use	Vector	50-10m	Europe	ETRS_1989_LAEA	1990, 2000, 2006, 2012, 2018	CLC is a project supervised by the European Environment Agency. It has so far produced four pan-European land use maps for 1990, 2000, 2006, 2012 and 2018. The maps are prepared mostly by manual classification of land cover patches from satellite imagery with a resolution of 25m or better. The inventory consists of 44 classes. The minimum size of areal features is 25 ha. For linear objects such as roads, railways, and rivers, a minimum width of 100m is used.	Corine Land Cover - CLMS	https://land.copernicus.eu/pan-european/corine-land-cover	open
IMD – Imperviousness degree	Raster	20m & 100m	Europe	ETRS_1989_LAEA	2006, 2009, 2012, 2015	The percentage of sealed area is mapped for each status layer for any of the 4 reference years. The status layers are available in the original 20m spatial resolution, and as aggregated 100m products.	HRL - CLMS	https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness	open
IMC - Imperviousness change	Raster	20m & 100m	Europe	ETRS_1989_LAEA	2006-2009, 2009-2012, 2012-2015	A simple layer mapping the percentage of sealing increase or decrease for those pixels that show real sealing change in the period covered. This product is available in 20m and 100m pixel size.	HRL - CLMS	https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness	open
IMCC - Imperviousness change classified	Raster	20 m	Europe	ETRS_1989_LAEA	2006-2009, 2009-2012, 2012-2015	A classified change product that maps the most relevant categories of sealing change (unchanged no sealing, new cover, loss of cover, unchanged sealed, increased sealing, decreased sealing). This product is available in 20m pixel size only.	HRL - CLMS	https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness	open
Element at Risk (Receptor)									
Rapid mapping and Risk and recovey Mapping	Report	NA	Europe	NA	NA	The Copernicus Emergency Management Service (EMS), managed directly by the European Commission, delivers warnings and risk assessments of floods and provides geospatial information derived from satellite images on the impact of natural and man-made disasters all over the world (before, during or after a crisis). The service has two main components: Early Warning and Mapping. Specifically, the EMS Mapping Service provides maps derived from satellite. The mapping service operates in two modes: Rapid Mapping for emergencies that require an immediate response, and Risk & Recovery	Copernicus Emergency Management Services (EMS)	https://emergency.copernicus.eu/mapping/#zoom=2&lat=44.18701&lon=45.3343&layers=00B0T	partially open

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						Mapping for situations that do not require immediate action such as prevention and disaster risk analysis and recovery activities. The Mapping service, produces spatial analysis using remote sensing techniques for events for which the service is activated.			
Healthcare facilities	Vector	1:10000	Lombardy Region	WGS84/UTM32	2016	Healtcare facilities for acute and post-acute rehabilitation. The information contained includes: the structure's code and name, address, type of relationship with the Regional Health Service (public structure, private contract, private non-contract) location in the Urgency Emergency network (First aid point, First Aid, Department Acceptance Emergency, High Specialty Emergency), presence of Pediatric First Aid. The perimeters of the buildings.	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Schools	Vector	1:10000	Lombardy Region	WGS84/UTM32	2016	Public and Private schools present in Lombardy in 2017 are represented. It includes 8,469 locations of nursery, primary, secondary schools, Territorial Centers for Adult Education, Technical and professional institutes. The information level, given the high number of points, is visible starting from the 1: 500.000 scale.	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Number of residents	Vector	1:10000	Lombardy Region	WGS84/UTM32	2014, 2017	The map service contains Istat data relating to the resident population in 2014 and 2017	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Shops and Historical venues	Vector	1:10000	Lombardy Region	WGS84/UTM32	2017	The database contains the historical sites of the Lombardy region, divided into three categories: - historical activities - historical shops and venues - historical and traditional signs	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Commercial District	Vector	1:10000	Lombardy Region	WGS84/UTM32	2019	Each District is made up of a single Municipality (DUC - Urban Commercial District, in the case of Province and Municipalities with more than 25,000 inhabitants) or a group of three or more Municipalities of the same Province.	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Cultural Heritage	Vector	1:10000	Lombardy Region	WGS84/UTM32	2017	It contains data relating to the historical architectural heritage cataloged in SIRBeC database (Sistema Informativo Regionale dei Beni Culturali). The pop up of each point or polygon on the map allows the connection to the complete resource published in lombardiabeniculturali.it, regional portal dedicated to cultural heritage.	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Subway, railways, and roads	Vector	1:10000	Lombardy Region	WGS84/UTM32	2019	The map service contains data relating to the networks: roads and highways (highways, state roads, provincial roads) of the entire territory of Lombardy, railways (including Alta Velocità), subways (Milan and Brescia).	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open
Population statistical data	Vector	1:10000	Lombardy Region	WGS84/UTM32	2001-2011, 2011-2014, 2014-2017	The map service contains census data relating to the resident population of 2001, 2011, 2014 and 2017, compared to the changes in the resident population between 2001 and 2011 and between 2014 and 2017 and the change in the n . of inhabitants per km^2 between 2001 and 2011 and between 2014 and 2017.	Geoportale Regione Lombardia	http://www.geoportale.regione.lombardia.it/download-ricerca	open

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Residential Buildings	Tabular	NA	Italy (municipalities)	NA	2011	General Population and Housing Censuses: The population and housing census collects information on persons usually resident in each municipality, thus providing an overview of the demographic and social structure of Italy and its territories. Residential buildings by period of construction (classes: up to 1918, 1919-1045; 1946-1960; 1961-1970; 1971-1980; 1981-1990; 1991-2000; 2001-2005; 2006 or after), Residential buildings by building material (class: load-bearing wall; reinforced concreete; different from load-bearing wall and reinforced concreete); Residential buildings by number of floors in the building (included ground floor) (classes: 1, 2, 3, 4, more than 4); State of the building (very good; good; poor; very poor); Residential buildings by period of construction (classes: 0;1;2;3-4;5-8;9-15; 16 and over)	Population Housing Census ISTAT	http://dati-censimentopopolazione.istat.it/Index.aspx?lang=en&SubSessionId=66e23a75-0bf5-4333-b5da-7710525c5756&themetreeid=16#	open
Exposure	Raster	100 m	Europe	NA	1870-2016	Maps for 37 countries and territories from 1870 to present in 100m resolution. HANZE-Exposure consists of high-resolution gridded data with information on land use, population, production, and wealth per 100m grid cell from 1870 to present. Exposure data are prepared with a 10-year time step for 1870– 1970 and a 5-year time step for 1970–present. The baseline land cover/use is based on CORINE Land Cover (CLC) 2012, version 18.5a. CLC 2012 is first displayed as a vector map, and can then be transformed into a raster with 100m resolution. The baseline population map is based on the GEOSTAT 2011 population grid, version 2.0.1 (Eurostat, 2017). This data set has 1 km resolution and for most countries it represents the actual population enumerated and georeferenced during the 2011 round of population censuses, complemented by estimates by the European Commission's Joint Research Centre. Data on soil sealing were obtained from the Imperviousness 2012 data set (Copernicus Land Monitoring Service, 2017). It was created based on high resolution satellite photos taken during 2011–2012 in visible and infrared spectrum. This data set has 100m resolution, which was resampled to a 1 km grid, so that average population density in grid cells with given imperviousness could be calculated.	HANZE-EXPOSURE	https://doi.org/10.4121/collection:HANZE	open
Building Height	WMS	1:10000	Italy	NA	1988, 1994, 2000, 2006, 2012	Building Height (classes [m]: 0 - 3; 3,1 - 5; 5,1 - 10; 11 - 15; 16 - 20; 21 - 25; 26 - 30; 31 - 35; 36 - 45; 46 - 100)	Geoportale Nazionale	http://www.pcn.minambiente.it/GN/	open
Damage and losses (Consequence)									
Building market value quotations	Tabular	NA	Italy	NA	2006-2019	geographical location (city center, semi-center, city periphery, suburban, extraurban), use (residential, commercial, tertiary sector; and typology, based on market value quotations by the official real estate observatory of Italy (Agenzia delle Entrate).	Agenzia delle Entrate - OMI	Agenzia delle Entrate: Osservatorio del Mercato Immobiliare – Quotazioni zone OMI, available at: http://www.agenziaentrate.gov.it/wps/content/Nsilib/Nsi/Reportazione/omi/Banche+dati/Quotazioni+immobiliari/	open

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Past flood disasters carachteristics	Tabular	NA	Europe	NA	1870-2016	It is a compilation of past flood disasters with information on dates, locations, and losses, currently limited to floods only. The database was constructed using high-resolution maps of present land use and population, a large compilation of historical statistics, and relatively simple disaggregation techniques and rule-based land use reallocation schemes. It allows one to derive potential damages for any past natural hazard with a defined spatial extent. Data encompassed in HANZE allow one to "normalize" information on losses due to natural hazards by taking into account inflation as well as changes in population, production, and wealth. This database of past events currently contains 1564 records (1870–2016) of flash, river, coastal, and compound floods. It is supplemented by economic data necessary for converting nominal monetary losses into a single benchmark. HANZE covers 37 European countries and territories constituting approximately 70% of the continent's population (Eurostat, 2017).	HANZE-EVENT	https://doi.org/10.4121/collection:HANZE	open
Reconstruction and restoration costs per EUR/m2	Report	NA	Italy	NA	NA	CRESME/ANIA data (Reconstruction and restoration costs per EUR/m^2):-reconstruction cost per square meter for residential buildings having 1-2 dwellings; -reconstruction cost per square meter for residential buildings having 3-15 dwellings; -cost of reconstruction in residential buildings with 16 and more dwellings	CRESME/ANIA	http://cresme.cineas.it/login.aspx?ReturnUrl=%2fdoc%2fmanuale-utente.zip	reserved
Natural and man-made disaster humanitarian datas (fatalities, injured and evacuated)	Tabular	NA	Global	NA	1900-2019	The EM-DAT (Emergency Events database) in force to the centre for research on the Epidemiology of Disaster (CRED) at the Louvain University in Belgium, it is one of the most known global datasets. It started operating since the 1988 with the initial support of the (WHO) and Belgian government. It contains data collected and stored focused on main health aspects with information going back to 1900,mainly humanitarian data such as fatalities, injured and evacuated. the EM-DAT International Disaster Database is the only dataset that uses a particular set of quantitative criteria for defining major floods, such events being considered only when fulfilling at least one of the minimum "disaster-threshold": >10 casualties, >100 affected persons; declaration of a state of humanitarian emergency, the need for international assistance. The EM-DAT is one of the most comprehensive and detailed global disaster database covering 1900-to date period. There are economic loss data based on information provided by the UN organizations and other institutions such as Lloyds and press agencies.	EM-DAT Centre for Research on the Epide-miology of Disasters (CRED)	https://www.emdat.be/	open
Calamitous events damages	Tabular and Report	NA	Lombardy Region	NA	2003-present	RASDA is the acronym of (Raccolta schede danni, damage formscollection) and it is an on-linedatabase system created by Lombardy region in order to face the occurrenceof calamitous events (D.G.R. 22 December 2008-n. 8/8755). Following the current use of the platform, the main aimis the assessment of the conditions of damaged towns and territory, the identification of disruption on critical infrastructures and the estimation of losses and costs of repairing both for public and private assets. The RASDA system is divided into 4 sections, for the public sector (A,B1,B2,B3), data can be uploadedfrom authorized figures. Then, once the request procedure is completed a, there is an on-field assessmentfrom the UTR (territorial office of the region), which has the duty to verify that the description of the consequences of the events are correct and correspond to the level of disruptionand to the amount of monetary resources required. The classification of the magnitude of the event is performed by a team of technician: Depending on the magnitude, and the dimension of the affectedzone it can be appointed as a national (c) event or if it is of minordimension, it is classified as a regional event (b) or even as a local event (a).	RASDA System (Lombardy Region)	http://www.rasda.regione.lombardia.it/rasda/	reserved
Hydrogeological disasters database	Report	NA	Italy	NA	1992-2000	The Information System on Hydrogeological Disasters (SICI) of the CNR-GNDCI provides bibliographic information relating to hydrogeological disasters that have affected the Italian territory.	SICI (CNR-GNDCI)	http://sici.irpi.cnr.it/index.htm	open

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Past flood catalogue	web-GIS	NA	Italy	NA	2011-present	FloodCat database is the national Italian catalogue for past floods designed by the Italian Civil Protection Department (DPC) with the support of the Italian national institute for environmental protection and research, and developed by the CIMA Foundation. FloodCat is the official Italian web-GIS platform for collecting information on past floods according to the EU Floods Directive (Dir. 2007/60/CE). The platform fulfils the function of catalogue of flood events, recording and sharing disaster damages and losses.	FloodCat	http://www.mydewetra.org/	reserved
Refundes Data	Report	NA	Europe	NA	2002-present	The Fund was set up to respond to major natural disasters and express European solidarity to disaster-stricken regions within Europe. The Fund was created as a reaction to the severe floods in Central Europe in the summer of 2002. Since then, it has been used for 80 disasters covering a range of different catastrophic events including floods, forest fires, earthquakes, storms and drought. 24 different European countries have been supported so far for an amount of over 5 billion €.	European Union Solidarity Fund (EUSF)	https://ec.europa.eu/regional_policy/en/funding/solidarity-fund/	open
Natural and man-made disaster economic loss, insured losses, victims and homeless	Report	NA	Global	NA	1970-present	Sigma database share historical data about natural and man made catastrophes, the number of lives lost and world re/insurance premiums going as far back as 1970. Specifically the Sigma platform provide access to loss data containing economic loss, insured losses and the number of victims and homeless.	SIGMA - Swiss Re Institute	https://www.swissre.com/institute/	partly open
Natural disaster direct economic losses, insured losses, socio-economic information, economic damaged sectors	Report	NA	Global	NA	1980-present	NatCatSERVICE archive provides comprehensive, reliable and profes-sional data on insured, economic and human losses caused by any kind of natural peril. Under the Events menu, users can choose one or more peril families (geophysical, meteorological, hydrological, climatological). There also is the option of viewing globally or by continent. The Focus analyses provide hazard-specific information. The country profiles provide more complex analyses, such as income groups according to the World Bank definition, insurance penetration, or an analysis of fatalities from natural catastrophes. They include graphics on number statistics, loss amount diagrams, percentage distributions, tables and a map. Among diverse sub-peril classes, all kinds of inland flood events based on general floods and/or flash floods. The topics in the Country profile include three aspect: 1) Income groups: The World Bank Income Group classification is used to give an overview of how affected the different groups are, in terms of natural catastrophe losses over the time. 2) P&C insurance penetration: Insurance penetration from non-life business coming from property & casualty insurance. The penetration is calculated using the primary insurance premium volume in % of GDP per country. 3) Fatality rate index: The index indicates a country's human vulnerability and exposure to natural disasters, based on the mortality rate standardised per 1 million population	NatCatSERVICE of munich Re	https://natcatservice.munichre.com/topten/6?filter=eyJ5ZWFyRnJvbSI6MjAxNiwieWVhclRvIjoyMDE2LCJldmVudEZhbWlseUlkcyI6WzVdLCJmb2N1c0FuYWx5c2lzSWQiOjYsImZvY3VzQW5hbHlzaXNBcmVhSWQiOjM1fQ%3D%3D&type=1	partly open
Flood events	Tabular, report	NA	Italy	NA	2016	National updated archive of flood events, specified by intense meteorological phenomena, highlighting their impact on the territory in terms of economic and human damage, also at the end of an evaluation of the ongoing climate modification changes	ISPRA (Istituto Superiore per la protezione e la ricerca ambientale)	https://annuario.isprambiente.it/ada/downreport/html/6660	open
Global Active Archive of Large Flood Events	Tabular, Report, Vector, WMS	NA	Global	NA	1985-present	Number of causalities and evacuees, damage costs, animations of flood events. Global The Active Archive of Large Flood Events information is derived from news, governmental, instrumental, and remote sensing sources. Each entry in the table and related "area affected" map outline represents a discrete flood event. However, repeat flooding in some regions is a complex phenomenon and may require a compromise between aggregating and dividing such events.	Dartmouth Flood Observatory (DFO)	http://floodobservatory.colorado.edu/	open

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						The Archive includes: 1) an online .html table of recent events, only; 2) Excel .xlsx and .xml files for all events, 1985-present, updated as the recent events html is updated; and 3) Zip-compressed GIS MapInfo format and Shp format files, each providing flood catalog numbers, centroids, area affected outlines, and other attribute information and updated as the recent events html is updated.			
European past floods	Tabular, Report	NA	Europe	NA	1985-present	Dataset contains information on past floods in Europe since 1980, based on the reporting of EU Member States for the EU Floods Directive (2007/60/EC) and combined with information provided by relevant national authorities and global databases on natural hazards. Reported data have been assessed and processed by the ETC-ICM and the EEA.	European Environmental Agency EEA	https://www.eea.europa.eu/data-and-maps/data/european-past-floods	open

Table 1 Information needed for implementing Geodatabases: data, data format, spatial resolution, coverage, coordinate system, reference years, data description, source, link, access are reported when available (NA: not available). All the information has been gathered following the proposed vulnerability prototype and the SPRC model: red=Flood hazard (Source); green= Land Cover/Land Use (Pathway); yellow= Element at Risk (Receptor); gray= Damage and losses (Consequence)

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1.3.1 Flood Hazard GDB

Flood Hazard GDB includes all layers of information that are useful to simulate impact of hazardous event and to associate a representative physical classification.
A collection of past events was considered a primary source of information. Flood related-hazard maps with information on selected significant events will be collected and stored in the Flood Hazard Geodatabase. Delimitation of the flood affected area and replicate the flood characterizes (depth of flood water and velocity if possible) using state-of-the-art hydrological and hydraulic models, and remote sensing data for selected past events in Lombardy Region. Where possible we will complement that information with reconstruction of flood extent and dynamics, also using the remote sensing data (e.g., flood delineation and depth reconstructed using Earth Observation (EO) such as Copernicus Sentinel) and Digital Elevation Model (DEM). We will use hydrological observation and flood extent reconstruction of the regional environmental agencies, and the Copernicus Emergency Service (EMS), and other available data such as GLOFRIS and LISFLOOD. Specifically, flood raster maps provide the expected flood geographical distribution and allow the physical event parametrization. In addition, when available Dartmouth Flood Observatory (DFO) and HANZE-event data are used to reconstruct flood events geographical distribution.

1.3.2 Land Cover-Land Use GDB

When analysing physical risk, the exposure component consists of the exposed physical assets, such as buildings and infrastructure. Land use data at coarse spatial resolution are often use as starting point for the creation of exposure data sets. The availability of this type of data is increasing. The best example can probably be found in Copernicus Land Cover Monitoring Service. General building stock are firstly categorized into 7 relevant impact categories using CORINE Land Cover, Urban Atlas (if available) freely available as perimeters dataset and Lombardy Region database (i.e., DUSAF-, Shops and Historical Venues, Commercial District, Cultural Heritage, Regional subway, railways, and road database): Residential, commercial, industrial, infrastructure, cultural heritage and rural heritage classes. The database also contains multispectral satellite imagery and the natural resources maps like land covers, natural protected areas, vegetation distributions, wetlands and water lens, etc. Land cover/use and soil sealing maps and green infrastructures, geomorphological, ecological and physical settings (e.g., terrain model, satellite images, orthophotos, habitat maps) if necessary, it provides important boundary conditions for the analysis. Therefore, land cover and soil sealing changes data can improve the understanding of how flood risk will be amplified as a result of environmental and climate change scenarios.

1.3.3 Element at Risk GDB

Elements at risk data are very often based on building footprint maps, which represent the location of buildings, with attributes related to their use, size, type and number of people during different periods of the year (e.g., daytime and nighttime). Remote

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Sensing is often used to extract these building maps if existing cadastral maps are not available. For other elements at risk like transportation infrastructure also remote sensing data can be used as important inputs.

Buildings and infrastructures are one of the most important group of elements at risk. Physical elements at risk information can be obtained in several ways. For instance, ideally data is available on the number and types of buildings per mapping unit, or even in the form of building footprint maps. These exiting data can be collected from cadastral data or census data. If such data is not available, building footprints maps can be generated using high resolution satellite images (Fraser et al., 2002), InSAR (Stilla et al., 2003), and specifically using LiDAR if available (Priestnall et al., 2000; Brenner, 2005; Oude Elberink and Vosselman, 2009). One of the necessary components to perform structural vulnerability modelling for a set of buildings, the exposure data set should include different information, such as their estimated value, spatial location, geometry, height, occupancy type as well as other characteristics to correctly estimate the damage (Figuriedo et al., 2016). In order to be able to assess the potential losses and degree of damage of elements at risk, it is important to analyze the type of negative effects that the event might have on the elements at risk exposed to it, and the characteristics of the elements at risk. At a residential building level relevant descriptive structural attributes specific building types classification, such as the building use, the period of construction, the material type, the maintenance state, the number of stories, building height and occupancy classes are important for determining the damage due to flooding allowing to specific building types classification. Information on residential building was mainly obtained from ISTAT (ISTAT, 2011), the Italian National Institute for Statistics. General Population and Housing 2011 Census data are used to define the period of construction, the material type, the maintenance state, the number of stories, and occupancy classes of residential building. Height information for the same buildings, are obtained from WMS Service of Geoportale Nazionale (Edificato e Civici dei capoluoghi di Provincia database). Other useful data can be found in OpenStreetMap (OSM), and Geofabrick database containing a large number of features, in which footprints of buildings are included. Critical Facilities identification is provide using Lombardy Region database including schools healthcare facilities and hospitals. Population is another important element at risk, with a static and dynamic component. The static component relates to the number of inhabitants per mapping unit, and their characteristics, whereas the dynamic component refers to their activity patterns, and their distribution in space and time. Population distribution can be expressed as either the absolute number of people per mapping unit, or as population density. Census data are the source for population and demographic indicators and they were selected from the database of the 2011 population census (ISTAT, 2011) (e.g., number of resident and Lombardy Region database, number of residents, number of inhabitants based on land use classes). Census data is aggregated to census tracts (i.e., divisions of land that are designed to contain a certain number of inhabitants with relatively homogeneous population characteristics, economic status and living conditions) and normally data at an individual household level is not available. In the absence of census data static population information can be derived directly using high resolution satellite imagery

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(Harvey, 2002) or through a building footprint map, where the land use type and the floorspace are used to estimate the number of people present in a particular building. But this is not the case.

In order to express losses in economic terms also an estimation of elements at risk costs needs to be done. Several sources of information can be used, such as data on house prices from real-estate agencies, information from cadastres, which indicate the value used as the basis for taxation, engineering societies, which calculate the replacement costs, or insurance companies (Grünthal et al., 2006). It is often difficult to get hold of the building values used by the cadastres, whereas it is easier to use the values from real estate agencies. Samples are taken from each type of building in the various land use classes. Cost estimation can be carried out by using the replacement value or the market value. Therefore, reconstruction and restoration costs per EUR/m^2 can be obtained from the CRESME/ANIA and Building market Value Quotations of OMI database (Agenzia delle Entrate). They can be used to convert the absolute damage values into relative damage shares.

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2. Impact database with gaps filled

A proper documentation and analysis of past events impact database is the backbone of disaster risk reduction, arising from EU legislation and policies and a priority for the Sendai Framework 2015-2030. The main aim here is to analyse and fill in the gaps in the past records of damage and losses caused by significant floods in Lombardy and, therefore, contribute to building an open-access, regional flood hazard, vulnerability and risk database. Recording disaster loss data is important, but no national agreed definitions or accounting practices exist for disaster loss data, making national incomplete and unreliable. Therefore, information from local archives, insurance companies and interviews of damaged owners integrate the degree of data completeness.

The GIS model developed for elements at risk assessment will be produced through a mix of tabular and spatial manipulations for specific estimation scores for critical land cover and specifically for topographic parameters. Then a calculation of the area value is a conditional concept:

• Hazards tabulate maps could be used to delineate the interested area;

• Land use maps could be used to define different economic sector categories within the area of element at risk.

Based on the monetary value of the areas applied, within the economic and environmental vulnerability of the site (parameter to be chosen), an overall value cost of a particular event can be calculated. This procedure will simply describe the extent of damage to existing land use. Obtained flood hazard categories will be used to quantitatively provide the levels of exposure of each element at risk stored in the geodatabase and attain an indication of the potential damage. Associated tangible losses to vulnerability are generally divided into direct and indirect losses:

- Direct tangible losses: Physical damages to assets (eg., Private and public buildings, infrastructure, installations, machinery, equipment, transportation means, storage and furniture etc.), business interruptions, loss of industrial production, consumption, cost of evacuation and rescue operations, estimated cost of demolishing and clearing areas where there has been destruction.

- Indirect tangible losses: Business interruptions (outside hazard area), loss of time and profits due to traffic disruptions, temporary housing for evacuees, lack of energy and telecommunication supplies and the interruption of supply with intermediary goods.

1.4 Empirical data collection and ex-post assessment

Empirical damage data are the most important set of information for improving and validating damage models. Empirical data collection and ex-post damage assessment

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for having an accurate prediction of the future disasters, decreasing the level of the uncertainty and improving the parameterization of the flood damage assessment models. The empirical data collection can be summarized in a step by step procedure as follows:

1. Review provided inventory data;
2. Perform data gap analysis;
3. Collect additional local data from local archives, insurance companies, and interviews of owners' elements, which have been damage;
4. Implement new data in the model.

On this track, we aim to promote a shared effort towards an updated catalogue of floods that includes damage information at the micro-scale .

Data from countries, institutions, and even the international databanks that already exist are still fragmented, structured differently, lack uniformity on the type of data and on how to gather and inform it. Empirical damage records were gathered starting from three global multi-peril loss databases, EM-DAT, NatCat and Sigma, which provide a global coverage for a large time span, to local administrations and RASDA service (i.e., Raccolta Scheda Danni) providing damage resulting from natural disasters occurred across Lombardy Region territory. Local data (i.e., at the micro-scale level, of the individual building) are usually collected by local authorities (Municipalities) using special reporting forms. Therefore, RASDA system is effectively used only when an event has such a magnitude that it is classified as regional or national. In global databases the data stored in the collection system are referred to overall data over the country affected and only in limited cases there are more in-deep specifications over specific regions and include diverse kind of damage and loss data, such as fatalities, injured, affected people, estimated economic losses, missing, homeless, and evacuated. At regional level, RASDA service could give important information on damaged elements location, damage description and amount, and damaged assets characteristics, including damages to both private and public sectors (i.e., structures, infrastructures, residential buildings, productive sectors). Each record includes claimed, verified and refunded damage to residential buildings. Moreover, RASDA allows to identify which sector is affected the most, because the economic losses are divided with respect to the sectors, while global databases give an overall datum. At last EM-DAT due to its structure is more precise with respect to the affected population, indeed there are specification over fatalities, injured and affected people, while in RASDA only about the evacuated population.

In order to complete the analysis of the economic losses on the different economic sectors an empirical-based classification of physical damages will be performed considering infrastructures and critical facilities for the public sector and residential buildings (quantification of damages to households) and business (quantification of damages to the assets) for the private sector. Furthermore, the types of building will be designed to represent the average characteristics of buildings in a class in order to develop loss prediction models for the “average characteristics” of building types.

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A catalog of different sources where to get historical damage and estimates of losses recorded (Table 1) is also stored in the database.

1.4.1 Preliminary Impact catalog on selected events

A preliminary and fragmented catalog of damages and losses data has been created for the selected past event occurred in Lombardy between 2014 and 2019 for which a national state of emergency have been declared by the Italian Government, the national Italian catalogue for past floods (Table 2). The preliminary catalog contains for each flood event relevant information, if available. Specifically, the database contents are:

- *Event ID*: event number in chronological order
- *Event period*: starting ended date and year of flood phenomena occurrence.
- *Region*: region in which the event occurred
- *Province*: province in which the event occurred
- *Municipality*: municipality in which the event occurred
- *Losses*: damages in monetary terms, in the currency and prices of the year of the flood event
- *Brief Description*: damages occurred brief description
- *Cause*: event typology (e.g., flooding, flooding and landslide, heavy rainfall etc.)
- *Flooded area*: Area inundated by the flood in ha.
- *Recovery found*: funds earmarked for the recovery
- *Intervention*: interventions during and immediately after flooding events
- *Total estimate damage/GDP*: Total damage from the event estimated at GDP
- *Evacuation and displaced*: number of people evacuated or displaced
- *Fatalities*: Number of deaths due to the flood, including missing persons
- *Affected people* affected Number of people whose houses were flooded.
- *Insured*: number of person whose life or property is covered by an insurance policy

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Event ID	Event period	Region	Province	Municipality	Losses [€]	Brief description	Cause	Flooded area [ha]	Recovery found [€]	Intervention	Total estimated damage/GDP [%]	Evacuation and displacement [no]	Fatalities [no]	Affected people [no]	Insured [no]
1	07 Jul 2014	Lombardy	Milano, Como, Lecco, Lodi, Pavia, Mantova, bergamo	Milano, Lodi, Vertemate, Cantù Asnate, Mariano Comense, Cariate Brianza, Erba, Lambrugo, Pavia, Dorno, Gropello, Zinasco, Besana Brianza, Villongo		Electrc lines, roads and subway interruption. basements, housing and stores flooded. Police headquarters flooded in Lodi. Serious damage to local crops and agricultural production in Pavia province.	Flooding								
2	13/11/2014	Lombardy	Varese	Ispra		1 residential settlement affected; 1,4 km of road network affected; 25 ha of grassland affected	Flooding	35					1	52	
3	08-30 Jun 2016	Lombardy	Bergamo, Sodrio, Brescia, Como, Lecco, Milano-Brianza, Milano, Mantova, Pavia, Varese	NA	€ 37.000.000,00	Considerable damage both to inhabited centers and to widespread flooding have involved and damaged public buildings and structures, as well as road network and service structures, as well as private property and industries. Serious damage to local crops and agricultural production.	Flooding and landslide		€ 37.000.000,00	0,0022					
4	11-12 Jun 2019	Lombardy	Brescia	Angolo Terme			Floding		€ 31.961,44	generic					
4	11-12 Jun 2019	Lombardy		Borno			Flooding and lateral erosion		€ 4.824,31	road network reparation					
4	11-12 Jun 2019	Lombardy		Borno			Flooding and Occlusion		€ 9.648,63	claening					
4	11-12 Jun 2019	Lombardy		Darfo Boario Terme			Flooding		€ 58.026,00	generic					
4	11-12 Jun 2019	Lombardy		Provincia di Brescia			Flood and Landslide		€ 244.248,42	rebuilding of the wall upstream of the collapsed road site					
4	11-12 Jun 2019	Lombardy		Niardo			NA		€ 89.899,32	generic					
4	11-12 Jun 2019	Lombardy		Breno Loc. Degna			NA		€ 49.926,71	generic					
4	11-12 Jun 2019	Lombardy	Lecco	Colico			Heavy rainfall		€ 50.632,44	generic					
4	11-12 Jun 2019	Lombardy		Cortenova			NA		€ 9.045,73	functionalyty restoration					
4	11-12 Jun 2019	Lombardy		Dervio			Flooding		€ 171.658,26	generic		900			
4	11-12 Jun 2019	Lombardy		Introbio			Flooding		€ 6.719,20	generic					
4	11-12 Jun 2019	Lombardy		Introzzo-Valvarrone			Flooding		€ 4.800,00	generic					
4	11-12 Jun 2019	Lombardy		Premana			Flooding and Landslide		€ 201.620,00	generic					
4	11-12 Jun 2019	Lombardy		Primaluna			Flooding		€ 220.932,35	generic		200			

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4	11-12 Jun 2019	Lombardy		Primaluna			Flooding		€ 147.041,12	Torrent Molinara redevelopment					
4	11-12 Jun 2019	Lombardy		Premana, Loc. Giabbio			Flooding		€ 56.820,30	Torrent Valle Marcia redevelopment					
4	11-12 Jun 2019	Lombardy		Premana			Flooding and Landslide		€ 400.000,00	generic					
4	11-12 Jun 2019	Lombardy		Dervio			NA		€ 38.560,80	Torrent Varrone redevelopment					
4	11-12 Jun 2019	Lombardy		Crandola Valsassina			NA		€ 26.000,00	road network reparation					
4	11-12 Jun 2019	Lombardy		Primaluna			Flooding		€ 608.155,00	road network reparation and services restoration					
4	11-12 Jun 2019	Lombardy		Casargo Loc. Faedo/Ronco e Ombrega			NA		€ 17.000,00	road network reparation					
4	11-12 Jun 2019	Lombardy	Sondrio	Andalo Valtellino			Flooding and embankment collapse		€ 16.732,60	putting in safety of the valley of the Lesina River					
4	11-12 Jun 2019	Lombardy		Campodolcino			Flooding		€ 53.923,04	Secondary river network redevelopment					
4	11-12 Jun 2019	Lombardy		Delebio			Flooding		€ 103.286,95	Secondary river network redevelopment and road network reparation					
4	11-12 Jun 2019	Lombardy		Madesimo			Flooding and Landslide		€ 121.239,18	cleaning					
4	11-12 Jun 2019	Lombardy		Novate Mezzola			Flooding		€ 32.329,30	generic					
4	11-12 Jun 2019	Lombardy		Piantedo			Flooding and Landslide		€ 54.256,74	putting in safety of the valley of the Madriasco torrent					
4	11-12 Jun 2019	Lombardy		San Giacomo Filippo			Landslide		€ 69.542,21	road network reparation					
4	11-12 Jun 2019	Lombardy		Samolaco			Flooding		€ 13.299,00	cleaning					
4	11-12 Jun 2019	Lombardy		Traona			Flooding		€ 3.710,44	cleaning and empting operation					
4	11-12 Jun 2019	Lombardy		Valdisotto			Flooding		€ 32.455,25						
4	11-12 Jun 2019	Lombardy		Utr Montagna			Flooding		€ 303.766,56	cleaning and consolidation works					

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Legend

Subject	Source	link
Civil Protection	Lombardy Region	https://www.regione.lombardia.it/wps/portal/istituzionale/HP/lombardia-notizie/DettaglioNews/2019/08-agosto/19-25/foroni-danni-alluvione-bs-lc-so
Civil Protection and Regional Functional Centres	ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale)	https://annuario.isprambiente.it/ada/downreport/html/6660
Consiglio Nazionale delle Ricerche Istituto di Ricerca per la Protezione Idrogeologica	POLARIS (Popolazione a Rischio da Frana e da Inondazione in Italia)	http://polaris.irpi.cnr.it/
Civil Protection	Civil protection press review (09/07/2014)	https://www.ilgiornaledellaprotezionecivile.it/rassegna-stampa/?paginasegue=6600&block=5
Copernicus Emergency Management Services (EMS)	EMSR108: Landslides and floods in Northern Italy	https://emergency.copernicus.eu/mapping/list-of-components/EMSR108

Table 2 Preliminary catalog of damages and losses data has been created for the selected past event occurred in Lombardy between 2014 and 2019 included in FloodCat database and source legend. NA= not available

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1.4.2 Significant flood events in Lombardy: Impact database set up

The next step will be the collection of a comprehensive dataset through the access to the RASDA archive, with gaps filled related to three significant flood events in Lombardy according with defined criteria, to finally apply economic modelling.

The dataset included reported losses according to the event characteristics as defined in Surname, N., Surname, N., Surname, N. (2020). M2.1 Screening report regarding the past flood events and re-assessment. Deliverable of EFLIP project:

1. An event in which there is a provision of detailed empirical data on the damage and perimeter of the flooded areas (possibly, where satellite images are also available). This event will be useful for the calibration of the models.

2. An event in which empirical damage data are available, but the flooded areas are missing. In this case satellite images will be used for the perimeter of the areas and economic modeling will be applied.

3. An event of particular interest to stakeholders in which the flooded areas are available (at least by satellite, if there are no state events during the event), but the impacts in terms of economic damage are missing. In this case, both hydrological-hydraulic modeling and economic modeling will be applied.

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