The KULTURisk Regional Risk Assessment Methodology for water-related natural hazards. Part 1: Physical-environmental assessment

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Abstract

In recent years, the frequency of catastrophes induced by natural hazard has increased and flood events in particular have been recognized as one of the most threatening water-related disasters. Severe floods have occurred in Europe over the last decade causing loss of life, displacement of people and heavy economic losses. Flood disasters are growing as a consequence of many factors, both climatic and non-climatic. Indeed, the current increase of water-related disasters can be mainly attributed to the increase of exposure (increase elements potentially at risk in floodplains area) and vulnerability (i.e. economic, social, geographic, cultural, and physical/environmental characteristics of the exposure). Besides these factors, the undeniable effect of climate change is projected to strongly modify the usual pattern of the hydrological cycle by intensifying the frequency and severity of flood events both at local, regional and global scale. Within this context, it becomes urgent and relevant the need of developing effective and pro-active strategies, tools and actions which allow to assess and (possibly) to reduce the flood risks that threats different relevant receptors. Several methodologies to assess the risk posed by water-related natural hazards have been proposed so far, but very few of them can be adopted to implement the last European Flood Directive (FD). This paper is intended to introduce and present a state-of-the-art Regional Risk Assessment (RRA) methodology to appraise the risk posed by floods from a physical-environmental perspective.. The methodology, developed within the recently completed FP7-KULTURisk Project (Knowledge-based approach to develop a cULTUre of Risk prevention – KR) is flexible and can be adapted to different case studies (i.e. large rivers, alpine/mountain catchments, urban areas and coastal areas) and spatial scales (i.e. from the large river to the urban scale). The FD compliant KR-RRA methodology is based on the concept of risk being function of hazard, exposure and vulnerability. It integrates the outputs of various hydrodynamic models (hazard) with site-specific bio-geophysical and socio-economic indicators (e.g. slope, land cover, population density, economic activities) to develop tailored risk indexes and GIS-based maps for each of the selected receptors (i.e. people, buildings, infrastructures, agriculture, natural and semi-natural systems, cultural heritages) in the considered region. It further compares the baseline scenario with alternative scenarios, where different structural and/or non-structural mitigation measures are planned and eventually implemented. As demonstrated in the twin paper (Part 2, Ronco et al., 2014), risk maps, along with related statistics, allow to identify and prioritize relative hotspots and targets which are more likely to be affected by floods and support the development of strategic adaptation and prevention measures to minimizing flood impacts. In addition, the outcomes of the RRA can be eventually used for a further socio-economic assessment, considering tangible and intangible costs as well as the benefits of the human dimension of vulnerability

1. Introduction

Extreme weather and climate events, the physical contributors to disaster risk, interacting with exposed and vulnerable human and natural systems, can lead to severe catastrophes (IPCC, 2012). Floods are the most threatening water-related disaster that affects human life, properties and infrastructures (Hewitt, 1997; Penning-Rowsell et al., 2005; Balica et al, 2009; Bates et al., 2008; Kubal et al., 2009), with an increasing occurrence as a consequence of many factors both climatic (increase heavy precipitation, changing in water natural cycle) and non-climatic (land use change, increases in population, economic wealth and human activities in hazard-prone areas and urban development). The combination of severe consequences, rarity, and human as well as physical factors makes disasters difficult to study. However, there are scientific evidences of an increased precipitation intensity, which implies that extreme floods events might become more frequent (Mitchell, 2003, Hirabayshi et al., 2013). At the same time, consequences for disaster related risks and impacts related to floods might be exacerbated due to increase exposure and vulnerability of elements at risk linked to population dynamics and the associated economic and urban development in flood-prone areas.

In fact, differences in vulnerability and exposure arise from non-climatic factors and from multidimensional inequalities often produced by uneven development processes. These differences shape differential risks from climate change (IPCC, 2014).

In Europe, floods, storms and other hydro-meteorological events account for around two thirds of the damage costs of natural disasters, and these costs have increased since 1980, according to EEA

(2012). Between 1998 and 2009, in particular, Europe suffered over 213 major damaging floods that caused 1126 deaths, the displacement of about half a million people and at least €52 billion in insured economic losses, including the catastrophic floods along the Danube and Elbe rivers in the summer of 2002 (see Fig.1) (Barredo, 2007).

Fig.1

Traditionally, the European flood control and management practices have been focused on reactive practices and largely relied on control of floods through structural measures, only later supported by sporadic non-structural measures. Currently, it is widely recognized that a paradigm shift is required to move from defensive to proactive action towards a culture of prevention by managing the risk of and living with floods (Annamo and Kristiansen, 2012). The latest concept is also supported by the recent outcomes of a study from Viglione et al. (2014) that demonstrate the relative importance of several socio-cultural-anthropogenic drivers for the (temporal) characterization of the vulnerability patterns in selected communities.

In this context, the European Flood Directive (FD) 2007/60/EC (2007) represents an ad-hoc legislative framework to support the development of proper flood management strategies, in order to reduce the adverse consequences for human health, the environment, cultural heritage and economic activities resulting from such calamities. According to the FD, risk assessment studies and relative maps enable the visualization of the spatial distribution of (flood) risks in the specific (flood) scenario, by considering the risk as the combination of hazard, exposure and vulnerability and by quantifying in particular, the number of people and economic activities potentially affected. Eventually, while it is indisputable that the European Union published a set of general reports which aim to support the current EU regulations, a lack of integrated criteria, methodologies and tools concretely supporting their practical implementation at the regional scale has been widely recognized.

In fact, several methodologies have been developed in order to assess flood risk; the choice of one methodology over another largely depends on the objectives of the analysis, availability of datasets, peculiarities of the context of application, level of detail to be achieved, dimensions of risk to be addressed. Cirella et al. (2014) recently published a comprehensive review and classification of current approaches and methodologies for the assessment of risks posed by a wide range of water-related natural hazards (coastal storms, tsunamis, river floods, avalanches, landslides, etc.). Based on different indicators and criteria (e.g. hazard of concerns, conceptual framework, analytical approach, role of experts and stakeholders, elements at risk, spatial scale, input and output, tools and models used, uncertainties, etc), the review demonstrated that there are very few examples of methodologies that consider the complete suite of elements at risk pointed out by the FD encompassing the entire varieties of risk dimensions (i.e. physical/environmental, social and economic) (Di Baldassarre et al., 2009; Di Baldassarre et al., 2010; Rotach et al., 2012). Most of the available methodologies, in fact, only targeted “classical” receptors, such as buildings, or infrastructures or population (e.g. Clausen and Clark, 1990; Citeau, 2003; Forte et al., 2005; DEFRA, 2006; Büchele et al., 2006; Kubal et al., 2009), that are usually analysed separately, in monetary terms and related damages only, neglecting the coexistence (and synergies) of multiple receptors living in the same geographical region. Moreover, while most of the approaches made a considerable use of GIS-based tools both for computational and outcome purposes, they were mainly developed for very specific contexts at a very local scale, with an high level of complexity and data demanding (e.g. Forte et al., 2005; Meyer et al., 2009; Kubal et al., 2009, Forster et al., 2008), and they can hardly be employed for a wide range of case studies. A recent attempt has been made by Balica et al. (2009) in proposing an innovative parametric approach for the estimation of the vulnerability of a system by using only few (readily available) parameters related to that system.

. Furthermore, by acknowledging different roots of the vulnerability paradigms embedded in multidisciplinary theories underpinning either a technical or social origin of this concepts, Papathoma-Kohle et al. (2011) and Fuchs et al. (2012) stated that methodologies for structural, economic, institutional or social vulnerability assessment should be inter-woven in order to enhance its understanding. In general, efforts to reduce exposure to hazards and to create disaster-resilient communities require intersection among disciplines and theories, since human actions cannot be seen independently from environmental features, and vice-versa (Hufschmidt et al., 2010). Moreover, the current and future flood risk assessments are also characterized by considerable uncertainty, which needs to be addressed and clearly communicated to decision-makers (Peppenberg et al., 2013). Finally, as suggested by Montanari et al. (2013) through the new “Panta Rhei-Everything Flows” paradigm for hydrological disciplines, the new challenge is to look at these (hydrological) processes as a changing interface between environment and society, whose dynamics are essential to set priorities for a (proper, effective and sustainable) environmental management, through an interdisciplinary approach between socio-economic sciences and geosciences.

Accordingly, there is the need to develop a comprehensive risk assessment methodology that could integrate information coming from deterministic and probabilistic flood forecasting, with the multi-faceted physical/environmental, social and economic aspects of exposure and vulnerability, in order to evaluate the consequences of floods for different elements at risk, as required by the

Directive. In this paper, the physical-environmental dimensions of risk have been assessed by considering the hazard, exposure and vulnerability components of flood risk analysis.

The paper will introduce both the conceptual framework and, in particular the computational procedure used to assess the physical-environmental (relative) risk posed by floods to a selected cluster of receptors. Before coming to the conclusion, the article will also present a simple but effective algorithm, based on Multi Criteria Decision Analysis, to combine the receptor-related relative risk into a single general (total) risk index. The (ultimate) objective of the methodology, successfully applied in the several case studies across Europe (see the twin paper, Part 2, Ronco et al., 2014), is to identify and prioritize areas and targets at risk in the considered region, in order to evaluate the benefits of different risk prevention scenarios to support relevant stakeholders in knowledge-based (land-use) planning and decision making.

2. The KULTURisk Regional Risk Assessment (KR-RRA) methodology

2.1. Conceptual Framework

The KULTURisk Conceptual Framework (KR-FWK) developed by Giupponi et al. in 2014 within the above mentioned project, shaped the basis for the development of the presented methodology to evaluate the benefits of risk prevention. By considering three main tiers of analysis, namely (1) the Physical/Environmental Regional Risk Assessment (RRA), (2) the Social and (3) the Economic Assessment, the Conceptual Framework has been built upon the consolidated formalization of risk being a function of hazard, exposure, and vulnerability, defined as: i) hazard, as “the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources” (IPCC, 2012); ii) exposure, as “the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected” (IPCC, 2012); iii) vulnerability, consisting of susceptibility as a Physical/Environment (P/E) component, and adaptive & coping capacities as the Social component. The P/E component is captured by the likelihood that receptors located in a considered area could potentially be harmed.

The above described elements are combined to calculate the Risk delineated as the combination of the probability of a certain hazard to occur and of its consequences.

Fig.2

The presented study only addresses the first tier of the analysis, namely the Regional Risk Assessment (RRA) that considered the flood hazard and the physical/environmental dimension of vulnerability (i.e. susceptibility) to identify and classify physical/environmental risks associated to floods for different receptors. The others two tiers are grouped into a single cluster of assessment, namely the Socio-Economic Assessment (SERRA) , where the information utilised for the RRA are merged with other social and economic indicators and monetary values of the assets at risk (Giupponi et al. 2014). The RRA provides an estimation of the physical/environmental risks that can be used as input for the social and economic tiers of analysis. These tiers can be used separately (i.e. considering only the social or the economic dimension) or sequentially (i.e. estimating the effects of the social and value indicators, together with the physical/environmental ones, on the expected costs).

2.2. Regional Risk Assessment: background, features and objectives

Since its first applications in 1997, the RRA approach has been successfully used at a variety of sites across the world, including marine coastal areas, fjords and hydrographic basins habitats (Landis and Wiegers, 1997). The RRA is aimed at providing a quantitative and systematic way to estimate and compare the impacts of environmental problems that affect large geographic areas (Hunsaker et al., 1990), by considering the presence of multiple habitats, multiple sources releasing a multiplicity of stressors impacting multiple endpoints (Landis, 2005). Specifically with the aim to rank potential impacts, targets and areas at risk from water-related natural hazard at regional scale, the KR-RRA integrates four steps of analysis, as follow:

- <u>hazard assessment</u> is aimed at characterizing the flood pattern by means of relevant metrics (e.g. flow velocity, water depth, flood extension) coming from hydraulic models, (deterministic or probabilistic) according to different scenarios to be investigated (baseline or alternative);
- <u>exposure assessment</u> is aimed at identifying the elements at risk. This step requires the analysis of land use/land cover datasets for the localization of people, environmental resources, infrastructures, social, economic and cultural assets that could be adversely affected by a flood;
- <u>susceptibility assessment</u> is aimed at evaluating the degree to which the receptors could be affected by a flood hazard based on physical/environmental site-specific information;
- <u>risk assessment</u> combines the information about a certain flood hazard scenario with the exposure and susceptibility of the examined receptors, providing a first evaluation of risks through the computation of a relative risk score. Risk scores varies from 0 (i.e. no risk) to 1 (i.e. higher risk for the considered area). The ranges for risk classes can be defined using different methods (e.g. Equal interval, Jenks optimization) and qualitative classes should then be assigned to them (i.e. low, medium, high risk). After the normalization of the receptor-related

risk, a total (integrated) risk index is calculated by means of Multi Criteria Decision Analysis (MCDA) functions.

As suggested by the Flood Directive (2007/60/EC), the KR-RRA methodology considers the following receptors:

1. People;
2. Economic activities, including: i) Buildings, ii) Infrastructures, iii) Agriculture;
3. Natural and semi-natural systems;
4. Cultural heritage.

As depicted in Fig.3, the main outputs of the RRA are GIS-based maps of receptor-related risks and of the total risk.

Fig.3

The KR-RRA method has been developed for analysis at the meso-scale level, adopting the land use/land cover classes proposed by the CORINE Land Cover, as major spatial units of reference (EEA, 2007). However, it is flexible to be applied at different spatial levels (i.e. the macro or the micro scales) based on the purposes of the assessment, the geographical extent of the case study and the level of detail of input dataset. The methodology can be applicable in different problem contexts, case studies and spatial scales with the aim to provide a benchmark for the implementation of the Floods Directive at the European level. In addition, GIS-based maps and outcomes result useful to communicate the implications of floods in non-monetary terms to stakeholders and decision-makers and can be a basis for a knowledge-based management of flood risks with information about the indicative number of inhabitants, the type of economic activities, natural systems and cultural heritages potentially affected by flooding. Concluding, the KR-RRA methodology allows to identify and prioritize areas and targets at risk in the considered region and to evaluate the benefits of different prevention scenarios.

In the next paragraphs, the computational procedure to estimate the relative risks, receptor-by-receptor, will be introduced, starting from the initial setting of the hazard scenario.

2.3. Scenario Development

In general, the proper selection of robust and reliable scenarios, defined as the plausible outcome of a possible future system state under different circumstances (baseline or alternative scenario), is primary for the quality and the robustness of the risk assessment (Mazzorana et al., 2009) since it allows the comparison of different (risk) scenario and, therefore, to evaluate the benefits of risk prevention measures. In fact, several approaches can be followed in scenario development, depending on level of detail, data availability and degree of experts involvement. For example, Scholz and Tietje (2002) and Mazzorana et al. (2009) provided a useful insight about the various scenario planning procedure and approaches by classifying the scenario analysis in three different types, among holistic (experts elicitation), model analysis (based on system modelling) and Formative Scenario Analysis, based on qualitatively assessed impact factors and tested in different case studies. When combined with conventional modelling, the last one,by meeting basic, operational and multidimensional principles and integrating bounding uncertainties, represents a robust technique for the development of reliable future hazard scenarios. According to KR-RRA, a preliminary analysis and screening of different scenario (baseline and alternative) is required. It should be based on different hazard magnitude, probability and/or alternative settings where structural and non-structural mitigation and adaptation measures are planned. These measures can affect (change) both the hazard as well as the exposure and vulnerability patterns. For example, the installation of an Early Warning System allows to decrease the vulnerability of the area (AV, see Eq. 3) and, therefore, the relative risk to people, while the re-calibration of the river cross section can contribute in decreasing the hazard metrics (water depth and velocity). Finally, it is worth to notice that the proposed approach does not provide a particular (bounded) method for scenario construction, rather it takes advantages from available techniques and models, depending on their applicability and reliability to the specific case study.

2.4. Physical/environmental risk assessment to people

River floods have the potential to cause serious risk to people and are considered as the most threatening water-related disaster that affects humans life (Hewitt, 1997; Penning-Rowsell et al., 2005; Balica et al., 2009; Kubal et al., 2009). Both river and coastal flooding affect millions of people in Europe each year; these events have a series of severe consequences on human health through drowning, heart attacks, injuries, infections as well as psychosocial effects (Fig. 4) (www.eea.europa.eu). During the past 10 years, floods in Europe have killed more than 1000 people and affected 3.4 million others (Jakubicka et al., 2010). Nevertheless, it is difficult to classify which deaths are actually associated with a flood. Immediate flood deaths are best recorded, but deaths during clean-up and longer-term mortality associated with flooding are often not recorded as such (Menne and Murray, 2013).

Fig.4

In 2008, Jonkman et al. provided an in-depth review of current available methods, tools and approaches for the estimation of loss of life due to different types of floods (e.g. for dam breaks, coastal floods, tsunamis), that are normally based on empirical data of historical flood events only, and not physically-based. Furthermore, the same authors proposed a new approach to estimate the risk related to the breaching of flood defences in the Netherlands and for similar low-lying areas. Despite being robust and scientifically sound, the method proposed by Jonkman et al. looks very case-specific and rather difficult to apply to a wide range of geomorphological situations and different water related hazards, as the KR-RRA is intended for.

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The proposed KR-RRA approach, in fact, allows the assessment of flood risks to human health (i.e. in terms of potential fatalities and injuries) associated with a flood event, by making the best use of available information at the meso-scale (i.e. CORINE Land Cover polygons). For this reason it focuses on residential areas identifying them as major hotspots where people live (Jonkman, 2008). In particular, the proposed approach is based on the methodology developed by Ramsbottom et al. for the UK Department for Environment, Food and Rural Affairs (DEFRA, 2006) for a wide range of case studies. This method was based on a multi-criteria assessment of factors that affect Flood Hazard, the chance of people in the floodplain being exposed to the hazard (Area Vulnerability) and ability of those affected to respond effectively to flooding (People Vulnerability).

2.4.1. Hazard, exposure and susceptibility assessments

The flood hazard classification considers the degree of impact and it is related to the specific physical characteristics of an individual (i.e. height, mass, age) for different population typologies (i.e. children, elders and infirm/disable; adult woman; adult man). The hazard assessment identifies water depth and velocity as relevant physical metrics, which are in direct (linear) relationship with the hazard magnitude (i.e. as water depth and velocity increase, the hazard score increases). Moreover, it is possible to consider also the presence of debris factor (i.e. floating material such as trees, cars, etc.) where it poses a threat to people. The (flood) hazard to people is calculated using the following equation:

$$H_{people} = d \cdot (v + 1{,}5) + DF \qquad (1)$$

Where:

H_{people} = *hazard score for people*

d = *water depth [m]*

v = *velocity [m/s]*

DF = *debris factor [0;1]*

Equation 1 allows to define a hazard map, in which the resolution depends on the outcomes and resolution of the hydraulic modeling and/or the historical dataset used to calculate and/or retrieve the physical metrics. DF is scored a value between 0 (i.e. low probability that debris would lead to a significant hazard) and 1 (i.e. high probability that the debris would lead to a significant hazard), according to different ranges of water depth and flow velocity (DEFRA, 2006).

The exposure assessment requires the localization of the people potentially affected by the hazard, that can be defined using census data of population density or the number of inhabitants per civic number within the residential areas, as Jonkman (2007) suggested. At any particular time, people may be present in various location (e.g. outdoors, indoors within a multi-storey building) that can be associated to different levels of risk. However, as stated above, the assumption is that all the people are present in their homes at the low ground where people do not have safe areas as refuge. For a sake of simplification, coping capacity during the event (people that are able to evacuate and/or shelter, as well as the solutions implemented by local Authorities to manage the emergencies) and adaptive capacity before-after the event (solutions implemented by people and Authorities in order to deal with the hazard) are not considered by the RRA since these terms are fully enclosed in the subsequent cluster of the KULTURisk methodology, the SERRA one (see Giupponi et al., 2014).

To characterize the susceptibility of people, namely the degree to which the receptors could be affected by the hazard, the KR-RRA methodology suggests to consider: i) the percentage of resident aged 75 years or over, and ii) the percentage of residents suffering from long term illness. These conditions are considered as factors that could increase the susceptibility because elderly people can be more prone to health and stability problems in a flood event and also because many pre-existing medical conditions can increase the probability of health problems related to flooding and of death (e.g. mortality for hypothermia). The susceptibility score (Eq.2) is therefore calculated by summing these two indicators (DEFRA, 2006):

$$SF_{people} = sf_1 + sf_2 \qquad (2)$$

Where:

SF_{people} = *susceptibility score for people (%);*

sf_1 = *% of people over 75 years;*

sf_2 = *% of people with disabilities.*

The susceptibility assessment is based on census data allowing the assignation of a susceptibility score to each census unit (e.g. municipality, census district) and a creation of a related susceptibility map. Indicators and data sources for the assessment of hazard, exposure and susceptibility of people at the meso-scale are reported in Table 7.

2.4.2. Risk assessment

The risk assessment produces the spatial characterization of a (relative) risk index to identify and rank areas and hotspots at risk within the studied area. Hazard (Eq.1), exposure and susceptibility (Eq.2) are used within the risk assessment to compute the number of people injured (R_1) and dead (R_2) during a flood event, as follow (DEFRA, 2006):

$$R_1 = \frac{\left(2\cdot E\cdot H_{people}\cdot {}^{AV}/_{100}\cdot SF_{people}\right)}{100} \qquad (3)$$

$$R_2 = 2\cdot R_1\cdot {}^{H_{people}}/_{100} \qquad (4)$$

Where:

R_1 = *number of injuries;*

R_2 = *number of fatalities;*

E = exposure (i.e. the number of people that can be potentially inundated);

H_{people} = *hazard score to people;*

AV = area vulnerability;

SF_{people} = *susceptibility score for people (%).*

As per the DEFRA (2006) approach, the area vulnerability AV is defined as the sum of flood warning, speed of onset and nature of area, ranging from 3 (i.e. low social vulnerability, high adaptive and coping capacity) to 9 (i.e. high social vulnerability, low adaptive and coping capacity). Moreover, in order to aggregate the different receptor-related (relative) risks for the computation of the total risk, a phase of normalization aimed at rescaling the receptor-related risk scores into a common closed numerical scale (0-1) is required (Zabeo et al., 2011),. The normalization is performed at CORINE polygon-scale; this spatial resolution has been selected according to the one that characterize the available dataset. For the people, the normalization is provided considering the number of people injured/dead and the number of people in the highest populated polygon, according to Eqs. 5 and 6:

$$R_1' = \frac{R_1}{Number\ of\ people\ in\ the\ highest\ populated\ polygon} \qquad (5)$$

$$R_2' = \frac{R_2}{Number\ of\ people\ in\ the\ highest\ populated\ polygon} \qquad (6)$$

Where:

R_1' = normalized risk score for injuries;

R_2' = normalized risk score for fatalities;

R_1 = number of injuries (Eq.4);

R_2 = number of fatalities (Eq.5).

This normalization allows to define risk scores between 0 (i.e. no people injured/dead) and 1 (i.e. all the people living in the highest populated polygon are injured/dead).

2.5. Physical/environmental risk assessment to economic activities

To fulfil with the requirements of the FD, the flood risk assessment related to economic activities has considered three relevant sub-receptors: buildings, infrastructures and agriculture.

2.5.1. Physical/environmental risk assessment to buildings

Floods have a potential massive impact on buildings infrastructures (e.g. to the structures and to the indoor goods), particularly in populated areas, corresponding to residential and commercial-industrial sites, triggering severe (socio-) economic damages.

Papathoma-Kohle et al. (2011) and Fuchs et al. (2012) recently provided an insight of the current approaches and future needs on vulnerability assessment of buildings, when affected by water-related natural hazards. The most frequent approach concerned the use of (empirical) stage-damage functions that linked inundation depth to expected losses, that is reliable method for still waters but do not consider the impact of flowing waters to the structures as relevant indicator (Buchele et al., 2006). In general, the above mentioned authors remarked a lack of multidimensional and dynamic approaches, and outlined some key issues that need to be addressed by an ultimate risk assessment methodology. It is worth to notice that some of these issues have been addressed by the KR-RRA, in particular as far as the involvement of end users, transferability of methods, spatial approach (GIS based) and hazard dependency are concerned. . Finally, in the proposed KR-RRA the receptor is define by considering the buildings footprint in the area as well as its economic use, according to the CORINE Land Cover classes of industrial and residential areas. At meso-scale level, this classification allows to define the percentage and the typology of buildings that could be affected by a flood event with different degrees of structural damage.

2.5.1.1. Hazard, exposure and susceptibility assessments

The above mentioned methods for vulnerability assessment to the buildings are characterizedby a consistent use of sophisticated physical approaches and screening methods, only applicable at the very local scale (micro-zonation). For example, they consider the damage related to different building typologies as suggested by Schwarz and Maiwald (2008), or the material construction and its quality, the building level, the state of conservation, contamination and precautionary principles (Büchele et al., 2006, Mebarki et al., 2012, Totschnig & Fuchs, 2013). Without excluding the possibility of future refinement and enhancement of the KR-RRA method by matching the level of detail and data availability required with the necessary portability of the same, some simplifications and assumptions have been considered in order to fully apply the methodology at regional (meso scale) level, in particular as far as the vulnerability assessment is concerned.

Within the proposed KR-RRA, reference is made to the approach proposed by Clausen and Clark (1990) where, by assuming that all the buildings are characterized by the same structure, the risks has been evaluated by directly considering the relationships between flood hazard classes and potential structural damages (Fig.5).

Table 1

Fig.5

2.5.1.2. Risk assessment

Based on the classes proposed by Clausen and Clark (1990), the methodology allows to calculate the number (and percentage) of buildings affected by floods, classified per typology and according to different risk classes as defined in Table 1. This method provides three risk classes (i.e. inundation, partial damage, and total destruction) differentiating the potential consequences of floods in a qualitative way, based on thresholds determined by flow velocity values and by the product between water depth and flow velocity (defined as intensity). The risk assessment to buildings (R_3) allows the estimation of the number, coverage (km^2) and the percentage of flooded buildings belonging to different uses (i.e. CORINE Land Cover polygons related to residential, commercial-industrial areas) in each risk class in the form of tables (summarizing the statistics) and maps (highlighting the areas at different risks). Again, this step requires a phase of normalization aimed at rescaling the receptor-related risk scores into a common numerical scale (0-1) (Zabeo et al., 2011). The scores proposed in Table 2 have been defined by the authors by using a dedicated qualitative evaluation. Of course, different scores based on site-specific knowledge, literature data and expert judgments, can be assigned during the application of the proposed methodology.

Table 2

2.5.2. Physical/environmental risk assessment to infrastructures

Floods affect infrastructures networks causing loss of services (e.g. not practicable roads and railways, interruption of power supply, etc.) in addition to structural direct damages (e.g. damages to roads, bridges, destruction of power stations, etc.). Studies of past flood events have showed that the majority of losses arise in urban areas, due to impairment of structures, costs of business shut-down and failure of infrastructures (EEA, 2010c; ADBI and The World Bank, 2010). Evacuations, property damage and infrastructure closures are amongst the challenges faced by those operating in a wide range of industries, including manufacturing, retail, transport, agriculture and tourism. A very recent example comes from the severe flooding experienced in Central-East Europe in June 2013, that had a significant cost for infrastructure-related businesses.

According to the Flood Directive (2007/60/EC), the KR-RRA methodology allows to identify roads and railways affected by flood hazard, by considering only the inundation of the infrastructures as main impact of interest. In this sense, the risk should be considered as the loss of services for the infrastructure during and after the event. For a sake of simplification, the methodology does not consider any structural damages related to the flood event (damage and/or collapse of roads, bridges, railways, etc.).

2.5.2.1. Hazard, exposure and susceptibility assessments

Based on these premises, the flood hazard assessment only considers the flood extension (flooded area) as relevant hazard physical metric. Water depths and its lower boundary conditions are not considered because of the scale of analysis and lack of specific literature on this topic. However, if data and research were available, the characterization of the functionality of (transport) infrastructures could be reasonably performed. The exposure assessment step focuses on the spatial localization and distribution of the roads, railways and pathways. These objects are geometrically characterized by their linear extension (length) rather than by their surface extension (area). Finally, the susceptibility assessment step assigns the same score to the whole set of assets (e.g. roads, highways, railroads). As for the buildings, at micro-scale level the physical susceptibility assessment can be improved by considering the construction typology, functions and dimensions of the considered infrastructure.

2.5.2.2. Risk assessment

Accordingly, the infrastructure-related risk (R_4) is calculated from the intersection between the flood extension map and the road and railway atlas in order to identify and characterize the infrastructures inundated by the flood event. In this case, the physical/environmental risk assessment for infrastructures results in the estimation of the length (km) and the percentage of infrastructures potentially affected by flood in each CORINE Land Cover polygon in the form of tables (summarizing the statistics) and maps (highlighting the areas at risk). Again, this step requires a phase of normalization aimed at rescaling the receptor-related risk scores into a common numerical scale (0-1) (Zabeo et al., 2011). For infrastructures, the normalization is performed considering the length of flooded items in each polygon and the total length within the same polygon, as by Eq.7:

$$R_4' = \frac{R_4}{Total\ length\ of\ infrastructures\ in\ the\ same\ polygon} \qquad (7)$$

Where:

R_4' = normalized risk score for infrastructures;

R_4 = length of flooded infrastructures in each polygon.

The normalization assumes that if in a polygon all the infrastructures were flooded, people cannot secure their health and their goods (i.e. all the safety way are not accessible). The normalization phase, where infrastructures-related risk score are between 0 and 1, is functional for the computation of the total risk index..

2.5.3. Physical/environmental risk assessment to agriculture

Floods can damage crops that become oversaturated, but can also cause damages to farmlands and infrastructures. These impacts can lead to economic damages both direct and indirect (e.g. loss of agricultural soil due to erosion, scarcity of cereals, etc.) with only few methodological approaches available for their (monetary) quantification (Dutta et al., 2003, Meyer et al., 2009). Recent events in Modena Province (Northern Italy) confirmed the importance of considering the massive floods impact to the agricultural sector with 54M€ of losses caused by (only) 2 days of rainfall in late January 2014 (ANSA, 2014). The KR-RRA approach is aimed at mapping potential flood risk to agriculture by means of ready-available data at the meso-scale level (i.e. CORINE Land Cover polygons of the agricultural areas) to spatially characterize the pattern of relevant crops. Specifically, the aim of the RRA methodology for agriculture is to define the percentage of the harvest loss due to a flood event, without any consideration about the damage to agricultural buildings since these have been already considered along with the assessment to the Economic Activities, see sect. 2.5.1. .

2.5.3.1. Hazard, exposure and susceptibility assessments

Based on the analysis proposed by Citeau (2003) concerning bibliographic data and in situ surveys, the proposed assessment requires the identification of water depth and velocity as relevant physical metrics to characterize the hazard. The exposure assessment step allows the localization of the different agricultural typologies considered (i.e. vegetables, vineyards, fruit trees and olive groves) in the case study area, according to the land use pattern provided by the dataset of reference. Moreover, a set of thresholds for the hazard metrics have been established for different agricultural typologies characterized by a different susceptibility factor, also according to the seasonality (e.g. the spring, summer and autumn) (Table 3). For example, vegetables are more susceptible than fruit trees to inundation phenomena, therefore their threshold for the flow velocity is lower for the former. Nevertheless, updated and site-specific thresholds can be established, when available, together with other relevant factors to better characterize the susceptibility score, such as the water stagnation

Table 3

2.5.3.2. Risk assessment

Within the risk assessment phase, giving the hazard thresholds provided by Table 3, it is possible to define if an agricultural area is inundated (i.e. if the flood hazard values are below the identified thresholds) or loss (i.e. if the flood hazard values exceed the thresholds) and therefore to calculate the total flooded agricultural area (km^2) and the percentage of agriculture typologies affected, in the form of tables, summarizing the statistics, and maps, highlighting the areas at different risk levels. Specifically, the agriculture-related risk (R_5) is calculated for spring, summer and autumn seasons by assuming that during the winter time there are no cultivations exposed to the impact of flood. Therefore, for this season, it is only possible to distinguish between inundated and not inundated agricultural areas. Finally, the normalization phase provides values between 0 and 1, according to the authors' evaluation, as summarized in Table 4. Local stakeholders and others can assign different scores based on site-specific knowledge, literature data and expert judgments.

Table 4

2.6. Physical/environmental risk assessment to natural and semi-natural systems

Floods tend to degrade natural systems (i.e. natural and semi-natural ecosystems, protected areas, wetlands) by destroying vegetation, degrading hill-slopes, river-beds, altering the pattern of erosion/sedimentation processes and the transfer of both sediment and nutrients. Other negative effects include loss of habitats, dispersal of weed species, release of pollutants, lower fish production and loss of recreational areas. Accordingly, the aim of the proposed KR-RRA methodology is characterize the degree to which environmental systems can be affected by a flood event due to their physical characteristics causing a permanent, or temporal, loss of ecosystems services.

2.6.1. Hazard, exposure and susceptibility assessments

Flood extension area (km^2) has been selected as relevant physical metric to characterize the hazard impacting natural and semi-natural systems. Moreover, the exposure assessment allows localizing the receptor by considering the CORINE Land Cover classes related to forest, semi-natural areas and wetlands. As far as the susceptibility assessment is concerned, following Pasini et al. (2012), a series of indicators have been selected to characterize the physical characteristics of the analysed territory reflecting variations in the degree to which the natural and semi-natural systems may be affected by a flood event. These indicators are as follow:

- Vegetation cover
- Slope
- Wetland extension
- Soil type

. Each susceptibility indicator is later classified and scored by expert judgment. For the vegetation cover, for example, susceptibility classes are defined by considering different land cover typologies such as grass, shrub and forest. Specifically, the susceptibility of soil to floods increases when vegetative cover and slopes decreases (Preston et al., 2008; Torresan et al., 2012) In fact, when it comes to loss of biodiversity and ecological value, especially in the medium-long term, environments characterize by lower slopes are more susceptible to floods since they are subject to water stagnation and therefore soil degradation, while steeper slopes are less susceptible as they do facilitate the water evacuation (Preston et al., 2008). The same applies for the soil type indicator, where classes and thresholds are established considering that the more waterproof soil type typologies are the most susceptible to flooding because they cannot drain the standing waters (Yahaya, 2010). Moreover, the higher susceptibility scores has been assigned to wetlands with lower surface area, which may be more sensitive to flood pressures than wider ones (Torresan et al., 2012). The relative classification of these factors is performed by using the equal interval classification (Zald et al., 2006).

Once susceptibility classes are defined, the assignation of therelative scores is provided by experts and local stakeholders following the linguistic evaluations reported in Table 5, in order to classify their (relative) importance in the analysed area. indicators..

Table5

Finally, the susceptibility indicators are aggregated through a Multi-Criteria Decision analysis (MCDA) function named “probabilistic or” (Kalbfleisch J. G., 1985), which provides a single normalized score of susceptibility for homogeneous areas, as follow:

$$S_{nat} = \otimes_i^n \left[sf_i'\right] \quad (8)$$

where:

S_{nat} = *susceptibility score of the cell;*

$\otimes$ = *“probabilistic or” function;*

sf_i' = i^{th} *susceptibility factor score (classified in [0,1]).*

When applying the “probabilistic or” function (Eq. 8), if just one susceptibility factor (*sf*) assumes the maximum value (i.e. 1) then the susceptibility score will be 1. On the other hand, *sf* with low scores contribute in increasing the final susceptibility score: the more is the number of low susceptibility factor scores, the greater is the final susceptibility (details in Appendix A).

2.6.2. Risk assessment

Finally, in this step the hazard and the susceptibility scores are aggregated in a relative risk score (R_6) to identify and prioritize natural and semi-natural systems potentially affected by loss of ecosystem services, as follow:

$$R_6 = H_{nat} \cdot S_{nat} \qquad (9)$$

Where:

R_6 = *natural and semi natural systems related risk*

H_{nat} = *hazard score (according to Table 6)*

S_{nat} = *susceptibility score calculated according to the “probabilistic or” function (Eq.8).*

Table 6

However, case study experts can assign different scores based on site-specific knowledge, literature data and expert judgments. The results of the risk assessment to natural and semi-natural systems are grid based layers where cells are ranked in different risk classes (e.g. low, medium, high) withtables summarizing the statistics and maps highlighting the areas at risk. As for the other receptors, a phase of normalization aimed at rescaling the qualitative risk classes (i.e. low, medium, high) is performed..

2.7. Physical/environmental risk assessment to cultural heritage

Flooding can damage architectural heritage, historic buildings and sites as well as objects of art . All these objects are subjected to various forces (e.g. static or hydrostatic pressure, flow velocity and waves) and actions during flood situations (Nedvědová and Pergl, 2013, Drdácký, 2010). According to the Flood Directive (2007/60/EC) which requires the localization of the potential cultural heritages affected by floods, the KULTURisk-RRA method includes cultural heritage as a relevant receptor for the integrated flood risk assessment.

2.7.1. Hazard, exposure and susceptibility assessments

It is worth to specify that the analysis of risk at meso-scale level is not oriented to the evaluation of structural damages to cultural assets but only to the identification of affected (flooded) items. Therefore, flood extension area (km^2) is identified as relevant physical metric to characterize the hazard assessment. The UNESCO World Heritage Convention (1972) distinguishes three different typologies of cultural heritages: monuments (which are of outstanding value from the point of view of history, art or science), groups of buildings (separate or connected buildings) and sites (which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological points of view). Spatially they can be considered as points (i.e. monuments) and areas (i.e. buildings and sites) overlapping with the polygons of the CORINE Land Cover.

Starting from the available information at the meso-scale (i.e. location and typology of cultural heritages) and assuming that the cultural assets are affected in the same way by the flood, the susceptibility assessment assumes a score equal to 1 for the entire suite of items, separately or attached as an integral group of buildings.

2.7.2. Risk assessment

The risk assessment for the cultural heritages aims at providing the number of flooded monuments, the coverage (km^2) and percentage of inundated cultural buildings and archaeological/historical sites in the form of tables (summarizing the statistics) and maps (highlighting the cultural heritages at risk). Accordingly, the cultural heritage-related risk for single monuments (R_7) and sites (R_8) are calculated from the intersection between the flood extension map and the cultural heritage map, in order to identify the number and surface of the cultural assets inundated.

For this receptor, the normalization phase is performed by considering the number of inundated monuments in each CORINE Land Cover polygon and the totality of assets lying in the polygon most populated by cultural objects (Eq. 10). For coverage, the cultural sites flooded area (km^2) in each CORINE Land Cover polygon and the total area (km^2) of cultural sites in the polygon more extensively covered by cultural assets (Eq. 11), are considered.

$$R'_7 = \frac{R_7}{\substack{total\ number\ of\ monuments\ of\ the\ polygon \\ with\ the\ highest\ number\ of\ monuments}} \quad (10)$$

Where:

R'_7 = normalized risk score for cultural heritages (monuments);

R_7 = number of flooded monuments in each polygon.

$$R'_8 = \frac{R_8}{\substack{cultural\ sites\ [km^2]\ in\ the\ polygon\ with \\ the\ highest\ cultural\ site\ area}} \quad (11)$$

Where:

R'_8 = normalized risk score for cultural heritages (sites);

R_8 = cultural sites flooded area [km^2], in each polygon.

Again, if more detailed information related to the cultural heritage (e.g. site-specific surveys and archives) were available, a deeper analysis at the micro-scale (structural damages) can be performed by considering further physical susceptibility indicators, such as the material construction, the state of conservation, etc.

Table 7

2.8. Total Risk Index

The (very) final result of the KR-RRA methodology is a GIS-based Total Risk Map which allows to identify and rank areas and hotspots at risk within the studied area. ,. Total risk index is calculated by aggregating different receptor-related risks by means of Multi Criteria Decision Analysis (MCDA) method. The field of MCDA encompasses different methodologies aimed at integrating heterogeneous criteria and decision maker insights towards the selection of alternatives. Outranking methods and Multi Attribute Value Theory are the most popular approaches in MCDA. The first ones, based on direct comparisons, have been discarded because of the complex and time consuming inputs required from users (Vincke, 1992). Instead, MAVT methodology has been selected which allows a sound ranking with relatively low user requirements (Giove et.al., 2009).

The KR-RRA methodology uses the weighted average (Eq.12) as effective method of aggregation, that is useful in liner additive contexts only, where receptors' risk are considered to be linearly additive and neither synergic nor redundant effects among risks and indicators are present.

$$R_{tot} = \frac{\sum_{\forall r} w_r \, R'_r}{\sum_{\forall r} w_r} \qquad w_i \in [0,1] \, \forall r \tag{12}$$

Where:

R_{tot} = *total risk;*

w_r = *weight associated with the r-receptor-related risk;*

R'_r = *normalized risk score associated to the r-receptor-related risk.*

The assignment of weights is performed by experts and local stakeholder’s consultation. The ranking process is supposed to give priority to those whose flooding damaging consequences are considered as burdensome. In this sense, weighting is a typical political decision making process and the involvement of relevant stakeholders is seen as a fundamental prerequisite for its effectiveness (Yosie and Herbst, 1998).

The final output is a Total Risk Map (with risk scores between 0 and 1) where classes has been defined using Equal Interval GIS tool (see Table 8). Risk scores are not absolute predictions about the risks related to floods, rather they provide relative classifications about areas and targets that are likely to be affected by these events more severely than others within the same region. By facilitating the localization of hot spots at risk, such as hospitals, schools, harbours, railway stations, airports, protected areas, potential installations causing pollution, these maps support decision makers and local stakeholders towards a knowledge-based disasters management, as well as the planning of mitigation measures and land use. Finally, a more detailed analysis of the most affected areas could be performed by examining the specific receptor-related risks..

Table 8

Conclusions

The paper proposes a state-of-the-art methodology, based on the Regional Risk Assessment approach and shaped on the framework of the European Flood Directive, for the integrated assessment of water-related hazards at regional scale (i.e. meso-scale) on multiple receptors/elements at risk (i.e. people, economic activities, natural and semi-natural systems and cultural heritages). For each of the selected receptors-elements at risk, and by making a considerable use of Geographic Information Systems (GIS) tools, the methodology proposes a specific procedure for the estimation of a (normalized and spatially distributed) relative risk index, through on a multi-layer analysis, based on the hazards, exposure and vulnerability assessments. Together with the GIS-based maps, the outcomes of the application are indicators and statistics that quantify the risk for the considered receptors (e.g. number of people at risk, coverage of flooded infrastructures at higher risk, percentage of residential buildings and commercial buildings at risk, extension of flooded agricultural lands, etc.). Finally, the Total risk is calculated by aggregating the different receptor-related risks by means of Multi Criteria Decision Analysis (MCDA) through experts and local stakeholders' elicitation. The KR-RRA methodology should not attempt to provide absolute predictions about flood impact. Rather, this instrument, by means of MCDA and GIS-based tools, provides the ranking of the area, sub-areas and hotspots at risk that are more vulnerable and possibly more strongly affected by the flood within the investigated region, to evaluate the benefits of different risk prevention scenarios (i.e. baseline and alternative scenarios) where structural and/or non-structural measures are implemented. With the ultimate aim to underpin risk prevention measures and, therefore, to communicate to decision makers and stakeholders the potential implications of floods in non-monetary terms, the proposed KR-RRA methodology demonstrate that prevention is accountable and its benefits are measureable, because it facilitates the quantification, in physical terms, of the risk avoidance due by the proposed prevention measures and considered by the different scenarios and settings. On this basis, investments on prevention by Public Administrations can be better evaluated and shared with citizens, also in order to support the rising of a culture of prevention in the whole society. In this sense, the proposed methodology represents an important scientifically sound instrument towards the implementation of the Flood Directive in different environments and contexts. Its flexibility really allow the application to different case studies (i.e. large rivers, alpine/mountain catchments, urban areas and coastal areas) and spatial scales (i.e. from the large river basin to the urban scale), but only to individuate particular criticisms in flood prone areas at the meso-scale: the implementation of the Flood Directive at the micro-scale requires inevitably a more detailed analysis. Moreover, it is undeniable that a further limitation of this methodology consists in its (relatively high) degree of (political) subjectivity when assigning weights and scores by means of experts 'elicitation. On the other side, as per the 2014 IPCC AR5 report, the expert judgement (using specific criteria) must be used to "integrate the diverse information sources relating to the severity of consequences and the likelihood of occurrence into a risk evaluation, considering exposure and vulnerability in the context of specific hazards" in order to cope with the fact that "data are seldom sufficient to allow direct estimation of probabilities of a given outcome" (IPCC, 2014). Furthermore, the methodology can be further improved by taking into consideration the complex dynamics of feedbacks between physical, social and political that relevant end-users, decision makers (and local experts) frequently pose (see the twin paper, Part2, Ronco et al., 2014). Moreover, an attempt towards the concept of dynamics in flood risk assessment by considering the new insights of the spatial-temporal evolution pattern of the four methodological steps, as proposed by Mazzorana et al. (2012) for the vulnerability assessment could be performed. Again, the characterization of the vulnerability patterns for (selected) communities and areas through the combination of different drivers, such as the collective memory, risk-taking attitude and trust in protection measures, as proposed by Viglione et al. in 2014, represents a new, challenging, frontier for the next generation of risk assessment methodologies. In a rapidly changing world, risk changes significantly across time, space and culture. Finally, in order to propose a harmonized overall approach to risk prevention for natural hazards other than floods, both the suitability and applicability of the overall KULTURisk methodological approach to other types of risks (earthquakes, forest fires, etc.) will be analyzed in detail, through the involvement of a number of experts in these fields.

Appendix A: Mathematical background

The "Probabilistic or" function (Kalbfleisch J. G., 1985) is expressed as:

$$\otimes_{i=1}^{4}[f_i] = f_1 \otimes f_2 \otimes f_3 \otimes f_4 \qquad \text{(A1)}$$

where:

f_i= i-th generic factor f

The "probabilistic or" operator can be evaluated as follow, due to the associative and commutative proprieties:

$$f_1 \otimes f_2 = f_1 + f_2 - f_1 f_2 = F_1 \qquad \text{(A2)}$$

$$F_1 \otimes f_3 = F_1 + f_3 - F_1 f_3 = F_2 \qquad \text{(A3)}$$

$$F_2 \otimes f_4 = F_2 + f_4 - F_2 f_4 = \otimes_{i=1}^{4}[f_i] \qquad \text{(A4)}$$

The process can be repeated until evaluating all operands.

If just a factor (f) assumes the maximum value (i.e. 1) then the result of the "probabilistic or" will be 1. On the other side, f with low scores contribute in increasing the final "probabilistic or" score: the more is the number of low factor scores, the greater is the final score.

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Table 1. Identification of the building-related risk classes according to different hazard thresholds for water depth (d) and water velocity (v), as proposed by Clausen & Clark (1990).

Flood hazard threshold	Building-related risk classes (R_3)	Definition
$v \leq 2$ or $vd \leq 3$	Inundation	Damage similar to that caused by a natural low-velocity river flood. No immediate structural damage.
$v > 2$ and $3 < vd \leq 7$	Partial damage	Moderate structural damage, i.e. windows and doors knocked out. Little damage to the major structural elements of the building.
otherwise	Total destruction	Total structural collapse or major damage to the structure necessitating demolition and rebuilding.

Table 2. Physical/environmental risk classes and normalized scores for buildings.

Classes	Normalized scores
Not inundated	0
Inundation	0,2
Partial damage	0,6
Total destruction	1

Table 3. Thresholds for the flood hazard metrics for different agricultural typologies in the spring, summer and autumn seasons (adapted from: Citeau, 2003).

Agricultural typologies	Maximum water depth [m]	Maximum water velocity [m/s]
Vegetables	-	0.25 m/s
Vineyards	0.5 m	0.25 m/s
Fruit trees and olive groves	1 m	0.5 m/s

Table 4. Risk classes and normalized scores for the agriculture receptor.

Risk classes	Flood hazard thresholds	Normalized scores
Not inundated	No flood	0
Inundated	Flood metrics values are below the thresholds	0.6
Destructed	Flood metrics values are over the thresholds	1

Table 5. Qualitative evaluations supporting the expert in the assignation of relative scores to susceptibility and risk classes.

Linguistic Evaluation	Score
Most important class	1
Weakly less important class	0.8
Rather less important class	0.6
Strongly less important class	0.4
Less important class	0.2
No susceptibility	0

Table 6. Hazard classes and normalized scores for natural and semi-natural systems

Classes	Normalized scores
Not inundated	0
Low	0.2
Medium	0.6
High	1

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Table 7. Summary of the indicators and data sources used to characterize the three steps of analysis during the application of the physical/environmental Regional Risk Assessment methodology at the meso-scale, for the selected receptors (P: People; B: Buildings; I: Infrastructures; A: Agriculture; NS: Natural and Semi-Natural Systems; CH: Cultural Heritage).

Steps of the physical/environmental RRA	Indicators/metrics	Data sources	Receptors
Hazard	Water depth	Flood modelling	P – B - A
	Water velocity	Flood modelling	P – B - A
	Flood extension	Flood modelling and mapping	I – A – NS - CH
	Debris Factor	Land cover map	P
Exposure	Presence of people in residential areas	Census data, Land cover/Land use map	P
	Presence of buildings	Land cover/Land use map	B
	Presence of infrastructures	Road and railway atlas	I
	Presence of agricultural typologies	Land cover/Land use map	A
	Natural & semi-natural systems	Land cover/Land use map, Protected area map	NS
	Presence of cultural heritages	Regional technical map, UNESCO cultural heritage map	CH
Susceptibility	People over 75 years and infirm/disable/long term sick	Census data	P
	Vegetation cover	Land cover/Land use map	NS
	Slope	Digital Elevation Model (DEM)	NS
	Soil type	Geomorphologic/soil map	NS
	Wetland extension	Land cover/Land use map	NS

Table 8. Risk classes score definition used to classify the total risk index (GIS Equal Interval classification).

Risk Classes	Score
Not at risk	0
Very low	0 - 0.2
Low	0.2 - 0.4
Medium	0.4 - 0.6
High	0.6 – 0.8
Very high	0.8 - 1

Figure.1. Occurrence of major floods in Europe (1998–2009); Source:; http://www.eea.europa.eu/legal/copyright). Copyright holder: European Environment Agency (EEA).

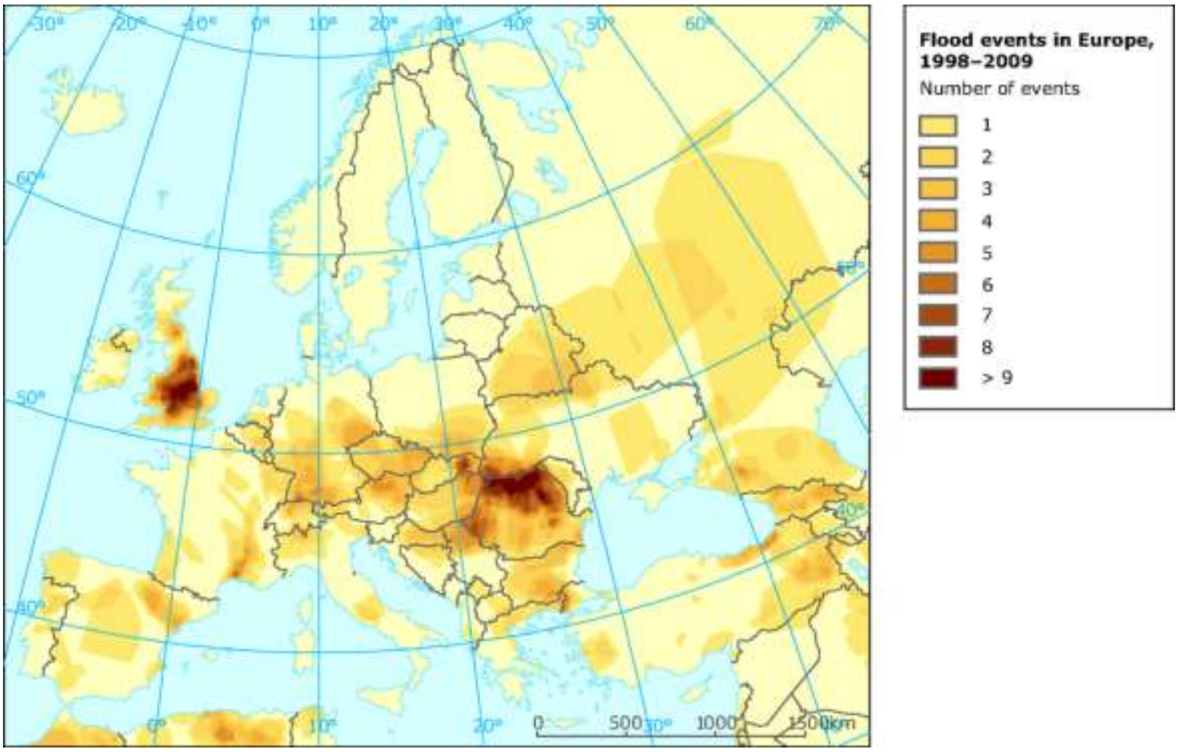


Figure 2. Tiers of analysis for the implementation of the KULTURisk methodology to estimate risk levels.

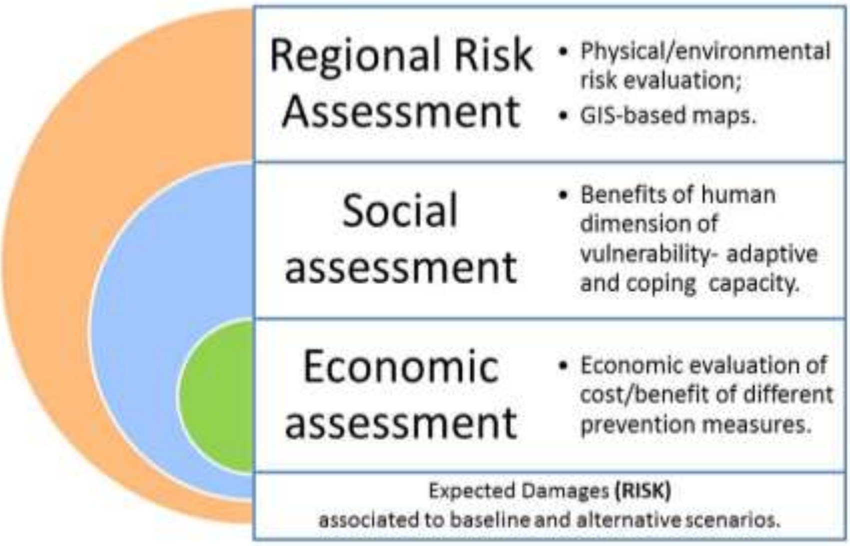


Figure 3. Physical/environmental KR-RRA, receptors, steps and outputs.

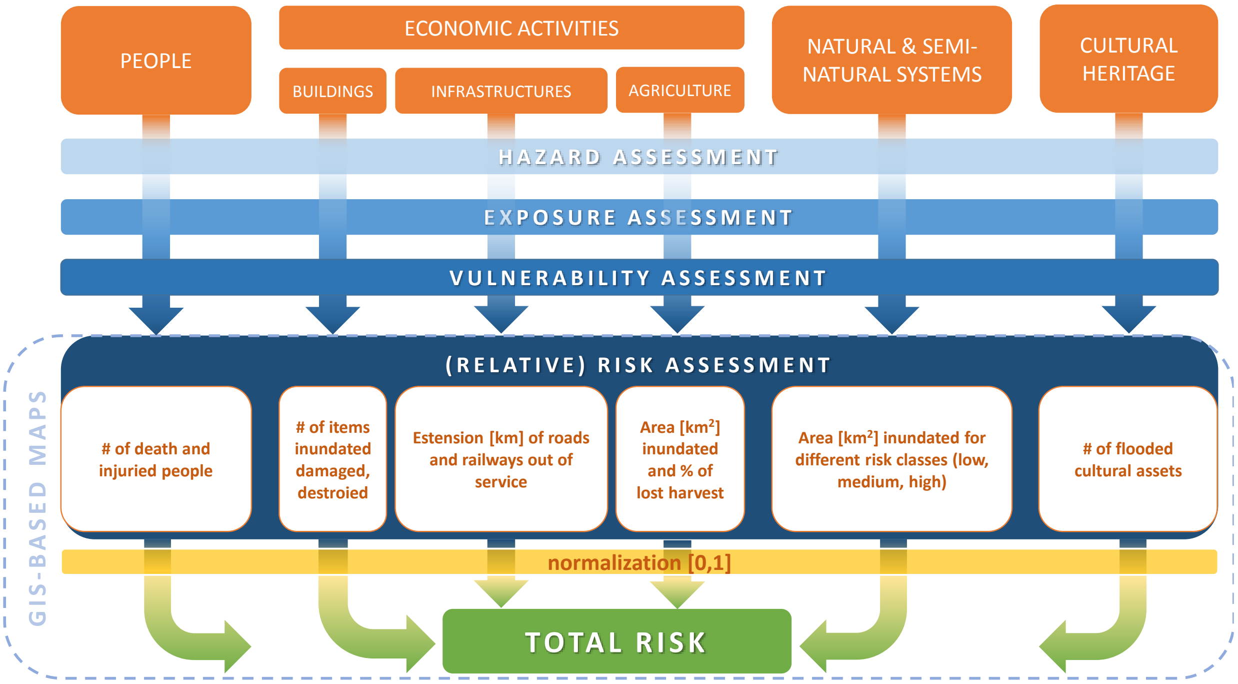
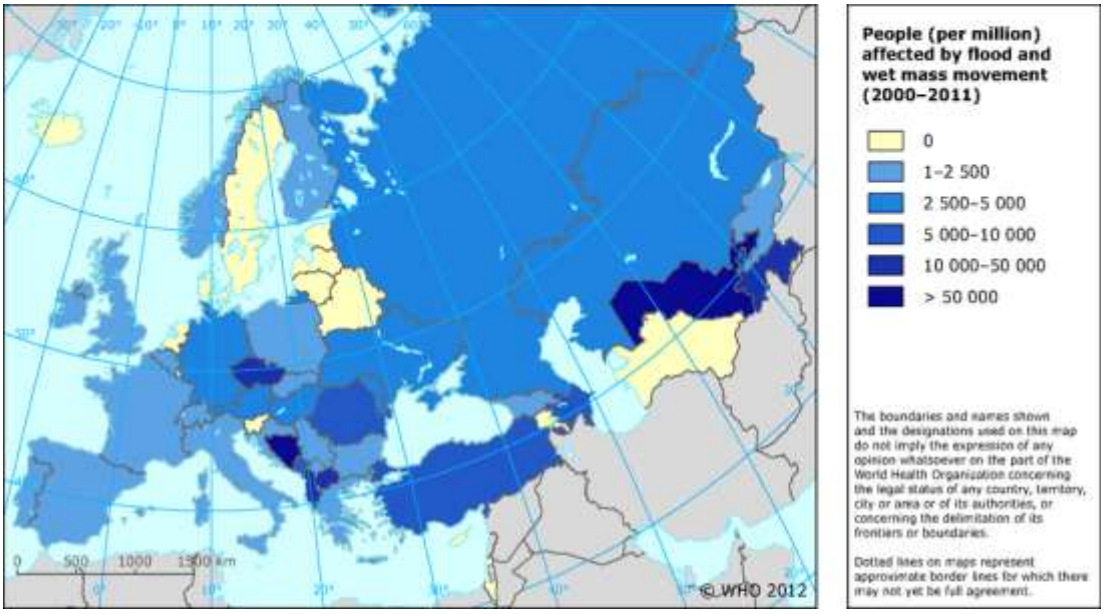


Figure 4. People affected by flooding in Europe from 2000 to 2011, per million population **(**WHO European Region). Source: http://www.eea.europa.eu/legal/copyright). Copyright holder: World Health Organization Regional Office for Europe (WHO/Europe)



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

Figure 5. Identification of risk classes for different products of flow velocity and depth for buildings (from Clausen & Clark, 1990).