Flood risk mapping at European scale

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Abstract The aim of this article is to illustrate a framework for flood risk mapping at pan-European scale produced by the Weather-Driven Natural Hazards (WDNH) action of the EC-JRC-IES. Early results are presented in the form of flood risk index maps. We assess several flood risk factors that contribute to the occurrence of flood disasters. Among the causal factors of a flood disaster one is triggering a natural event in the form of extreme precipitation and consequently extreme river discharge and extreme flood water levels. The threatening natural event represents the hazard component in our assessment. Furthermore exposure and vulnerability are anthropogenic factors that contribute also to flood risk. In the proposed approach, flood risk is considered on the light of exposure, vulnerability and hazard. We use a methodology with a marked territorial approach for the assessment of the flood risk. Hence, based on mathematical calculations, risk is the product of hazard, exposure and vulnerability. Improvements on datasets availability and spatial scale are foreseen in the next phases of this study. This study is also a contribution to the discussion about the need for communication tools between the natural hazard scientific community and the political and decision making players in this field.

Keywords European scale; flood risk mapping

Introduction

There is a growing need of accurate and reliable georeferenced information concerning flood risk and other natural hazards as an aid to political and economic decision making (Berz et al., 2001). In the framework of the European Union’s (EU) Flood Action Programme, the European Commission (EC) is currently developing the forthcoming Floods Directive relating to the assessment and management of flood risk (CEC, 2006). The objective of the Floods Directive is to reduce and manage flood-related risks to human health, infrastructure and environment. To this end flood risk mapping is one of the key issues defined in the Directive. DG-Joint Research Centre’s (JRC) Weather-Driven Natural Hazards action (WDNH) carries out the work on flood risk mapping to evaluate how land use changes and a changing climate potentially change flood risk. Accordingly several actions are being carried out at the JRC for the study and mitigation of the effects of floods in Europe. In particular, JRC’s WDNH is developing tools, models, a European Floods Alert System (EFAS see at: http://natural-hazards.jrc.it), and flood hazard and risk assessments at pan-European level.

The aim of this article is to illustrate a framework for flood risk assessment at pan-European scale produced by WDNH action (Barredo et al., 2005). Preliminary results are presented in the form of flood risk index maps. We assess several flood risk drivers which contribute to the occurrence of flood disasters. Floods are the result of interactions that involve nature and society. Among the causal factors of a flood disaster one is triggering a natural event in the form of extreme precipitation and consequently extreme river discharge and extreme flood water levels. The threatening natural event represents the hazard component in our assessment. Furthermore exposure and vulnerability are “non-natural” factors that contribute as well to an increasing flood risk. Anthropogenic
activities leading to an increase in flood risk include intensified land use and settlements growth in flood-prone areas, forestry practices, river regulation measures, low level of awareness among the public and decision makers in understanding the impacts of extreme events, lack or loose application of adaptation measures to the impacts of a changing environment, and lack of information and mapping of risk areas that could be useful for rising awareness and planning.

In the proposed approach the risk is considered in the light of exposure, vulnerability and hazard (Crichton, 1999; Kron, 2002). We use a methodology with a marked territorial approach for the assessment of flood risk. The methodology firstly considers the available geo-referenced information at pan-European level in order to give a realistic view of its potentialities and limitations. Hence, based on mathematical calculations, risk is the product of hazard, exposure and vulnerability. By following this approach a large GIS database has been designed and developed in order to spatially represent the three components of risk. The difficulty lies in the need of spatially and thematically homogenous data for the countries that cover the whole of the European Union. So far the database contains several layers with information on GDP, population density, land use, flood hazard, etc. The flood hazard layer is the result of the potential flood hazard map of Europe (De Roo et al., 2006). Examples of particular cases as a result of this study, including the Danube, will be shown, as well as comparisons with national flood risk maps. Improvements on datasets availability and spatial scale are foreseen in next phases of this study. This study is also a contribution to the discussion about the need for communication tools between the natural hazard scientific community and the political and decision making players in this field.

Methods
Components of flood disasters
There are several components which contribute to the occurrence of flood disasters. Among those elements one is the natural extreme event in the form of extreme precipitation and consequently extreme river discharge and extreme flood water levels. Nevertheless, anthropogenic issues also take part in the process of flood disasters generation:

- Socio-economic trends such as land use and population patterns, and increased wealth who may produce housing in ex-urban vulnerable areas (i.e. urban decentralisation, sprawl, development in flood-prone areas e.g. floodplain development).
- Low level of awareness among the public in understanding the impacts of extreme events.
- Low level of awareness among policy makers, decision makers and other stakeholders on the impacts extreme events.
- Lack or loose application of adaptation measures to the impacts of extreme events of a changing climate in the spatial planning framework.
- Lack of information and mapping of risk areas that can be useful for example for rising awareness among other purposes.

Comprehensive flood risk studies should consider a number of anthropogenic factors which increase exposure and vulnerability to floods. Extensive building in flood-prone areas may also increase the number of flood disasters. Current land use trends together with the number of urban areas historically placed in floodplains make a dangerous cocktail in Europe. The result of a shift in the climatic conditions could well be a dramatic further increase of flood disasters with implications to the economy, sustainable development and human health in the affected areas. Mitchell (2003: 570) remarks that “the spread of low-density suburbs and ex-urbs is a particularly significant factor in the conversion of rural lands near European cities, including floodplains. But far more important
than any of these are shifts in the location of industries and homes impelled by economic factors and lifestyles choices.” Hence, flood disasters are caused by a number of interactions between hazardous events and the characteristics of exposed elements that make them susceptible to damage (Dilley et al., 2005). By following this approach, potential damage to persons, assets and environment due to a given hazard must be assessed by considering their exposure and vulnerability to that hazard. Where there are no people or assets that can be affected by a given hazard or where there is no vulnerability, then there is no risk (Crichton, 1999; Kron, 2002). Vulnerable elements are represented by people, infrastructure and economically or environmentally important land uses (Dilley et al., 2005).

From flood hazard to flood risk

In the scientific community it is widely agreed that natural risks are the product of a hazard and its consequences (Kron, 2002). Hence, on the basis of the proposed framework, risk is a function of hazard, the exposed values/people and their vulnerability. The increase in flood disaster loses must be attributed to changes in each of these three factors. The following definitions framework is used in this study (Crichton, 1999; Kron, 2002):

- Risk is a potential loss having uncertain occurrence and size.
- Hazard is the threatening natural event including its probability/magnitude of occurrence.
- Exposure is represented by the values/humans that are present at the location involved. This is typically expressed by statistics on population, socio-economic data on sectorial activities and infrastructure.
- Vulnerability is the lack (or loss) of resistance to damaging/destructive forces. It is therefore the indication of the measures taken (or to be taken) to mitigate the effects of extreme events. This factor measures the extent to which the subject matter could be affected by the hazard.

The key feature in the proposed methodology is that exposure and vulnerability are specific for each type of hazard (Dilley et al., 2005), although we have to be aware that the term risk is understood in different ways by different people. For instance risk is understood differently in the fields of floods and forest fires. The three components that determine the risk have to be represented by using available georeferenced datasets in order to be able to produce a flood risk layer. Spatial analysis techniques using Geographical Information Systems (GIS) are probably the only way to deal with the huge volume of data necessary for the assessment of large regions. To this end, data availability has to be taken into account in order to achieve a realistic representation of risk and its three components.

Based on mathematical calculations including return period probabilities for each location, risk can be calculated. However in practice this kind of analytical calculation for assessing risk is seldom possible, mostly in the case of very large study areas. This is because the available data is usually very thin (Kron, 2002; Dilley et al., 2005). Instead simplified procedures are usually applied and a number of assumptions have to be made in order to produce flood risk index maps.

Results: Flood risk mapping

By following the proposed approach a large GIS database has been designed and developed in order to spatially represent the three components of risk. The difficulty lies in the need of spatially and thematically homogenous data for the countries that cover our study area i.e. EU, Bulgaria and Romania. So far the database contains several layers with
information on GDP, population density, land use, flood hazard, etc. The sources of information are EUROSTAT, CORINE Land Cover and GISCO. The hazard component represented by the potential flood hazard map of Europe (De Roo et al., 2006) was derived using a 1 km digital elevation model and the 1 km grid European flow network developed by WDNH.

**Exposure**

The interaction between hazardous events and the characteristics of exposed elements is what produces potential disaster losses. The exposure component has been produced by merging the effect of population density at NUTS 3 level and land use potential cost of damage due to a flood, obtained from CORINE 2000. In the case of population the assumption is obvious. The number of people in danger is one of the basic indicators for flood exposure. On the other hand, the land use type serves for measuring the economic damage as result of a potential flood, including flood water depth estimations (Figure 1.A).

**Hazard**

With the aim to provide an overview of potential areas susceptible to flood hazard, the JRC has produced a potential flood hazard map of Europe (De Roo et al., 2006). In order to estimate flood hazard on European scale several methodological steps are followed. Currently a potential flood hazard map at 1 km grid size is available. The map was produced by using a 1 km spatial resolution digital elevation model (DEM) and the European flow network developed by JRC (Hiederer and De Roo, 2003), using water-level assumptions based on

![Figure 1](https://iwaponline.com/wst/article-pdf/56/4/11/437785/11.pdf)

Figure 1 Flood risk assessment for the EU, Bulgaria and Romania. 1.A) Flood exposure, 1.B) Flood hazard, 1.C) Flood vulnerability, and 1.D) Flood risk at NUTS 3 level
upstream catchment area (see: De Roo et al., 2006). An algorithm has been developed to calculate the elevation difference between a specific grid-cell and its closest neighbourhood grid-cell containing a river, while respecting the catchment tree-structure, in this way a grid-cell can never be linked to a river in another (sub)-catchment area.

Hydrological processes such as flooding and soil erosion are determined by topographic parameters, and therefore digital elevation data play a crucial role in modelling. The accuracy of the DEM is of utmost importance for the accuracy of the final flood hazard map. DEMs are the essential element to produce a flood hazard map. The vertical accuracy is of crucial importance to achieve accurate results, as demonstrated by Wilson (2004) and numerous others. Inaccuracies in the final predicted flood extent arise from unknown surface roughness values, or linear features on floodplains such as roads, ditches, etc, that are not well incorporated in the DEM.

The current potential flood hazard map is an intermediate product towards up-graded versions based on the use of higher resolution DEMs (250 m and 100 m grid size) and estimation of water levels from the LISFLOOD model (De Roo et al., 2000; De Roo et al., 2003). The current potential flood hazard map has been validated against actual maps of floods which occurred in Europe in the last few years. A further description of the method used for the production of the potential flood hazard map can be seen in De Roo et al. (2006) (Figure 1.B).

Vulnerability

Landscapes and societies are composed by a large number of integrated sub-systems that interact between them as a whole. These sub-systems may be affected differently by a given hazard, and even the same sub-system might be affected in different ways by a hazard with the same magnitude and frequency. For instance, it is well known that people affected regularly by floods are less vulnerable to floods than groups having a similar socio-economic condition but who have never or rarely been affected by a flood. The first group knows how to react, they know what to do in the case of a flood. The experience has shown to them how to save their life. Vulnerability is without doubt the most complex component of flood risk. It is changing in time and space. In the case of studies at very local level vulnerability analysis require detailed knowledge of households or community characteristics and behaviour in the case of extreme weather events. In large scale studies as this one, “vulnerability assessment is at best only possible through the use of general proxies” (Dilley et al., 2005: 7).

In this study GDP per capita at NUTS 3 level is so far the only proxy available for vulnerability for the whole of EU. A more detailed approach will be used in next phases of this study. By using GDP per capita the assumption is simple, “poorest” regions are worst prepared and are more vulnerable to the effects of flood hazards. Moreover, natural hazards may even produce an increase in the gap between “poor” and “rich” regions (Figure 1.C).

Integration of the risk’s components

In order to avoid artificial weighting assignments in the input factors, a non-compensatory approach is used for the production of the standardised index map for flood risk. Initially all input factors have been standardised in a range of 1 to 100. Being 1 the lower risk contribution and 100 the maximum. For GDP per capita and population density a linear standardisation with saturation is used. A saturation of 5% is used in both layers in order to avoid the effect of extreme low and high values. The land use potential damage due to floods has been produced by using the approach developed by Van der Sande (2001). In this approach each CORINE land-use class is assessed on the basis of the
monetary cost of several water depth scenarios. Indeed, the hazard factor has been stand-

dardised with a linear function considering its more homogenous histogram. The inte-

gration of the standardised factors is done by simple multiplication of the corresponding

input layers. In addition a binary risk/no-risk mask layer has been used in order to define

risk areas in only those pixels in which hazard > 0 is reported. Thus the products so far

obtained are:

- Flood risk model layer: Standardised risk index map (grid size 1 km). This layer
  shows on each pixel an index for flood risk. The layer can be classified on several risk
  levels, from very low to very high, as a function of the risk values.
- Flood risk layer at NUTS 3: Risk assessment at NUTS 3 (province level). This layer
  shows the average value of risk for each NUTS 3 area. As in the previous case it can
  be classified on several risk levels, from very low to very high, as a function of the
  average risk values (Figure 1.D).

**Discussion and conclusions**

The last couple of decades have experienced a significant increase of impacts of events

driven by extreme weather conditions. There are several concurrent causes for this trend,

which are confirmed at both global and European levels. From one side, it is now widely

accepted in the scientific community that there is an increased frequency of extreme

events due to on-going climate transformations (IPCC, 2001). From the other side, uncon-
trolled developments have originated an increased exposure of assets which in turn results

in higher impacts when the extreme event occurs (EEA, 2004).

Usually flood risk studies are produced for policy and decision making, and to raise

awareness in citizens and politicians. Hence the results of risk assessments are often

expected to reach a wide and diverse range of stakeholders. The delivery of results

becomes a communication fact. While the evaluation of risk is based on scientific

methods, its communication depends also by the perception of risk of the receiver of the

information (German Advisory Council on Global Change, 2000). Sometimes the read-

ability of complex scientific results for a wide range of players becomes a difficult task.

In the case of risk assessments for large areas the issue is even more challenging because

of the different potential impacts for people and assets that could be interpreted from the

risk maps. One of the aims of the study is to alleviate the need for documentation that

concisely presents global flood risk for the EU within a territorial framework. Furth-

ermore this is a first step supporting the forthcoming Floods Directive (CEC, 2006). In the

frame of an analysis of the harmonised development of the European Union, it is evident

that natural hazards can well be considered elements of territorial disparities (i.e. of

causes that threat the harmonised and sustainable growth across the continent) because

consequences of extreme events and plans to reduce exposures (for instance intensive

actions such as dykes or zoning regulation measures) have an impact on the socio-econ-

omic growth of the concerned region. The European policy framework is duly consider-

ing and taking on board this aspect. Indeed, as a contribution to prevention and

damage reduction, the new regulations Structural Funds and instruments for the period

2007–2013, foresee specific measures for “developing plans and measures to prevent and

cope with natural risks”. The regulation on the European Agricultural Fund for Rural

Development (EAFRD) also includes risk provisions. Additionally, the European Climate

Change Programme foresees the concept of “adaptation to climate change” which

involves measures and programmes for risk prevention and mitigation.

In order to evaluate regional variations in vulnerabilities and define sustainable reme-
dial strategies, both direct and indirect impacts have to be considered in quantitative and

qualitative manners. The pan-European flood risk map under development by the JRC, as
described in this article, aims to combine and quantify the factors determining the potential harm of flood disasters. In particular, the territorial approach herein described, allows considering features and measures taken at different government levels (e.g. provincial, regional and/or national), while still providing a harmonized European approach. As such, flood risk mapping activities represent an important tool to evaluate Community interventions to reinforce coping mechanisms and contribute to the definition of regional development strategies.

References