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Integrated spatial flood risk assessment: The case of Zaragoza

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ABSTRACT

Flood-risk prevention measures are designed to reduce the adverse consequences associated with floods for humans, the environment, cultural heritage and economic activity, as per the EU Floods Directive (2007/60/EC). An economic assessment of the risk provides advantages for the identification of single hazards. Policy makers thus receive relevant information on the sectors and places at risk. This article provides an integrated spatial assessment of the flood risk for human beings and for the residential, non-residential, agricultural and environmental sectors. The methodology used is applied to the city of Zaragoza and downstream municipalities in the Ebro river basin (Spain). The analysis emphasises that flood-risk assessment must account for two measures of risk. The first is the expected annual damage, which is used to prioritise locations and sectors for prevention. The second comprises damage-probability curves, which provide information on the distribution of the risks, taking into account whether they originate from frequent floods with slight consequences or from exceptional floods with major consequences. The spatial assessment of risk reveals how the risk is distributed between upstream and downstream cities. This opens up a discussion on the issue of equity in flood risk-sharing in spatially integrated analysis.

Introduction

In the period 1987–2011, the Spanish Insurance Compensation Consortium estimated that floods were the main risk in which compensation was required and that they accounted for about 69.06% of disaster compensation (CCS, 2012). Moreover a series of floods and dam failures with loss of life and large tangible losses in Spain have raised awareness among public authorities regarding flood prevention measures and programmes (Serra-Llobet et al., 2013) such as dam construction, flood monitoring and warning systems. The regulations on the construction and security of dams were organised in a Governmental Order of 1967, covering the preparation of projects, the construction and the operation of dams. For purposes of unification of regulations Royal Decree 9/2008 applies. In 1985 a long term river monitoring programme (Automatic Hydrological Information System—SAIH) was launched to improve the monitoring of river flows and improve flood alert systems. Prevention of flood disasters is therefore an important question for authorities from national to local governmental level, including river basin authorities, and for civil protection agencies and the general public.

Prevention policies have evolved with experience, with lessons learned from past disasters and with European directives. Flood risk was traditionally managed by means of infrastructures to protect against flooding. The efficiency of these structures, along with their environmental impacts, is currently being questioned (Werrity, 2006; Brouwer and van Ek, 2004). In the European Union, a shift in environmental policy orientation occurred at the turn of this century with the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC), along with Common Agricultural Policy reforms and the associated Rural Development Regulation payments linked to nature conservation. This shift provides further space for environmental measures and seeks to favour the good ecological status of rivers.

A spatial dimension needs to be factored into the design of flood-risk prevention plans in order to identify places at risk, i.e. locations where the consequences of river flooding are high for society. Moreover, integrated flood management strategies are more relevant in the assessment of flood risk and in the design of prevention policies as such strategies recognise the link between risk

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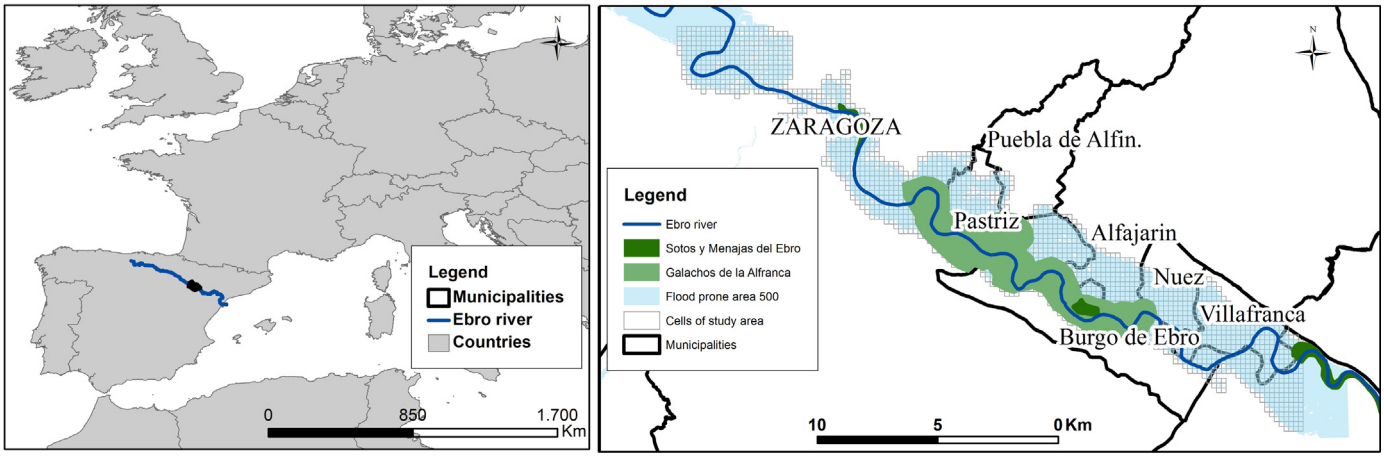

Fig. 1. Location of the study area.

management measures, their analysis, their cost and effectiveness, and equity within changing social, economic and environmental contexts (Hall et al., 2003; Brouwer and van Ek, 2004; Jonkman et al., 2008; Erdlenbruch et al., 2009; Ward, 2013). Specifically, upstream-downstream links must be accounted for to prevent risk from being transferred from upstream to downstream locations. In addition, avoiding the transfer of risks between sectors (residential, non-residential, agriculture, ecosystems) is a crucial point for the development and expansion of municipalities. Similarly, river restoration and infrastructure interventions therefore also need to take spatial and sectoral transfers of risk into account. To that end, flood-risk prevention policies based on an integrated assessment of risk are more relevant in dealing with measures efficiently and equitably. These assessment methods can serve as a support for more sophisticated decision-making processes such as cost-benefit analysis or multi-criteria analysis.

Against this background, this paper presents a first flood risk assessment covering the Ebro river basin downstream from the city of Zaragoza, the main socio-economic hub of the basin. Natural floods in this basin can have two origins: persistent rainfall in large sub-basins increased by high temperatures leading to rapid thaws in the Pyrenees, and short-duration, high-intensity local rainfall that gives rise to extremely rapid, violent flash floods in a limited area. Between 2000 and 2010 the Ebro river basin experienced two major floods. Between 28 January and 6 February 2003, a combination of precipitation episodes from the Atlantic and thaw episodes in the Pyrenees resulted in one of the three most serious floods in the Ebro in the last 50 years. At its peak the flow was 2800 m^3/s in Zaragoza. The National Catalogue of Historical Floods (Catálogo Nacional de Inundaciones Históricas (CNIH), 2008) reports that in the Ebro river basin one person died, 1315 were evacuated and 4072 residential buildings and 150 industrial firms were affected. In early spring 2007 the combination of several episodes of precipitations in both the Mediterranean and the Atlantic and the thaw in the Pyrenees produced an unequally distributed flood in the Ebro. These floods are characterised by different return periods all along the Ebro, from 5 years to 50 years in terms of flow velocity.

Given these past events, it is important to study the current flood risk in the Ebro river basin in order to support prevention policies. The case study area measures nearly 90 km^2, and covers the municipalities of Zaragoza, Pastriz, Alfajarin, el Burgo de Ebro, Nuez de Ebro and Villafranca de Ebro. The total population at risk in these municipalities is around 680,000, with 98% of that number resident in Zaragoza. The density of population in the area varies widely from 13 to 697 persons per km^2. The study area covers urban and rural zones and the natural areas of Galachos de la Alfranca and Sotos y Mejanas del Ebro (Fig. 1).

Our analysis assesses the places and sectors at risk in the area and shows how risk is distributed geographically and between sectors of society. We discuss how policy makers should take these results into account in designing future land use plans efficiently and equitably.

We propose a spatial economic valuation of flood risk for people, the economy (residential and non-residential sectors) and the environment. We synthesise and apply flood risk assessment methods to assess the risk involved in monetary terms and propose a methodological extension for the environmental consequences. We conserve the spatial dimension of the risk by using a Geographic Information System (GIS) (Zenger and Wealands, 2004). This GIS approach combines hydrological and hydraulic information (flood hazards) with the consequences of land settlement.

The paper is organised as follows. Flood risk assessment methodology section explains the flood-risk assessment method used and how risk is measured as an average measure and a distributional function. Results section presents the results of the risk assessment in the area surrounding the city of Zaragoza for the residential, non-residential, agricultural, human and environmental sectors. Integration of flood risk: Sectoral and the spatial issue section provides a spatial and sectoral analysis of risk. Limitations section discusses the limitations of the model and Conclusions and discussion section concludes.

Flood risk assessment methodology

Flood risk is a product of flood hazard and the negative consequences of flooding. The method used to assess flood-risk consists of four steps (Penning-Rowsell et al., 2005; Foudi and Osés-Eraso, 2014): (i) hazard assessment; (ii) exposure assessment; (iii) vulnerability assessment; and (iv) risk assessment. The succession of these steps can be represented as in Fig. 2.

Hazard assessment informs about flood characteristics (water depth, surface area flooded, flow velocity, etc.) with different return periods that can be summarised in flood maps. These maps are overlaid on land-use maps to form the basis of the exposure assessment, whose objective is to provide spatial references for the elements at risk of being flooded, such as residential, non-residential uses, agricultural uses and people. However, being exposed does not necessarily result in negative consequences. It is the vulnerability assessment that determines how likely these elements are to be harmed by flooding. This is defined by their susceptibility to