Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/envsci

Flooding hazard in the Tagus estuarine area: The challenge of scale in vulnerability assessments

Alexandre Oliveira Tavares [a], Pedro Pinto dos Santos [b,*], Paula Freire [c], André Bustorff Fortunato [c], Ana Rilo [c], Luís Sá [d]

[a] Centre for Social Studies and Earth Sciences Department of the University of Coimbra, Largo Marquês de Pombal, Coimbra 3000-272, Portugal

[b] Centre for Social Studies of the University of Coimbra, Colégio de S. Jerónimo, Largo D. Dinis, Apartado 3087, 3000-995 Coimbra, Portugal

[c] National Civil Engineering Laboratory, Av. do Brasil, 101, 1700-066 Lisbon, Portugal

[d] National Authority for Civil Protection, Av. do Forte em Carnaxide, 2794-112 Carnaxide, Portugal

ARTICLE INFO

Article history:
Received 29 January 2015
Received in revised form
9 April 2015
Accepted 12 April 2015
Available online

Keywords:
Vulnerability
Flood
Storm surge
Tagus estuary
Local scale

ABSTRACT

This paper describes the methodology of the vulnerability assessment to flooding in an estuarine context and presents the final results for the Tagus River estuary, in the metropolitan region of Lisbon (Portugal). Performing a local study adapted to a specific type of hazard posed two initial methodological challenges: the selection of the unit of analysis and the identification of the pertinent and available variables. Both challenges were addressed assuming that the area to be assessed should also include the units outside the inundated area, a buffer zone that would include areas indirectly affected. The application of the statistical procedures established in the SoVI® methodology indicate that certain widely used variables in vulnerability assessments on smaller scales are inadequate at the statistical block scale and that specific variables must be defined and integrated to represent more broadly the dimensions of vulnerability related to social assistance, infrastructures and commutability.

The extracted principal components identified the vulnerability drivers in the riverside and surrounding areas. These drivers identify the urban context, the family structure, and the socio-economic condition expressed in terms of housing characteristics, education, mobility and commuting as the dimensions that most differentiate territorial and individuals' vulnerability. Applications of vulnerability research in risk management are found in the fields of risk communication, stakeholders' involvement and strategic and operational planning in emergency planning as in other concurring sectors.

1. Introduction

The assessment of vulnerability is a complex challenge in regard to data availability and analysis and is a central issue in coastal flood risk governance. Vulnerability, as a major concept, refers to the degree to which communities and individuals are susceptible to – and unable to recover from – the effects of hazardous processes, encompassing the physical, social and organizational components of social systems.

* Corresponding author. Tel.: +00351 239855570; fax: +00351 239855589.
E-mail addresses: atavares@ci.uc.pt (A.O. Tavares), pedrosantos@ces.uc.pt, pedrompsantos@yahoo.com (P.P.d. Santos), pfreire@lnec.pt (P. Freire), afortunato@lnec.pt (A.B. Fortunato), arilo@lnec.pt (A. Rilo), luis.sa@prociv.pt (L. Sá).
http://dx.doi.org/10.1016/j.envsci.2015.04.010
1462-9011/

The ''condition of a community,'' in terms of its degree of vulnerability and resilience, can establish whether the disaster threshold is crossed when a hazardous event occurs (Haigh, 2010). Therefore, vulnerability assessments must be conducted considering that vulnerability is an ''integral part of the causal chain of risk'' and that reducing vulnerability is a cost-effective strategy of risk management (Kasperson et al., 2001) and a key element in any risk governance process. Understanding vulnerability is one of the foundations that support the achievement of the 10 essentials of safe and resilient cities articulated in UNISDR (2012), primarily focusing on the essentials of multi-hazard risk assessment; protection of vital education and health facilities; training, education and public awareness; effective preparedness, early warning and response; and recovering and rebuilding communities.

Assessing vulnerability in estuarine margins is a matter of key importance given the natural susceptibility to flooding in these areas – at the interface between low-energy fluvial conditions and high-energy maritime hydrodynamics – aggravated by the increasing influence of natural and human-induced factors such as sedimentation, sea level rise and settlement of human activities in intertidal and proximal areas (McLean et al., 2001). Estuarine margins, and coastal margins in general, can have a high risk of flooding, as shown by the recent impact of inundation events, as the hurricane Katrina (2005) in New Orleans, the storm Xynthia (2010) in the French coast and the hurricane Sandy (2012) in New York (e.g., Bertin et al., 2014; André et al., 2013). Moreover, the inundation hazard is expected to increase in severity and frequency due to climate change effects, in particular sea level rise and growing storminess.

The study area of the present paper is the Tagus estuary, whose morphological settings and hydrodynamic conditions, as the amplification upstream of the semi-diurnal tides (Fortunato et al., 1999; Guerreiro et al., 2015), promote high risk to flooding of estuarine margins (Rilo et al., 2013). The conjugation of extreme tidal levels and storm surge conditions can lead to inundation episodes along the estuarine margins, such as the one that occurred on February 15th 1941, with high human casualties and property damages (Muir-Wood, 2011). Fig. 1 illustrate the events of 1941 and 1954 as they were reported in national scope newspapers. Historically, flood-prone areas of the Tagus estuary have been used for residential and economic activities. With the growth of the capital, Lisbon, in the northern margin, a consequent growth in the southern margin has occurred, especially in the 20th century. This increasing dynamic between margins merges in the movement of people and goods.

This manuscript presents the social and territorial variables that characterize the Tagus estuary, specifically focusing on the flood hazard, identifying the components of vulnerability to this hazard on a local scale and providing insights into the manner of transferring the knowledge associated with these components of vulnerability to risk management policies and practices. Scale poses a major challenge because a general differentiation of municipalities, or even parishes, is considered inadequate for the purposes of this study. In fact, the goal is to assess the vulnerability of individuals and communities to estuarine flooding at the local level, i.e., classifying neighborhoods and urban zones by their distinctive vulnerability factors.

The development of indexes as a manner of quantifying vulnerability reduces the multidimensional complexity of vulnerability to a single metric (Tate, 2013). Assessments of vulnerability indexes in Portugal, similar to the one here presented, include the application of the SoVI® by Mendes (2009) to 78 municipalities of the central region; and, more recently, Guillard-Gonçalves et al. (2014) applied the same index to a group of 149 civil parishes of Greater Lisbon, in which the final model was performed with 38 variables after multicolinearity elimination. Mendes et al. (2011), based on the statistical procedure behind the SoVI®, developed a new social vulnerability index that considers the components of criticality and support capability. Criticality is the ''ensemble of individuals' characteristics and behaviors that may contribute to the system's rupture,'' and support capability is the ''set of territorial infrastructures that enable the community to react in case of disaster'' (Mendes et al., 2011: 446). This methodology has since been applied to several Portuguese municipalities at the statistical block level (e.g., Tavares and dos Santos, 2014).

In this study, vulnerability is approached in its territorial and individual dimensions; the considered variables extend beyond social vulnerability to include land use, mobility and infrastructure dimensions. Nevertheless, the adopted concept of vulnerability is closely related to the concept of social vulnerability, which is defined as a pre-existing condition of individuals and communities that influences their preparation, response and recovery from hazard events (Chen et al., 2013; Bergstrand et al., 2014), resulting from both social inequalities and place inequalities (Cutter et al., 2003). Understanding vulnerability is crucial to the development of disaster mitigation plans and policies. In fact, vulnerability sources are not only addressed via civil protection action but also require a broader concerted action among practitioners of distinct public and private sectors and fields. The most relevant fields include health, education, social assistance, the economy, spatial planning and transportation. It is therefore significant that the Portuguese legal transposition of the European Union directive (2007/60/EC), through the Decree-Law no. 115/2010 of 22nd October, which establishes the framework for the management of flood risks, stipulates the necessity of conducting an analysis of the vulnerability of exposed population, equipment, lifelines and environmental values.

2. The Tagus estuary

2.1. *Territorial and socio-economic context*

The Tagus estuary is located in Portugal and named for the transnational river that flows into the Atlantic Ocean near the capital city of Lisbon and its metropolitan area (Fig. 2). In addition to the relevance of social and economic exchanges within margins and between the left and right margins, the area is also sensitive in terms of densely urbanized areas, the exposure of critical and sensitive infrastructures and because of the area's ecological functions, with a portion of its eastern upstream area legally protected as a natural reserve.