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Scale issues in local vulnerability assessment: implications in risk and urban planning

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Abstract: The assessment of vulnerability provides valuable knowledge in the risk assessment steps of a risk governance process. Given the multiscale, multilevel and multisectorial aspects of flood risk, the diversified entities that directly and indirectly intervene in risk management require specific outputs from the assessment studies. Vulnerability assessment methodologies should, therefore, produce the most adequate information considering their final end-users.

Urban areas in estuarine margins are particularly exposed and vulnerable to flooding due to the high dynamics of such natural and human systems. That interface conditions are found in the Old City Centre of the Seixal municipality, located in the left margin of the Tagus River, near Lisbon (Portugal).

In this study area two distinct methodologies were applied for the assessment of territorial vulnerability to estuarine flooding. After a description of the assessment procedures results are presented, compared and discussed.

A first, lower-scale, methodology explores the application of the statistical procedure based on the SoVI[®] at the statistical block level. The second, higher-scale, methodology is based in data collected through field matrices at the building and statistical sub-block level.

The comparison of both vulnerability classifications revealed that the lower-scale vulnerability assessment provides information with the ability to identify vulnerability drivers at the regional and municipal level. Nevertheless, only at a higher-scale it is possible to characterize and differentiate the smaller units of analysis that compose the Old City Centre of Seixal. It is argued that the most efficient implementation of local flood risk management strategies in the study area – such as urban planning, risk communication and early warning systems –, would better be achieved considering the local higher-scale vulnerability data.

Keywords: flood hazard, vulnerability, multiscale, risk management

1. Introduction

The definition of vulnerability, by White (1974), as the “degree to which a system, sub-system, or component is likely to experience harm due to exposure to a hazard, either a perturbation or stress” is still valid and encompasses a wide range of aspects that are to be considered in vulnerability assessments. The prediction of flood impacts, in particular, vary from approaches that focus mainly on the economic direct and indirect losses (e.g., Carrera *et al.*, 2015) to social-oriented approaches such as the Social Flood Vulnerability Index (Tapsell *et al.*, 2013) or the Social Vulnerability Index (Cutter *et al.*, 2003), involving broader dimensions of flood risk. The need to consider specific vulnerability indexes to urban contexts is increasing among the scientific community (Fang *et al.*, 2016).

The richness and diversity of approaches considered in the assessment of vulnerability (Nguyen *et al.*, 2016) turn them into valuable knowledge in the risk assessment steps of any given risk governance process. It is significant, therefore, that the recently agreed framework for disaster risk reduction stresses the relevancy

of assessing vulnerability: “policies and practices for disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability (...)” along with the knowledge on the installed capacity, exposure of persons and assets and hazard characteristics (UNISDR, 2015).

Given the multiscale, multilevel and multisectorial aspects of flood risk, the diversified entities that directly and indirectly intervene in risk management require specific outputs from the assessment studies. Vulnerability assessment methodologies should, therefore, produce the most adequate information to respond to the different needs of risk managers and practitioners (Mendes, 2009).

Beyond the scope of the assessments, methodological issues such as the scale and data level of disaggregation are equally relevant to the adequacy of results to efficient risk management (Schmidtlein *et al.*, 2008, Tavares and Santos, 2013, Tavares *et al.*, 2015). This paper discusses two vulnerability assessment methodologies that follow distinct scalar approaches and suggests that the efficiency of estuarine flood risk management strategies is dependable on the capacity to understand and apply both results in the most adequate manner. The vulnerability assessment attempts to specifically address the estuarine flood hazard under storm surge conditions. Under these conditions, tide, wind and atmospheric pressure can override the role of riverine flow in explaining the observed flood levels.

2. Study area

The Old City Centre (OCC) of the Seixal municipality, located in the left margin of the Tagus River, near Lisbon (Portugal) is the selected local study area, presenting an area of 10.39 hectares. The OCC of Seixal testifies the interface conditions that are found in estuaries, characterized by strong dynamics of the natural and human systems (Figure 1).

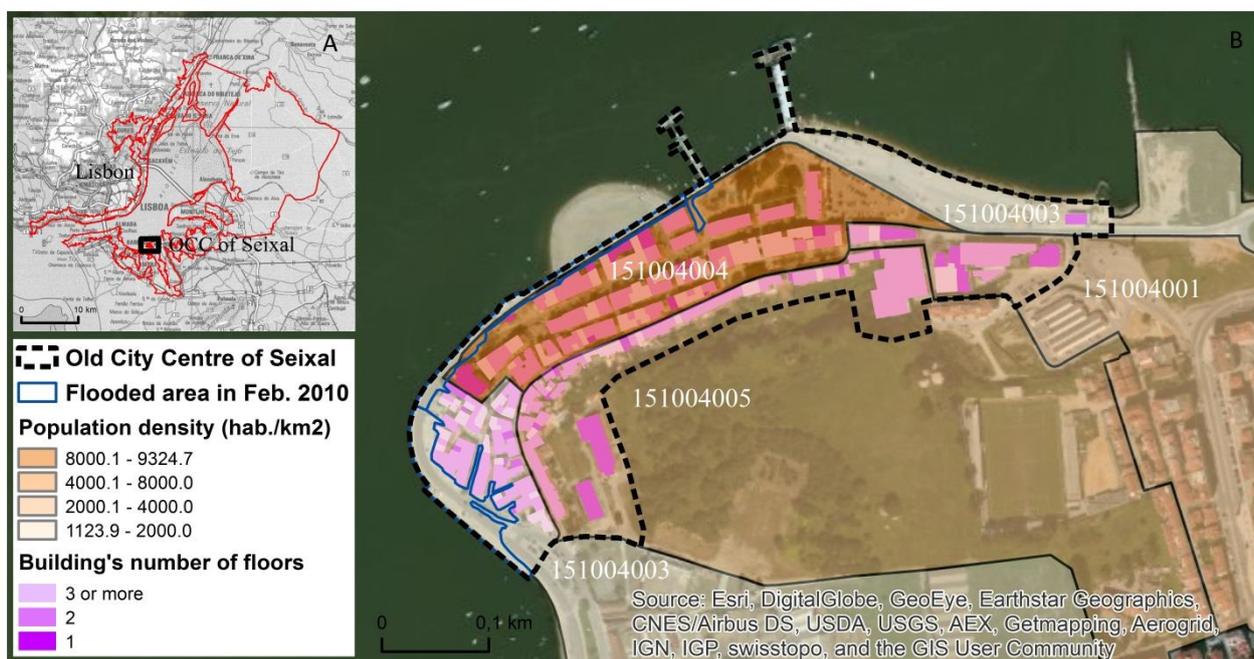


Figure 1 – Geographical context of the OCC of Seixal in the Tagus estuary

The OCC of Seixal is particularly exposed and vulnerable to flood hazard forced by tides and storm surges, as testified by the flooded area in February 2010 (Figure 1), associated to the Xhynthia storm event (Andre *et al.*, 2013). Its water front is characterized by a low density consolidated urban area – mostly buildings with 2 to 4 floors –, where administrative, commercial and residential functions are dominant. A longitudinal seawall separates estuarine waters from urban areas, only discontinued by accesses to a small sand beach and docks. Along the seawall, a locally relevant road and leisure areas are found. Socioeconomically, the demographic spectrum is marked by aged population (207 in 686 residents are over 65 years old). Near 14%

of the residents aged between 25 and 64 years old are unemployed (46 in 337) (INE, 2011). The OCC of Seixal comprises 4 statistical blocks (SB's) and a total of 344 buildings⁶.

3. Methodology

3.1 Statistical block level approach

The lower-scale methodology explores the application of the statistical procedure based on the SoVI® (Cutter *et al.*, 2003), at the statistical block (SB) level. The methodology is described more thoroughly in Tavares *et al.* (2015). Using the SB as the geographical unit of analysis, a total of 1147 SB's were defined around the Tagus estuary – see the red polygon in Figure 1-A –, for which a set of data regarding 126 variables was collected. After the elimination of redundancies between variables, Principal Component Analysis (PCA) was performed with z-scores of 34 variables representing distinct dimensions of vulnerability (age, education, housing, employment, lifelines, rural/urban contrast, social infrastructures, mobility and commutation). The scores of each principal component (FAC) are summed, resulting in the territorial vulnerability (TV) at the SB level, classified in five classes according to the standard deviation (Tavares *et al.*, 2015).

3.2 Sub-statistical block and building level approach

The higher-scale approach is based in data collected through two field matrices – one at the building level and another at the statistical sub-block (S-SB) level – and in specific data from the Census 2011 collected at the S-SB level of aggregation (Table 1).

For the data in each question of the field matrices – whether collected at the S-SB or the building level –, a score between 0 and 1 is attributed according to the role of each characteristic in providing low vulnerability (score 0) to high vulnerability (score 1). Some of the parameters calculated from field matrices, P3 to P8, are the result of the combination of more than one matrix question, cases in which a simple average was calculated.

Table 1 – Vulnerability parameters defined at the sub-statistical block level

Data collection level	Parameter	Raw units	Source
Sub-statistical block	P1. Profile of the more vulnerable population	%	Census data
Sub-statistical block	P2. Absolute resident population	n.º of inhabitants	Census data
Sub-statistical block	P3. Present population	Scores [0,1]	Field matrix
Sub-statistical block	P4. Surrounding urban context	Scores [0,1]	Field matrix
Building	P5. Vital functions in buildings: social, health, administrative and civil protection infrastructures	Scores [0,1]	Field matrix
Building	P6. Severity of the individual loss	Scores [0,1]	Field matrix
Building	P7. Buildings' physical vulnerability	Scores [0,1]	Field matrix
Building	P8. Human presence inside buildings	Scores [0,1]	Field matrix

Parameters P1 and P2 are defined upon Census data. P1 is calculated upon three input variables: population above 65 years old, population under 5 years old and population without economic activity. The percentages are linearly transformed to the interval [0,1] and, using those values, a simple average is calculated. The score

⁶ Each SB is identified as illustrated in Figure 1, coded uniquely as follows: DTMNFRSEC, being “DT” the district code, “MN” the municipality code, “FR” the parish code and “SEC” the SB code. As a simplification, SB will be referred to by the “SEC” code only (cf. Table 2). The 4 SB's of the OCC of Seixal are subdivided into 20 statistical sub-blocks (S-SB's) – which add 2 more digits to the SB codification.

of parameter P2 is the result of the linear transformation of the absolute number of residents to the interval [0,1]. Parameter P3 is based on the questions of the S-SB level field matrix related to the estimation of transient population and the permanency to exposure (day and night fluctuation and punctual permanency, as in the cases of exhibitions and sport events). Parameter P4 represents the surrounding urban context and is based on the following data: land use; linear (not buildings) critical infrastructures and urban fabric; and flood defense infrastructures.

Severity of individual loss (P6) is assessed by attributing scores to building functions according to their relevance to users in case of flood damages. For example, garages are scored with 0.4, commercial buildings with 0.8 and residential buildings with 1.0. Parameter P7 stems from the scores attributed to the following building characteristics: existence of windows and doors on the seaside, existence of underground floors, conservation condition and number of floors. Parameter P8 is based on the evaluation of the number of housing units in each building as well as its function (residential, commercial, social, sports and leisure, etc.). Finally, the scores of the eight parameters are summed, appearing in the final score of territorial vulnerability (TV) in the OCC of Seixal, at the S-SB and building level.

4. Results

4.1 Statistical block level approach

Results from the PCA at the SB level shows that eight principal components (FAC's) are explaining the territorial vulnerability patterns of the 1147 SB's located around the Tagus estuary margins: FAC1 (old neighbourhoods and population with constraints), FAC2 (residential areas of families with care-giving responsibilities), FAC3 (residential areas of population with high economic status), FAC4 (population mobility), FAC5 (building size), FAC6 (old urban areas with an aged population), FAC7 (educational level of the population) and FAC8 (urban development). Territorial vulnerability results at the estuary level are, in detail, explained in Tavares *et al.* (2015). Table 2 presents a resume of the TV results obtained with this lower-scale approach. Negative scores mean low vulnerability and vice-versa. Scores between -0.5 and 0.5 are classified as moderately vulnerable.

When assembled in the context of the Tagus estuary, the OCC of Seixal is characterized by specific drivers of vulnerability, although not equally observed in its 4 SB's (Table 2). According to the standard deviation classification, SB 004 for example, is classified with high TV, while SB's 003 and 005 have moderate and SB 001 low TV. But even the SB's classified with high TV may present negative scores in one or more principal components (e.g., the score of SB 004 in FAC5, highlighting the benefits of this methodology, by allowing risk decision-makers and practitioners to plan and act upon the most relevant drivers of vulnerability.

In fact, it is observed that the 4 SB's scores in FAC1 and FAC2 are in general higher, i.e. more vulnerable, than the majority of SB's in the Seixal municipality and even in the Tagus estuary. In the other principal components the behaviour of the 4 SB's is not homogeneous. For example, in FAC3, the SB 001 counters the vulnerability showed by the other units in terms of economic condition.

4.2 Sub-statistical block and building level approach

Results at this level of analysis identify blocks and buildings that are more vulnerable to flooding (Figure 2). As verified in the assessment conducted using PCA at the SB level, this local higher-scale approach also allows identifying specific characteristics that define territorial vulnerability in the OCC of Seixal. At this level of detail it is possible to differentiate areas with a reduced number of residents, contiguously located with areas highly populated (Figure 2, P2). Nevertheless, some of those S-SB's with small number of residents can present high vulnerability in terms of present population during the day (commercial areas) or during punctual events, which are identified with parameters P3 and P8. The parameter related to the vital functions on buildings is identifying social and civil protection equipment such as retirement homes, the local administrative seat and police stations which are due – and/or require – specific procedures in case of flooding (Figure 2, P5).

Table 2 – Territorial vulnerability results at the statistical block level in the Old City Centre of Seixal, compared with mean and range values for the entire Tagus estuary and the Seixal municipality

		Tagus estuary (1147 SB's)	Seixal municipality (144 SB's)		Old City Centre of Seixal (4 SB's)			
					001	003	004	005
FAC1	Min.	-1.75	-1.71					
	Mean	0.00	-0.64	Score	0.78	1.39	0.19	1.06
	Max.	3.31	1,39					
FAC2	Min	-6.43	-3.67					
	Mean	0.00	-0.60	Score	0.01	0.17	0.44	0.24
	Max	2.91	1.81					
FAC3	Min	-6.39	-2.17					
	Mean	0.00	0.54	Score	-1.13	0.83	0.08	0.84
	Max	2.14	1.85					
FAC4	Min	-2.22	-0.63					
	Mean	0.00	0.26	Score	1.26	-0.14	0.21	-0.11
	Max	3.53	1.84					
FAC5	Min	-2.71	-1.99					
	Mean	0.00	-0.21	Score	-0.80	-1.74	-1.69	-1.62
	Max	2.62	1.08					
FAC6	Min	-4.14	-2.48					
	Mean	0.00	-0.10	Score	-0.82	-0.26	0.12	0.18
	Max	2.99	1.22					
FAC7	Min	-2.31	-1.99					
	Mean	0.00	-0.30	Score	-0.86	-1.18	0.62	-0.72
	Max	5.64	4.69					
FAC8	Min	-2.30	-1.63					
	Mean	0.00	0.14	Score	-0.71	-1.12	2.68	-1.35
	Max	5.47	2.67					
TV	Min	-9.86	-4.87					
	Mean	0.00	-1.21	Score	-1.95	-0.89	3.48	-0.72
	Max	11.43	3.46					

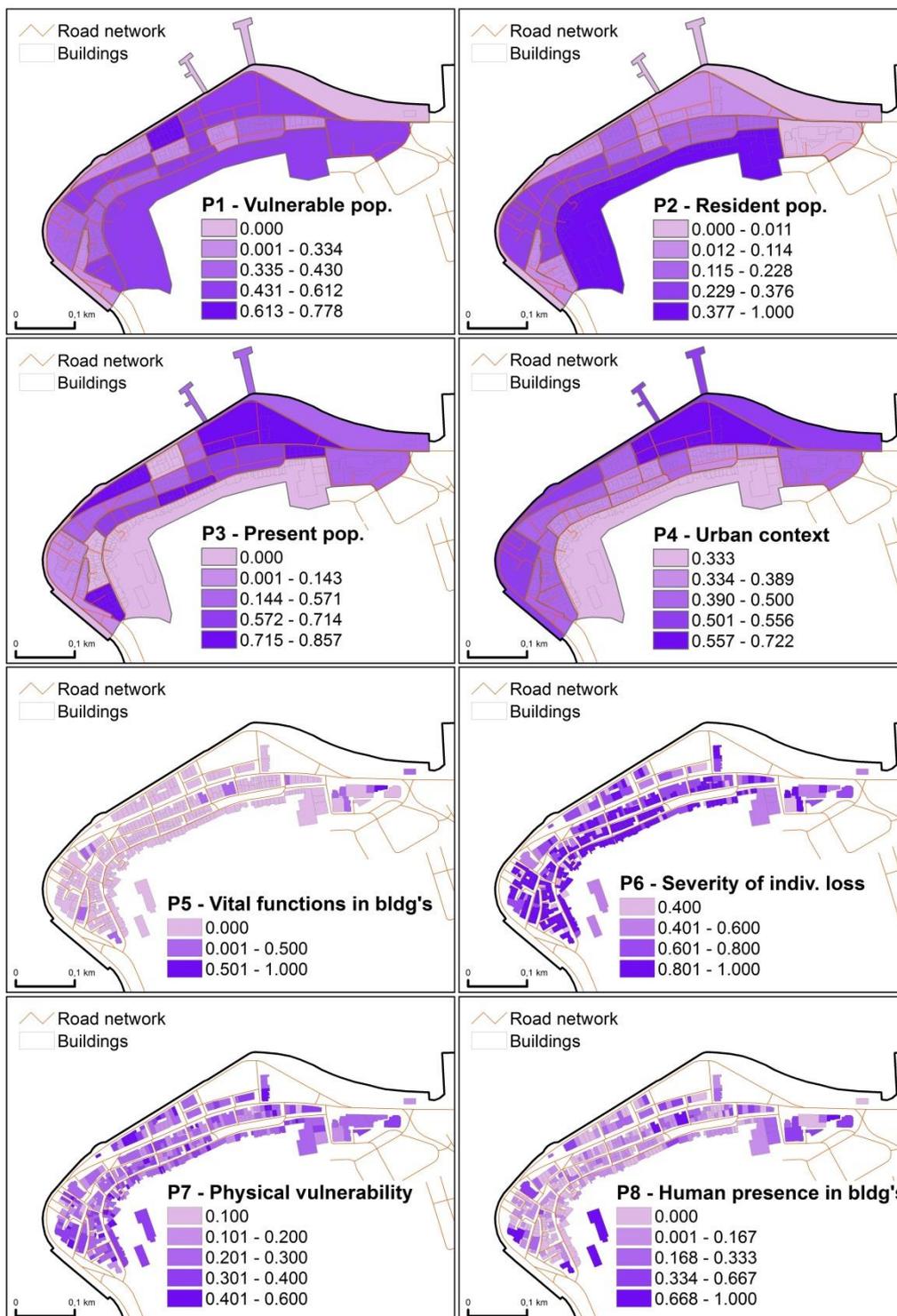


Figure 2 – Vulnerability parameters in the OCC of Seixal

4.3 Comparison of results

Combining input data into a single metric in both methodologies provides distinct cartographic expressions of territorial vulnerability for the OCC of Seixal (Figure 3). Figure 3-A represents TV in the 4 SB's that overlay with the study area, showing that only one SB is entirely within the OCC of Seixal. In Figure 3-B the same graphical scale is used but the higher tenuity in the geographical representation allows a more detailed analysis of the TV represented. Naturally, since the TV final score at the S-SB and building level is the result

of a sum, built areas are scored higher as 8 parameters are being considered, while areas without buildings are only being assessed with parameters P1 to P4, i.e., those defined at the S-SB level.

Where the SB level approach defines homogeneous areas, the S-SB and building level approach locates smaller units of analysis with distinct urban dynamics, like blocks of buildings where transience predominates over permanency of people. The assessment of physical vulnerability of buildings performed with parameter P7 also provides greater insight over the housing conditions characterized at the SB level approach through the principal components (FAC1 and FAC6) related to this aspect of vulnerability.

Ultimately, the dominant urban function and features of each block, as well as the assessed characteristics of each building, are differently represented in the S-SB and building level assessment.

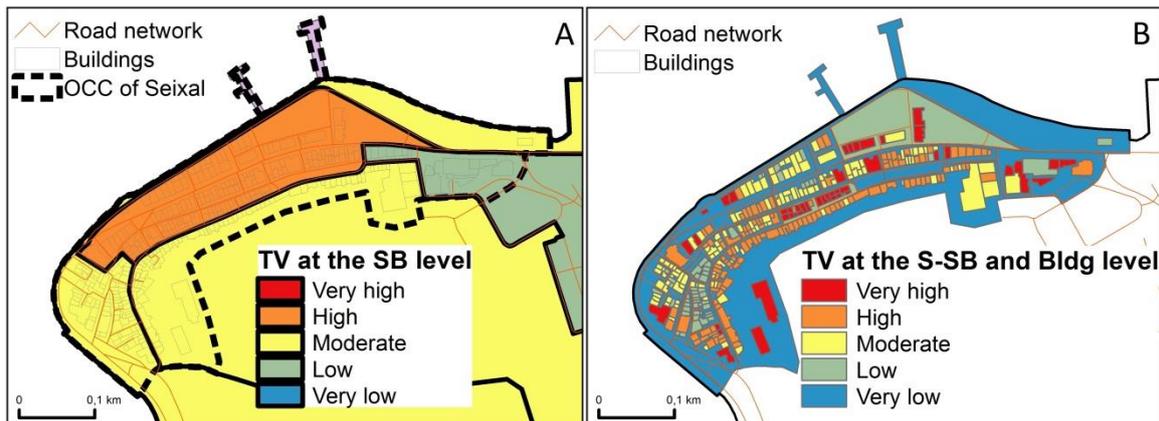


Figure 3 – Comparison of results from the territorial vulnerability assessment at the statistical block level (A) and the statistical sub-block and building level (B) in the OCC of Seixal

5. Discussion and conclusions

The definition of local estuarine flood risk management strategies must not be indifferent to the type of vulnerability nor to the geographical level at which it is assessed. Risk management aspects such as risk communication, emergency planning, spatial planning and mobility/transport planning need to consider the different outputs that vulnerability assessment provide.

After the individual and compared analysis of the results of both assessments of territorial vulnerability, it is possible to conclude that both methodologies have the capacity of identifying drivers of vulnerability, although at different levels of detail.

The lower-scale approach, at the Tagus estuary level, provides information with the ability to identify aspects of the social, urban and economic dynamics at the regional and municipal level that can influence the impact of flooding and the capacity of communities and day-to-day activities in coping and recover from the disaster events. Meanwhile, SB results are not adequate to characterize TV inside the OCC of Seixal due to two main reasons: clear insufficiency in the level of detail; and non-coincidence between the outer limits of the OCC and the limits of the SB's, which implies that input data from other areas outside the OCC boundaries was considered in the assessment of TV inside the OCC of Seixal.

Accordingly, only the approach at the statistical sub-block and building level is able to represent vulnerability in a way that can provide civil protection planners and practitioners with accurate data to act at the built-up area level.

Mobility and commutation emerged as a relevant driver of vulnerability for particular areas in the Tagus estuary. Inside the OCC of Seixal, one SB appears as particularly more vulnerable even when compared with the context of the municipality and the Tagus estuary as a whole. Strategic mobility planning can benefit from this assessment in order to assure contingency of the transport systems, improving the connectivity between

the fluvial, train and bus services. On the other hand, the assessment at the S-SB and building level identify the urban zones where disruption in the road network would have the greater impacts, allowing local authorities to plan in advance for the redundancy of mobility systems and contingency of economic activities inside the OCC of Seixal.

In other areas of disaster risk reduction – such as urban design and planning, risk communication and early warning systems –, it seems plausible to conclude that their most efficient implementation in the study area would better be achieved considering the local lower-scale vulnerability data.

Even so, if the nature and scope of both assessments are considered, a final conclusion is that the classifications of territorial vulnerability by both methods are not antagonistic, but rather complementary, having in mind the multiscale and multilevel requirements of flood risk governance models.

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