Flood damage cost assessment. A case study in Águeda flood-prone area

Sandra MOURATO[1,5,*], Paulo FERNANDEZ[2,5], Luisa PEREIRA[3,5], Madalena MOREIRA[4,5]

[1]School of Technology and Management, Polytechnic Institute of Leiria
[2]Polytechnic Institute of Castelo Branco
[3]Águeda School of Technology and Management, Aveiro University
[4]Évora University. ICAAM - Institute of Mediterranean Agricultural and Environmental Sciences, Évora University
[5]Geo-Space Sciences Research Centre, Porto University
*Presenting author
(sandra.mourato@ipleiria.pt; palex@ipcb.pt; luisapereira@ua.pt; mmvmv@uevora.pt)

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Abstract: Several flood events occur in Águeda City causing property damages, the most recent being in 2016. In this paper was assessed the flood risk as the result of two components: i) hazard, as the threatening event including its probability of occurrence; and ii) vulnerability, considered as the extent of damage under certain conditions of exposure.

Flood damage assessment to mitigate of expected losses is an important part of the risk management process as referred in the European Parliament and Council flood risk management directive. The results will provide decision-makers, civil protection, and insurance companies with a tool for planning risk mitigation strategies to cope with future disasters.

The focus of this study is on direct, tangible damages of building, roads and agricultural land use.

Flood hazard maps are provided by the Portuguese Environment Agency for the return period of 20 and 100 years. The function approach with synthetic depth–damage is a common methodology for estimating the relative or absolute value of losses through a relationship among the hazard (water depth), the level of vulnerability (landuse type), and the expected damages.

Spatial flood risk classification provides relevant information for integrated risk management, which can support decision-making in prioritizing risk reduction measures.

Due to the use of European average depth-damage functions, the model over estimates the damage costs for both 20 and 100 years return period, urging the need for specific site curves.

1. Introduction

Flood events are one of the natural disasters with more impact, affecting people and causing casualties and high economic losses (Balica and Wright, 2010; Fernandez *et al*., 2016). They are one of the natural disasters, whose frequency is likely to increase (Alfieri *et al*., 2015; Balica and Wright, 2010), with more impact, affecting people and causing casualties and high economic losses (Hu *et al*., 2018). The European Parliament and Council, Directive 2007/60/EC on the assessment and management of flood risk requires state members to prepare flood hazard and risk maps. Nonetheless, in spite of all the potential that these maps have to help identifying adverse consequences associated with different flood scenarios, the reality is that when a flood event occurs, often citizens barely have time, when they do, to save their goods or their lives.

In Portugal, there are several zones regularly flooded, often with severe consequences. Águeda, a small town in the centre of Portugal is included in the national list of the critical flooded zones (Brandão *et al*., 2014). Its urban area, crossed by the river with the same name, is one of the areas with the greatest number of flood occurrences. Albeit the investment of some millions of euros in the construction of a secondary river channel to divert the river flow, the impact of flooding has not been totally mitigated.

The term flood risk may be considered as the result of two components: i) hazard, as the threatening natural event including its probability of occurrence; and ii) vulnerability, considered as the extent of damage, which can be expected under certain conditions of exposure, susceptibility and resilience. Flood damage assessment is an essential aspect of flood risk management (Merz *et al*., 2010).

The flood damage can be defined as direct and indirect loss, and whether the loss is tangible or not. Direct losses are defined as losses that occur as a consequence of a direct contact with the water, whereas indirect losses only occur as a consequence of the flooding. Direct losses are directly correlated with the duration of the flood, whereas indirect losses can have effects on time scales of months and years (Kreibich *et al*., 2010; Merz *et al*., 2011). In contrast to intangible losses, tangible losses are losses that can be objectively quantified, i.e., the loss can be accounted for in direct monetary value, which can be determined based on whether or not a market exits for the asset in questions (Hammond *et al*., 2015). The analysis is usually focused only on direct tangible damages on public and private properties (e.g., buildings, cars, roads) (Büchele *et al*., 2006).

The calculation of flood potential damage is of importance for different institutions, such as civil protection, water resources and territorial planning authorities, or insurances companies. There is a growing need to simulate potential flood damage respectively flood risks with a high spatial and temporal resolution on different scales. Such calculations support the creation of flood risk maps, as they are mandatory, for example, for Europe through the European Floods Directive 2007/60/EC (European Parliament and Council, 2007).

For an effective flood risk assessment it is required: i) Accurate prediction of flood inundation performed both by hydrologic and hydraulic modelling; ii) Elements at risk, which consists of the identification of potentially damaged assets (location, number and type) and attribution of economic values based on land use or individual objects; iii) Damage functions that describe the relationship occurring between the level of damage and flood characteristics, such as the flooding depth, the combination of water depth and velocity, the duration (Dutta *et al*., 2003), or the load of sediments with respect to different land uses, characteristics and types of harmed goods (buildings, household furnishings, vehicles, etc.) and social and economic conditions of the affected area (Oliveri and Santoro, 2000).

However, damage assessment is affected by large uncertainty, mainly related to the use of depth-damage functions.

Stage-depth damage curves can be defined either as absolute or relative damage. Absolute damage curves provide the absolute damage for the specific predefined damage, and thus, their period of validity is short. Relative damage curves express the flood damage as a percentage of the total replacement value of a flood-affected property. Both absolute and relative damage curves are either empiric or synthetic. The latter employ theoretical damage data collected via inventories or interviews and are based on hypothetical analyses and expert judgments.

In some countries, where no site-specific curves are available, a transfer of damage models developed from other areas is required, adding extra uncertainty in the modelling process. Even though relative damage functions are preferred because they are easier to transfer from one country to another, provided that local values of exposed assets are given (Merz *et al*., 2010), the results must be assessed carefully. Transfer functions to a new geographical condition do not establish an appropriate relationship between the magnitude of the flood and the value of losses unless they have been adapted and calibrated with the conditions of the new region of study (Cammerer *et al*., 2013; Molinari *et al*., 2014).

Thus, the main objective of this paper is to present a damage analysis performed at the micro-scale spatial level within an urban environment. Synthetic depth-damage curves for the direct tangible damage assessment related to different land uses were considered.

The paper outline is as follows: Section 1 introduces the aim of the study. Section 2 presents the study area and describes the land use data. The flood risk results according the synthetic depth damage curves are presented and discussed in Section 3 and finally some conclusions are presented in Section 4.

2. Case study

Águeda municipality suffers with frequent flooding (Brandão *et al*., 2014; Zêzere *et al*., 2014) and it is signalized as a prone flood area in the flood hazards maps available on the Water Information System for Europe (WISE). Consequently, the municipality has made, in 2015, a large investment of some millions of euros in the construction of a secondary river channel to divert the river flow. Regrettably, it did not totally mitigate the impact of flooding for, in February 2016, one of the largest flood events from the last 15 years affected the region.

Its urban area, crossed by Águeda River, is one of the areas with the greatest number of flood occurrences facilitated by the steep slopes of Serra do Caramulo, where Águeda River is born, but mainly by large impervious alluvial areas in its entire catchment. Beside these aspects that tamper the runoff flow, there is still the side effect of forest fires that have been ravaging Caramulo. Being the understory vegetation burned, the precipitation contributes to a great soil erosion, dragging eroded and burned material to the river. This material accumulates and hinders the flow which may reach hydrometric historical levels, with minor quantitative precipitation. Furthermore, the probability of flooding is expected to increase due to the climate change projections with the amount of precipitation expected to be concentrated in smaller periods (Arnone *et al*., 2018; Brunner *et al*., 2018).

Regarding land use, the map has been produced by integration of two spatial data sets from different scales: large scale cartography at scale 1: 10,000 and small scale cartography at 1: 25,000 (Figure 1).

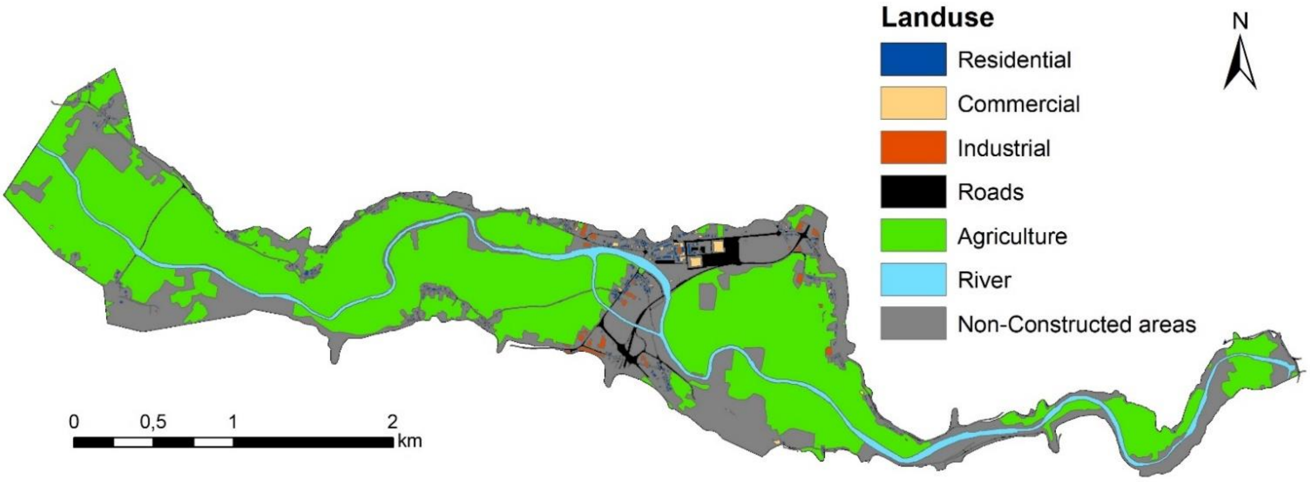

Figure 1 – Landuse types in the Águeda flood plain area

3. Flood risk

3.1 Flood Hazard

The flood hazard is assessed with the water depth map for floods with a return period of 20 and 100 years with a spatial resolution of 10 m provided by the Portuguese Environment Agency (APA). These maps were produced by MOHID Land model based on a Digital Terrain Model (DTM) derived from cartography at scale 1:10,000 (Brandão *et al*., 2014). The accurate estimation of flood depth is crucial for a local scale assessment such as this one. The spatial distribution of the calculated depth as a function of the return period can be used to describe the flood hazard (Figure 2).

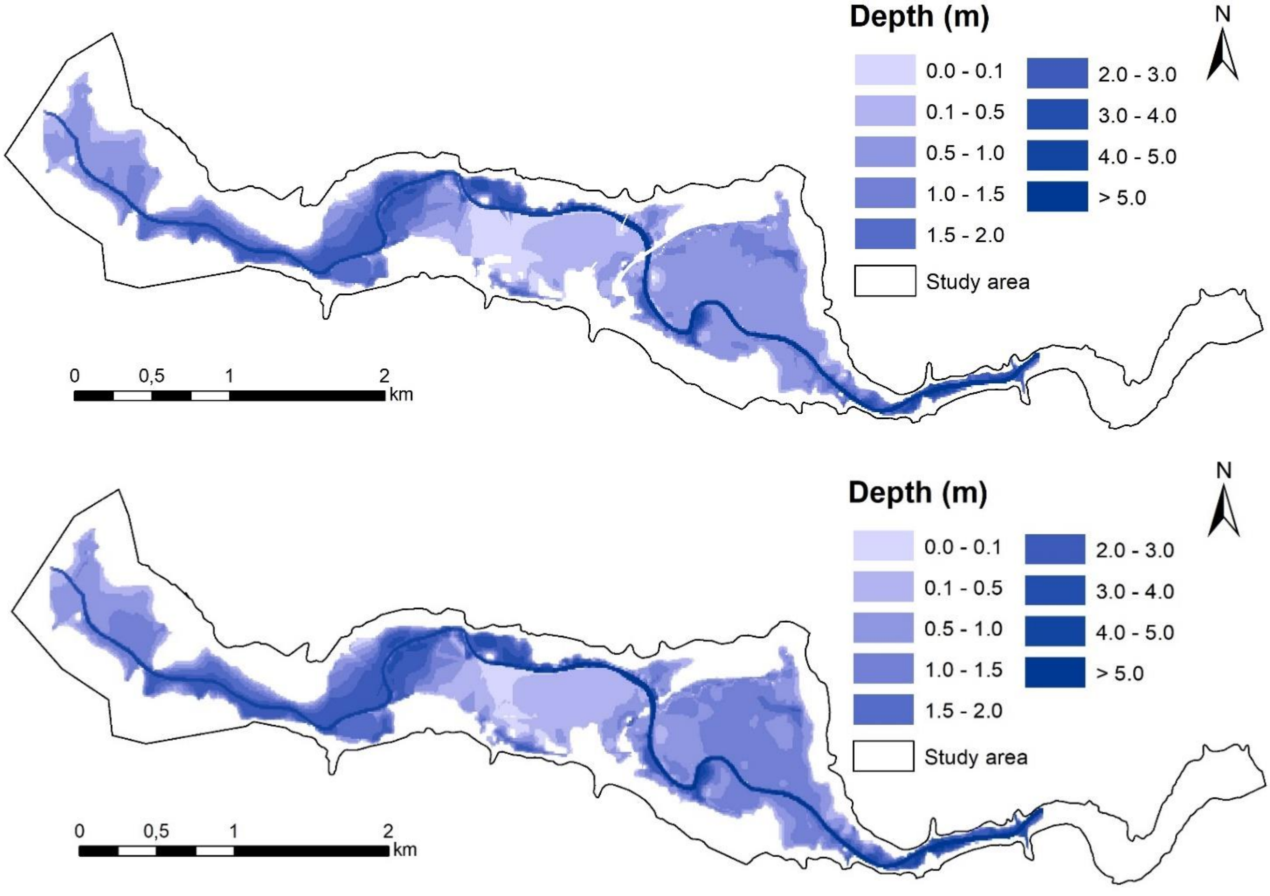

Figure 2 – Flood depth in the Águeda flood prone area for a rain event of return period of 20 years (upper) and 100 years (lower)

3.2 Flood damage

Since there were no curves specifically representing the flood damage in the studied area, it was used synthetic absolute depth damage curves (Table 1) according the European Commission Joint Research Centre's (JRC) database of flood damage functions, particularized for Portugal (Huizinga *et al*., 2017). Such curves are used to estimate costs for a certain water depth relative to the extent flooded and have been created for different types of land use. Taking into account the main uses identified in the case study area, five different categories have been defined (residential; commercial; industrial; roads and agriculture). Building contents were not considered in this analysis because of the lack of specific and reliable information on their potential maximum damage values.

The proposed methodology interlinks water depths from hydrodynamic modelling, accurate spatial data for buildings and land use units. After the simulation of flood events to obtain the flood depths in the flood prone area, a water depth is assigned to each land use. By interpolating this value in the depth damage curve the potential damage is obtained (Figure 3).

Table 1 – Depth-damage functions (Huizinga *et al.*, 2017)

Flood depth [m]	Damage function				
	Residential	Commercial	Industrial	Roads	Agriculture
0	0.00	0.00	0.00	0.00	0.00
0.5	0.25	0.15	0.15	0.25	0.30
1	0.40	0.30	0.27	0.42	0.55
1.5	0.50	0.45	0.40	0.55	0.65
2	0.60	0.55	0.52	0.65	0.75
3	0.75	0.75	0.70	0.80	0.85
4	0.85	0.90	0.85	0.90	0.95
5	0.95	1.00	1.00	1.00	1.00
6	1.00	1.00	1.00	1.00	1.00

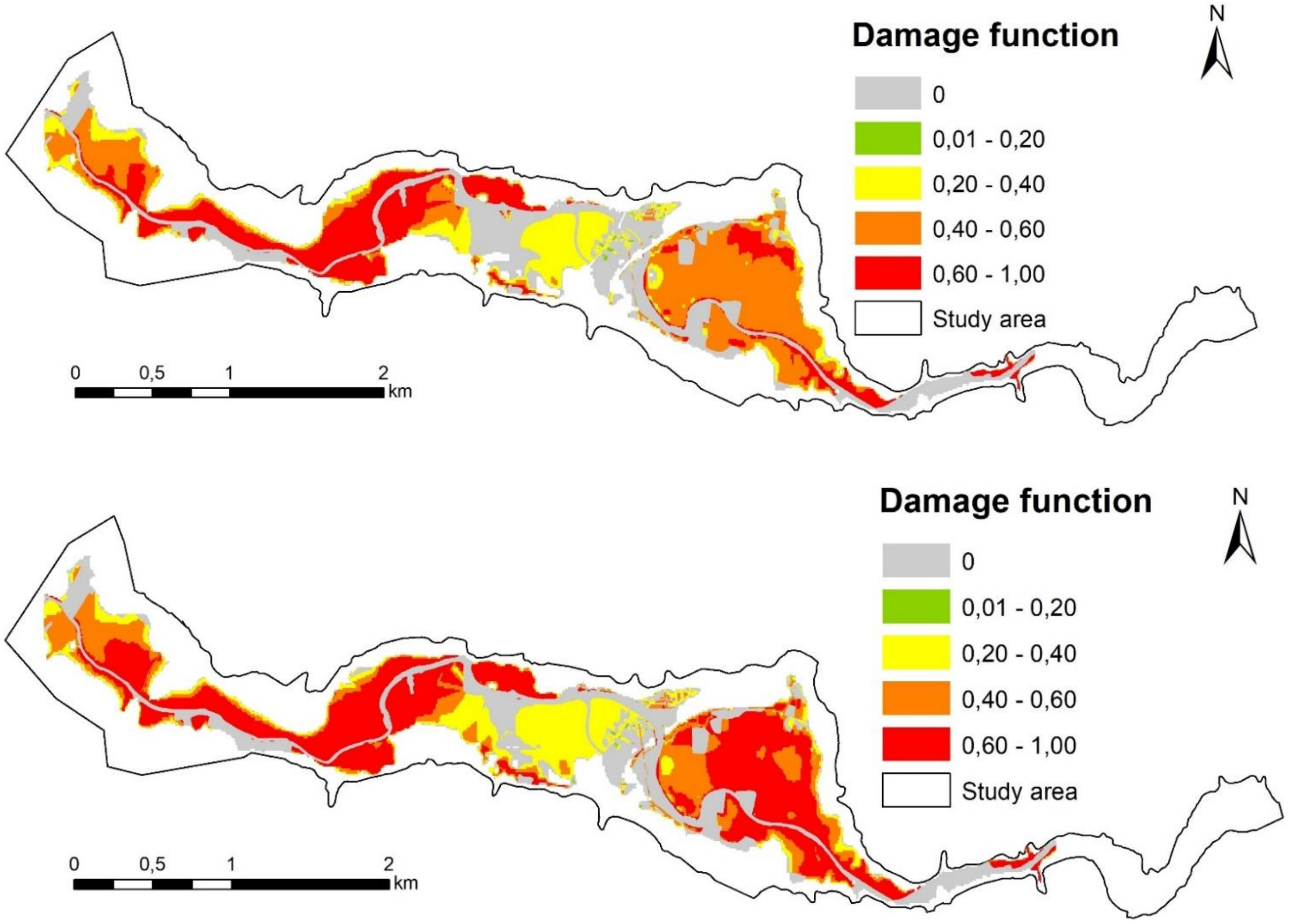

Figure 3 – Damage map, presenting the potential damage of the assets at risk for an event of return period of 20 years (upper) and 100 years (lower)

Multiplying the relative potential damages, obtained from the stage damage curves, by the maximum damage cost for each land use (Table 2), the total costs can be obtained (Figure 4).

Table 2 – Maximum damage costs per land use (Huizinga *et al.*, 2017)

Land use	€/m^2 (2010)	€/ha (2010)
Residential	412	-
Commercial	435	-
Industrial	288	-
Roads	13	-
Agriculture	-	966

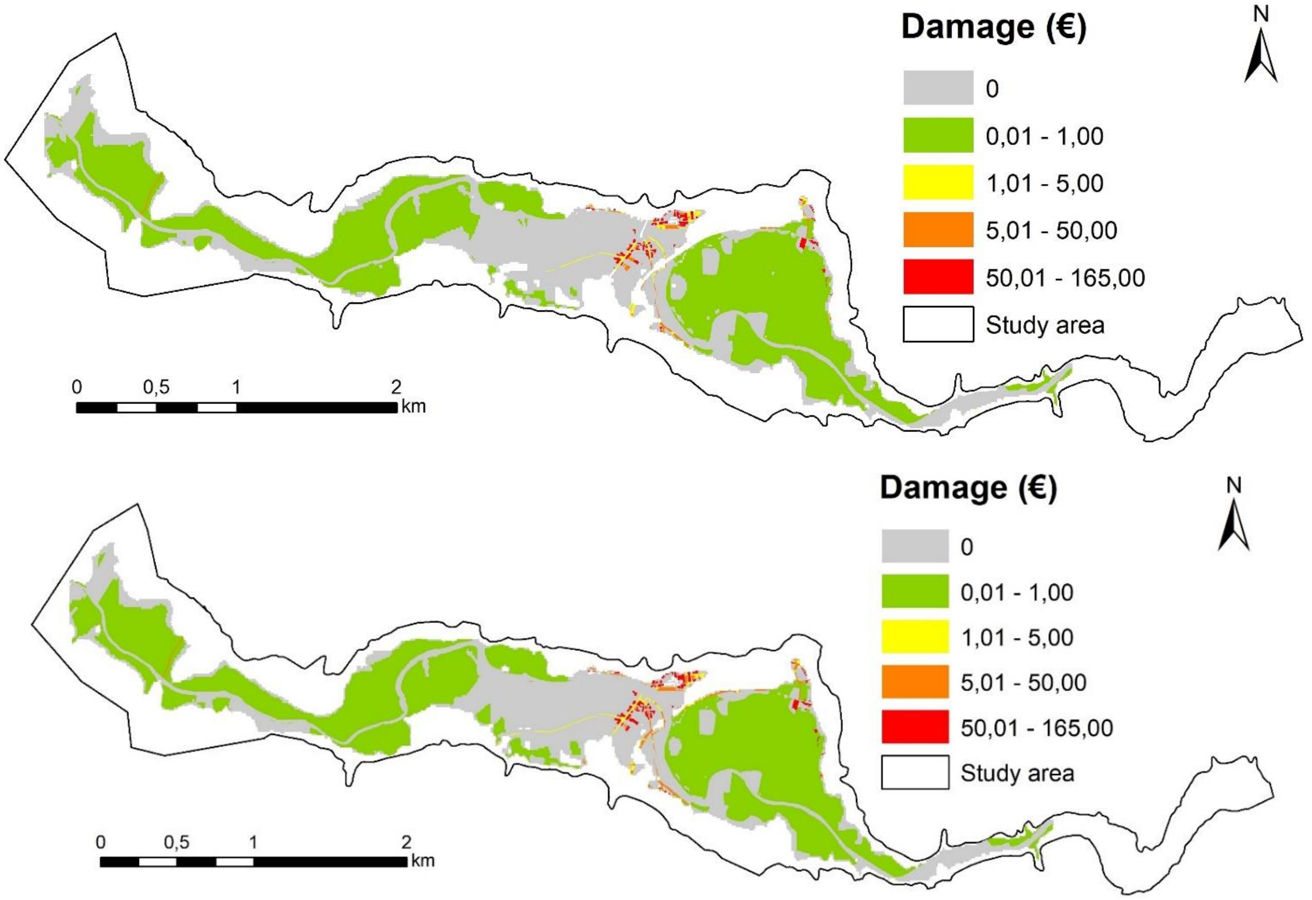

Figure 4 – Flood damages cost in the Águeda flood prone area for a rain event of a return period of 20 years (upper) and 100 years (lower)

As it can be seen in figure 4, the higher values are as expected in the urban areas which are also the most vulnerable to floods. Finally, the damage cost for the whole area has been estimated. For a 20 years return period the model gave an estimated damage cost of 3.1 million euros and for a 100 years return period the total damage was up to 4.1 million euros. Table 3 presents the estimated damage cost by land use, and the largest losses are related with the residential buildings. The land use which has the largest increase in losses related to the return periods are the roads infrastructures (increase of 63% in damage costs).

Table 3 – Estimated damage costs (€) by land use and return period

	T=20	T=100
Residential	1,965,772	2,553,045
Commercial	389,299	535,960
Industrial	585,287	719,783
Roads	121,188	197,498
Agriculture	107,235	121,502

4. Conclusions

Damage cost modelling is increasing of importance in flood risk management. As it its affected by a large uncertainty, mainly related to the quality/suitability of depth-damage curves, model validation is fundamental to obtain a reliable estimation of flood damages. In this sense, an accurate and calibrated depth-damage function is considered crucial.

In this work, damage cost modelling with adapted depth-damage functions to Portugal was used. Due to a lack of empirical data from recent extreme events in the study area, to the model was not validated. It is also important to have data of maximum damage costs to assess the magnitude of damage costs in absolute monetary values.

The estimated damage cost values were over-estimated because the depth-damage functions and the maximum damage cost per land use were not developed for specific flooded area. Nonetheless, they are valuable information to understand the potential impacts of a given flood hazard.

With the development of synthetic depth damage curves for the case study, an exhaustive economic impact assessment can be carried out when flood occurs. Implementing the described methodology within a Geographic Information System-based model like the Flood Forecast and Alert System (FFAS), the damage cost can be estimated in real time forecast. This enables the determination of the critical points of a flood prone area in terms of flooding impacts and highlights the need to implement strategies to minimize these impacts. The presented methodology establishes thus a very useful framework to assess flood impacts in urban areas. Our goal is to have a full model ready to assess the potential future damage costs, taking into account socio-economic factors and climatic changes.

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