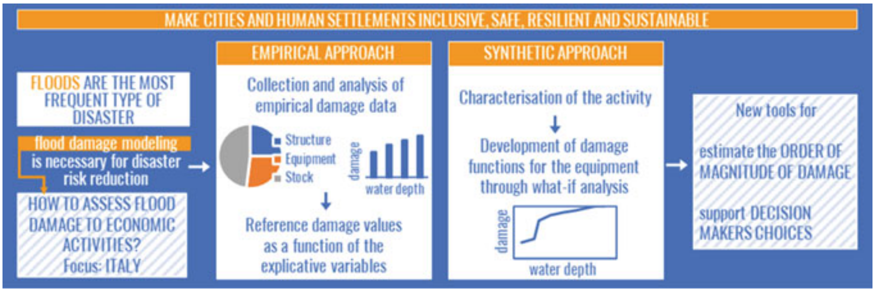
Flood Damage Assessment to Economic Activities in the Italian Context

Marta Galliani

Abstract In the last century the number of floods affecting people increased across Europe, due to both more frequent intense events and the growth of population and urbanization in flood-prone areas. Equipping cities with tools for flood damage assessment is crucial to effectively manage and reduce flood risk. The sector of businesses has a key role in cities development and suffers high losses in case of inundation, but damage appraisal to economic activities is still a challenging task. This study took up the challenge of addressing this topic, with specific reference to direct damage and the Italian context. Two approaches have been implemented: the analysis of about a thousand damage data regarding economic activities in four Italian flood events and the development of damage functions for retail activities by means a synthetic approach. The results led to the identification of the most vulnerable elements of different types of economic activities and provided reference values to assess the order of magnitude of flood damage.

Graphical Abstract



Keywords SDG 11 · Flood · Damage · Flood risk · Economic activities · Damage model

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1 Introduction

In the last twenty years, flooding was the most frequent type of natural disaster, affecting more than one and half billion of people and causing damage equal to 651 billion US$ in the world [1]. Nonetheless, flood damage is expected to further increase in the future, as a consequence of more frequent extreme events caused by climate change [2–5] as well as of the new urbanization of flood-prone areas, leading to growing exposure of people and resources [6, 7]. The implementation of suitable Disaster Risk Reduction (DRR) measures is key for reducing the impacts of extreme events [8]. The Sendai Framework for Disaster Risk Reduction [9], adopted at the Third UN World Conference in Sendai on March 2015, recognizes the need of developing and implementing DRR policies as a priority at the international level. In detail, it identifies four priorities of intervention: (i) understanding disaster risk, (ii) strengthening disaster risk governance to manage disaster risk, (iii) investing in disaster risk reduction for resilience, and (iv) enhancing disaster preparedness for effective response and to "Build Back Better". The 2030 Agenda for Sustainable Development [10] reaffirms the objectives of the Sendai Framework and the need of reducing disaster risk within the Goal 11: "make cities and human settlements inclusive, safe, resilient and sustainable". This Goal proposes to significantly reduce economic losses caused by disasters and to increase the number of cities developing and implementing holistic disaster risk management at all levels. In order to achieve these objectives and guarantee an efficient allocation of financial resources for risk mitigation, the quantification of potential damage caused by disastrous events like floods is required [11].

According to the EU Floods Directive 2007 [12], flood damage is the potential adverse consequences of floods for human health, the environment, the cultural heritage and economic activities. This work focused on the appraisal of flood damage to economic activities, in the Italian context. Indeed, although in Italy 24% of the territory is exposed to flood risk, including 18% of industrial and service premises [13], tools to quantify damage to enterprises are still scarce [14, 15].

Quantifying the consequences of flooding to an economic activity is not an easy task, as they depend on the interaction among numerous factors acting over time and space. For instance, we can distinguish between physical damage, due to the direct contact of premises components with water, and damage related to business interruption or to the disruption of the systems interconnected with the activity. This study focused on the first type of damage, referred to as direct damage [16]. The aim of this research is to obtain a better knowledge of damage mechanisms to economic activities and develop tools to represent and quantify direct damage to this sector in flooding events. Two approaches were implemented to reach this goal, which are defined as empirical and synthetic approach.

The first consisted in the analysis of empirical damage data, collected in the aftermath of flood events occurred in Italy, aiming at the acquisition of better knowledge on types and magnitude of damage to economic activities in case of flood. Results supply a first estimate, although rough, of flood damage to economic activities in Italy in relation to its main explanatory variables: water depth, activity surface and activity type.

The second approach aimed at developing damage functions by means of an expert analysis (what-if questions) of damage mechanisms [17]. The synthetic analysis focused only on retails trade activities and restaurants and implied a detailed characterization of the equipment of the activities.

2 Methods

2.1 Empirical Approach

The empirical approach was implemented on a dataset including post-event damage records for four case studies:

- *Lodi*. The flood occurred in the town of Lodi (Northern Italy) in November 2002 due to the overflow of the Adda river [18, 19].
- *Secchia*. The flood occurred in the province of Modena (Northern Italy), in January 2014 [20], caused by a dike breach along the river Secchia. Data refer to three municipalities: Bastiglia, Bomporto, and Modena.
- *Enza*. The bank breakage of Enza River in the municipality of Brescello (Northern Italy) caused the flooding of the village Lentigione in December 2017 [21].
- *Sardegna*. The floods due heavy rain flows and bad weather in Sardegna Region (Southern Italy) in November 2013. Collected data refer in particular to the city of Olbia (Northern Sardegna).

For each affected activity, the dataset contains information about the water depth, the damage, and the characteristics of the activity. Information on water depth was obtained from hydraulic modeling [18, 20]. Damage data derive instead from the declarations filled in by the owners of the affected enterprises, to ask for national compensations. Damage data is specified for three components: damage to structure, equipment, and stock, where structure identifies the building with the internal systems necessary to the function of the building (e.g., electrical system or heating system); equipment refers to machineries, furniture, vehicles, and tools necessary for functions of business; stock refers to raw material, semi-finished and finished products. The information about the activities differs according to the case study, as it depends on the degree at which authorities processed the claims and on the actual information included in the original forms. For instance, for all case studies, the information about the type of activity (identified by the NACE code, that is Statistical Classification of Economic Activities adopted in the European Community [22]) is present. Differently, information about the number of employees is available only in Secchia claims. Information about the area of the activity, if not present in the claims, was

Table 1 Information about the cases studies and number of activities per provided information

Case study	Event date	Source		Information on affected activities			
			Damage	Water depth	Activity type	N employees	Surface
Lodi	Nov-02	Municipality	88	77	87	–	83
Sardegna	Oct-13	Region	637	240	514	–	431
Secchia	Jan-14	Region	226	226	201	105	142
Enza	Dec-17	Region	46	46	42	–	46

computed through GIS based-tools as footprint area of the building in which the activity is located. The main information included in the claims is summarized in Table 1

The dataset was used to implement various analyses aiming at (i) identifying the composition of damage for different activity categories, (ii) studying the relation of damage with its explanatory variables, (iii) computing the relative damage. All the analyses were based on an essential conceptualization of damage: each component of damage $D_{component}$ (i.e. structure, equipment and stock) was expressed as a function of three significant variables, that are activity type, activity surface, and water depth (Eq. 1).

$$D_{\text{component}} = f(\text{activitytype}, \text{waterdepth}, \text{activitysize}) \quad (1)$$

In fact, a first analysis investigated the composition of damage according to the activity type. The information about the activity type, identified by the NACE code, was joined with information about damage components, in order to observe if there were similar behaviors in the case studies and to obtain the average composition of damage. This analysis focused only to the NACE categories with more than 10 data and considered representative of the sector "economic activities" (e.g., no agriculture or infrastructure). In detail, the NACE codes were aggregated into four macro-categories, analyzed in this study, being: "Manufacturing" (NACE C), "Commercial" (NACE G), "Restaurant" (NACE I) and "Office" (NACE J, K, L, M, N).

A second analysis studied the relation of damage with water depth splitting data per damage component, activity categories (Manufacturing, Commercial, Restaurant and Office) and classes of water level. Furthermore, the relation of damage with activity size, related to the footprint area of the activity, was investigated, for different activity types; the average damage was computed for surface intervals and for the macro-categories of activities, to observe the prevalent trend. For these analyses, damage data were not divided per case study but revaluated to the year of the most recent event (2017), by considering the variation in the harmonized consumer price index supplied by ISTAT.

The empirical approach also aimed at studying the relation between the observed damage and the exposed value of the activity, in order to evaluate a relative damage. To compute the exposed values, a simplified method, based on the Flood-IMPAT procedure, was implemented [14]. The procedure considers the net capital stock as a measure of the exposed value of an enterprise. The net capital stock is the sum of the value of buildings, machinery, equipment, cultivated biological resources and intellectual property products of activities, and is provided, aggregated for NACE classes, by ISTAT. To estimate the exposed value, only the value components referring to structure and equipment were considered, for each NACE category. The value of the stock was instead not evaluated, as stock is not considered in the definition of the net capital stock, and no other sources of information were found for its estimation. Indeed, the stock value is hard to appraise due to the variability of goods constituting the stock, the variability of costs of these goods, and the variability of the amount of stock in time. The value of structure and equipment for NACE category was then divided by the total number of units (at the national level) per NACE class, to obtain a unitary reference value (e.g. the net capital stock per unit). Once the exposed value was estimated, the relative damage was computed per activity category as the ratio between the observed damage and the product between the exposed value and the number of activities of the same category.

The whole empirical analysis allowed to compute reference damage values as a function of different variables (i.e. activity type, activity surface, water depth). To guarantee the usability of results, such reference values were computed for various implementation scenarios, characterized by different available information on which performing the estimation. Consistency of results was verified comparing simulated and observed damage in the case studies of Lodi, Secchia, Sardegna and Enza.

2.2 Synthetic Approach

The synthetic analysis focused on the development of a new set of synthetic stage-damage functions for the assessment of damage to equipment of some types of retail trade activities. The development of the damage functions was the final step of a process of characterization and classification of economic activities developed in the project Flood-IMPAT+ [18] (www.floodimpatproject.polimi.it). Different types of retail trade activities were characterized in terms of typical size, main equipment components and reference costs to estimate the exposed value of equipment. Information was collected from national regulations, handbooks, AutoCAD libraries, commercial design sites, furniture and equipment catalogues, estimates for shop fittings. Table 2 shows, for example, the characterization of a pharmacy. Then, activities were classified in clusters on the basis of commonalities in equipment components (and in their vulnerability) and then in expected damage mechanisms (Table 3). The sum of the costs of the equipment elements constitutes the total value of the equipment, in terms of maximum, minimum and average value. Dividing the total value by the dimension, the equipment value as €/m^2 is obtained.

To develop damage curves, three further steps were implemented. First, for each equipment element, the water level for which the element is damaged was assumed, according to the nature of the element. Electric appliances (as counter, refrigerator,

Table 2 Characterization of pharmacy type

Pharmacy | Area 60 m^2						
Element	Elevation (cm)	Height (cm)	Quantity	Cost of single element [€]		
				Min	Max	Average
Gondola shelving	20	120	4	738	1,563	1,150.5
Display furniture	20	200	14	295	477	386
Counter	0	100	3	960	960	960
Anti-shoplifting kit	0	150	4	1,000	1,700	1350
Desk	0	74	1	225	225	225
Chair	0	90	2	75	75	75
Galenical Laboratory	0	75	1	1,250	3,400	2,325
Drawer cabinets for medicines	0	220	8	1,376	1,930	1,653
Refrigerators	5	180	1	1,780	5,700	3,740
Warehouse shelves	10	200	8	525	894	709.5
Equipment value				32,575	54,677	43,626

Table 3 Clusters of non-food retail trade activities

Clusters of non-food retail activities	
1	Clothing, footwear, underwear, leather goods, shirts, costume, sporting goods
2	Pharmacy, herbalist's shop, medical and orthopedic articles, optics
3	Tobacconist, stationery, receipt-lot, newsstand, bookshop, comics
4	Household shop, soaps, gifts, appliances, electronics, informatics, toys, telephony, photography
5	Hardware store, paint factory, building materials, sanitary articles, gardening, security systems
6	Jeweler, silverware, watchmaking
7	Art objects, art gallery, articles for fine arts, religious articles, philately
8	Pet shops, aquariums, florists
9	Musical instruments
10	Funeral and cemetery items
11	Cars, motorcycles, vessels, bicycles
12	Service stations/petrol pumps

anti-shoplifting systems), wood elements and equipment for cooking were considered damaged at the minimum water level reaching the element, considering their elevation from the floor level. Metal elements, as shelves or cabinets, were considered damaged when water depth reach around half the height of the element. Second, the replacement costs of the elements damaged at different water level were added up to obtain the total absolute damage for each water depth. Third, absolute damage was divided by the sum of values of all elements (the equipment value) to obtain the relative damage. It is worth noting that replacement is the only considered cost, thus the only considered damage. Costs related to process as repair or cleaning were not included. The damage functions were finally tested using data collected for the empirical approach: Lodi, Sardegna, Secchia and Enza. These data had the necessary information to implement the damage functions, i.e., activity type, water depth and activity surface. The latter is required to evaluate the total value of the equipment of the activity, having previously calculated the value as €/m^2 for the types of activities studied. Because observations refer to different years than prices assumed to evaluate equipment value (2019), observed damage were discounted to the 2019 price value.

3 Results

3.1 Empirical Approach

The first result of the empirical analysis was the characterization of damage composition for the activity categories Manufacturing, Commercial, Restaurant and Office. Similarities were observed among the case studies, thus the fraction of damage components, on the total damage, was computed per activity type as weighted average on the number of data per case study (Table 4). Secondly, the analysis of the relation of damage with its explanatory variables and the computation of the relative damage lead to the results shown in Table 5.

Table 5 shows reference damage values obtained from the analysis, as functions of different variables. Such values can be used for a first estimation of damage, according to the available information for the assessment. For example, the first row corresponds to the case in which no information is available except the fact that the activity is flooded. In this case, the reference damage value was computed as average of total damage of the affected economic activities (excluding agriculture and infrastructure) and could be used as first, rough damage estimation. The second row supplies the average damage as €/m^2, in the case at least information on the activity size is available. The reference values were computed as ratio between the total damage and the sum of surface of all the affected activities. The third scenario

Table 4 Fraction of damage component, i.e. structure, equipment, and stock, on total damage

Fraction of damage component on the total			
Activity category	Structure	Equipment	Stock
Manufacturing	0.20	0.44	0.36
Commercial	0.25	0.27	0.48
Restaurant	0.46	0.44	0.10
Office	0.63	0.30	0.07

Table 5 Reference damage values to a single economic activity, per different scenarios of available knowledge

Scenario of available knowledge		Unit of measure		Average damage	
1	No information	(€/unit)		Total damage	
				72000	
2	Activity surface	(€/m^2)		Total damage	
				66	
3	Activity surface Water depth	(€/m^2)	Water depth (m)	Total	
			0.0–0.3	40	
			0.3–0.6	70	
			0.6–1.0	90	
			1.0–1.5	95	
4	Activity surface Activity type	(€/m^2)	Activity type	Total damage	
			Manufacturing	70	
			Commercial	85	
			Restaurant	120	
			Office	30	
5	Activity type Exposed value of structure and equipment	Relative damage (/)	Activity type	Structure	Equipment
			Manufacturing	0.08	0.10
			Commercial	0.13	0.30
			Restaurant	0.05	0.37
			Office	0.07	0.10

corresponds to the case in which both the surface of the activity and the water depth at its location are known. The analysis of the relation of damage with water depth revealed an increasing trend of total damage with water depth. Still, the same trend was not visible considering the activity type. In fact, dividing the dataset by type of activity considerably reduces the number of data for the analysis, to the point they are not sufficient to observe a representative trend. Thus, the reference damage values are supplied expressed in €/m^2 per water depth intervals but not per activity type. In the fourth scenario the activity type is supposed to be known and the damage values are provided as a function of the surface. The table supplies only the total damage, but the damage components can be computed knowing the damage composition in Table 4. The reference values were computed as ratio between the total damage and the sum of surface of the affected activities per activity category. In the last scenario, the available information is the type of the activity and the exposed value. The reference damage value is the relative damage per activity category and component, to be multiplied by the exposed values to get an estimate of the absolute damage. Relative damage is supplied only for structure and equipment, because of the lack of data/method to compute the exposed value of the stock (see Sect. 2.1). However, damage to stock can be calculated knowing the portion of damage to stock in the total (Table 4).

Consistency of results (i.e., reference damage values) obtained for the various scenarios of available knowledge was verified by comparing simulated and observed damage for the four case studies (Table 6). The comparison was performed only for the activities belonging to the investigated categories and with information about water depth and surface.

3.2 Synthetic Approach

The result of the synthetic analysis is a set of stage-damage functions for the types of activities: clothing shop, pharmacy, tobacconist, supermarket, and restaurant. To be noted that the first three functions can be considered valid for all the types of activities included in the respective clusters (Table 3). Figure 1 shows the functions in terms of relative damage. To obtain the functions in absolute terms, it is necessary to multiply the relative damage by the equipment value. The characterization of these activities provided the computation of equipment value, as sum of values of the single elements that compose the equipment (Sect. 2.2). Table 7 shows the average equipment value for the analyzed activity types.

Damage simulated by these functions was compared to observed damage for a small set of activities, composed by the enterprises of Lodi, Secchia, Sardegna and Enza that belong to the typologies clothing shop, pharmacy, tobacconist, supermarket and restaurants. Table 7 compares observed and estimated damage in the four case studies, in terms of absolute damage, for the activities of interest.

Table 6 Comparison between observed and computed damage with reference damage values supplied in Table 5

		N data	Observed damage (2017)	Scenario of available knowledge				
				1	2	3	4	5
Total damage 10^6 €	Lodi	56	2.2	4.0	3.2	3.4	3.7	4.0
	Sardegna	112	4.0	8.1	2.1	2.5	2.3	6.1
	Secchia	90	8.0	6.5	8.0	9.2	8.2	8.0
	Enza	20	5.2	1.4	5.1	6.5	4.7	1.5
Computed/observed	Lodi			1.8	1.4	1.5	1.6	1.8
	Sardegna			2.0	0.5	0.6	0.6	1.5
	Secchia			0.8	1.0	1.1	1.0	1.0
	Enza			0.3	1.0	1.2	0.9	0.3

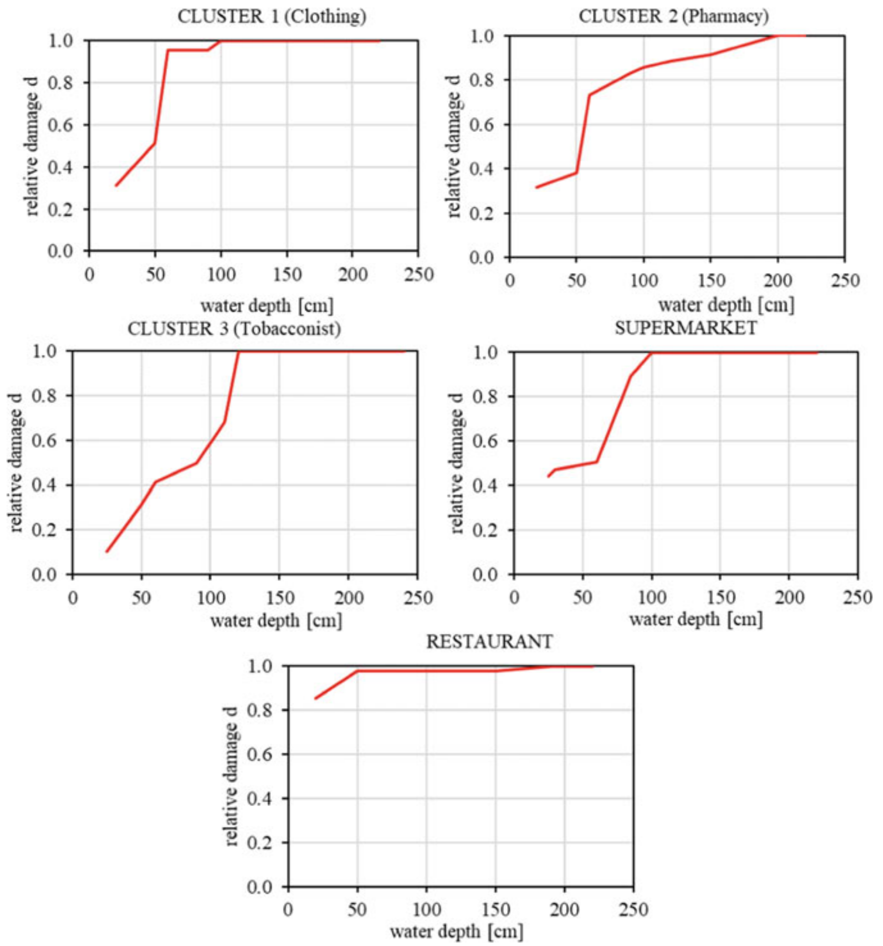

Fig. 1 Stage-damage curves of equipment of cluster 1 (clothing), cluster 2 (pharmacy), cluster 3 (tobacconist), supermarket, and restaurant activities

4 Discussion and Conclusion

The results of both approaches constitute a base knowledge to develop a more complete damage modeling tool. In fact, the empirical approach supplies reference damage values that can be used to assess the damage for macro-categories of activities as a function of different variables. The synthetic approach provides simple damage functions to assess damage to equipment for a limited number of activity types, but more specific, and as function of water depth only. These tools can be used together, according to the available information, to obtain an appraisal of the order of magnitude of potential damage.

Table 7 Comparison of observed and calculated damage using the equipment damage functions in Fig. 1

Clusters and activity types		Equipment value (€)	n° activities	Sum observed damage (10^3 €)	Sum calculated damage (10^3 €)	Calculated damage/observed damage
1	Clothing	13,070	10	54	257	4.8
2	Pharmacy	43,626	2	211	129	0.6
3	Tobacconist	12,854	8	24	755	31.9
	Supermarket	66,180	12	120	457	3.8
	Restaurant	49,120	23	406	318	0.8
	Weighted average					6.7

Despite these results represent a first attempt of developing a flood damage model for economic activities in Italy, the error computed from the comparison with observed damage has the same order of magnitude of more developed models. In the synthetic approach, excluding tobacconists, simulated/observed ratio varies between 0.6 and 4.8 (Table 7). These results do not exceed expectations and are in line with the estimation errors observed in other case studies. For instance, for the residential sector, analysis in [19] revealed an average ratio between damage calculated by different European models and observed damage of 4.06. Reasons of estimation errors are related not only to the uncertainty of the model, but also to the quality of data, deriving from different citizens and processed from different authorities.

To conclude, this study contributes to improve the present knowledge on damage mechanisms to economic activities in the Italian context. In particular, the performed analyses led to the characterization of damage composition, and to the estimate of relative damage and mean absolute damage by categories of activity. The study faced some obstacles as the little number of data, the lack of homogeneity in the information included in collected damage data and the lack of available and complete databases to characterize the enterprises. The results need to be tested and validated with further data and in new case studies, before actually be delivered to end-users. Nevertheless, they allow to obtain a quantitative appraisal of potential damage, that is recommended for an objective and transparent evaluation of protection measures, both before and after a disastrous event. Moreover, quantitative assessment of damage is at the base of cost–benefit analyses implemented to evaluate effectiveness of mitigation interventions and their prioritizing. It is also useful for managing damage compensation in the post-event, especially in countries like Italy, where the insurance system is not enough diffused and compensation is mostly in charge of public authorities.

The current global context, characterized by an increase of intense events and risk-prone assets, requires an increasing effort in actions of prevention and mitigation of risk. Flood damage assessment to economic activities contributes to improve these actions, considering the central role of businesses in the wellbeing of society [11].

Consequently, it contributes to the management of more safe and resilient cities and to the achievement of goals of 2030 Agenda for Sustainable Development.

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