Understanding Flood Damage To Economic Activities In Italy From Post-Event Records

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Research Article

Keywords: Flood, Flood damage, Economic activities, Flood risk, Damage model

Posted Date: February 1st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1247277/v1

Abstract

The evaluation of flood impacts to economic activities is characterized by obstacles like the paucity of available data to characterise the enterprises, the lack of high-quality data to derive new models or validate existing ones, and the high variability of activity types which hampers generalisation. This study contributes at improving knowledge about types and extent of impacts of flood events on economic activities through the analysis of empirical data, focusing on direct damage and with specific reference to the Italian context. The collaboration among different research groups allowed to collect around a thousand of observed damage records after four flood events in Italy: the inundations that occurred in the town of Lodi (Lombardia Region) in 2002, in Sardegna Region in 2013, and in the Emilia-Romagna Region caused by the Secchia (2014) and Enza (2017) Rivers. The analysis of these data lead to a better knowledge of the types of losses suffered by economic activities, to a representation of damage composition and to the computation of reference damage values. Such a result supports the identification of the more vulnerable elements within the business sector as well as the estimation of the order of magnitude of potential damage, orienting modellers' and decision-makers' choices.

1 Introduction

This paper presents an analysis of empirical flood damage data to Italian economic activities, with the final aim of improving modelling capability and knowledge of damage mechanisms, towards more reliable and comprehensive flood risk assessment. The study of flood impacts on the different sectors that compose the built environment and the society is crucial to implement actions of risk prevention, protection, mitigation and risk-aware planning; nonetheless, the capability to perform a comprehensive flood damage assessment, including all potentially affected elements and kinds of damage, is still partial. In particular, despite the businesses sector assumes a critical role, for both its importance for the economic well-being of the society and the high losses it suffers in case of inundations, methods to assess damage to economic activities are much less developed and affected by higher uncertainty compared to other sectors, as the residential (Gissing and Blong, 2004). In fact, studying damage to the business sector means facing a complex problem, involving interconnections among several systems, e.g., the society, the reference market, the financial system. Indeed, floods may have devastating effects not only on the businesses survival but also on the economic and social fabric (Menoni et al. 2016, Wedawatta et al. 2014).

This paper focuses on a piece of the problem, i.e., the physical impacts of floods on the economic activities, defined as direct and tangible damage; the scale of analysis refers to the single economic activity, i.e. the micro-scale level. Examples of micro-scale models for assessing direct flood damage to economic activities can be found both in Europe and Italy (see section 2). However, on the one hand, existing damage models in Italy are few and scarcely validated, on the other hand, the literature is unanimous in defining the transferability of damage models as an action that should be done with caution, as it implies significant uncertainty, especially in data-scarce regions. Moreover, it is recommended to use models developed in regions similar to that of the initial application, because characteristics of flood, vulnerability or exposed elements and relative values are strongly context specific (Smith, 1994, Merz et al. 2010, Cammerer et al. 2013).

The analysis presented in this paper contributes to fill the gap existing in flood damage modelling capability to economic activities in Italy by investigating empirical damage data collected in the aftermath of flood events. In detail, data refer to four different floods that affected the Italian country in the last twenty years, all characterised by the common feature of being riverine and low-velocity floods.

The aims of the analysis are (i) to obtain a characterisation of the physical damage and the composition of damage to economic activities, (ii) to study the relation between damage and its main explanatory variables, and (iii) to get a preliminary, although rough, estimation of flood damage for different categories of activity.

Results give a clearer idea of the order of magnitude of damage to economic activities due to a flood event in Italy, providing reference damage values according to the activity size, the water level and the type of activity. Estimates supplied by reference damage values have been compared to the observed damage data of the analysed case studies to test their reliability and consistency.

The paper is organised as follows. A description of available damage models for the business sector is firstly provided, in Europe and Italy, along with a brief discussion of their limitations (section 2). Sections 3 and 4 describe the data, the methods and the results of the analysis, which are critically investigated in section 5. Further steps and studies that are required to develop a reliable model for assessing damage to the business sector in Italy are finally discussed in section 6.

2 State Of The Art

Examples of micro-scale models for assessing direct flood damage to economic activities can be found both in Europe and Italy (Bombelli et al. 2021). For instance, in the European context, FLEMOcs (Kreibich et al. 2010) is an empirical model based on data collected in Germany, which estimates the loss ratio of buildings, equipment and goods, products and stock for four sectors: public and private services, industry, corporate services and trade. According to the model, losses depend on several hazard and vulnerability variables being water depth, economic sector, company size, precautionary behaviour taken by company owners and the level of contamination of water. In the UK, the Multicoloured Manual (Penning-Rowsell et al. 2005) includes synthetic damage functions to estimate the damage to different categories of non-residential properties, including economic activities (e.g., retail, office, distribution/logistics, manufacturing). Susceptibility functions proposed by the model relate damage to water depth, flood duration and activity surface. Finally, France developed national damage functions to assess damage to equipment, stock and structure of economic activities, as a function of water depth and flood duration (Bremond et al. 2018, Grelot and Richert 2019). Functions vary with the category of the activity, identified by the NACE code, which is the Statistical Classification of Economic Activities adopted in the European Community (Eurostat, 2008). Although properly conceived and calibrated, foreign models can be hardly transferred to the Italian context due to the lack of data for their validation and the absence of databases supplying suitable input data for their implementation (Galliani et al. 2021). In addition, in Italy, tools to assess damage to enterprises are scarce. Three main studies propose methods to assess the exposed value and the potential damage to economic activities: Arrighi et al. (2013), Molinari et al. (2016), and Marin and Modica (2017). Arrighi et al. (2013) propose a method to assess direct damage to structure and contents of commercial activities at the scale of the census block, i.e. at the meso-scale, by developing stage-damage curves for the urban context of Florence. However, this model is strictly related to the exposure and vulnerability parameters of the city of Florence, therefore not transferable in a different context. Molinari et al. (2016) show another approach, named Flood-IMPAT, to assess direct damage to the business sector, again at the meso-scale. It proposes the net capital stock, supplied by the Italian Institute of Statistics (ISTAT), as a proxy indicator of the value of contents and structure of businesses and uses the depth-damage functions by the International Commission for the Protection of the Rhine – ICPR (ICPR 2001) to assess the damage. Still, the authors highlight the limitation of using a foreign model, in terms of reliability of results, and the importance of implementing models that are specific for the context under investigation and that work at lower scales. Finally, the third cited work (Marin and Modica, 2017) focuses on socio-economic exposure assessment, not on the damage. They use turnover and capital stock as proxies of direct costs due to business interruption and destruction of capital goods respectively and propose a method to downscale these values at the local unit level, that is a “micro-scale”. Thus, available tools do not allow estimation of damage to economic activities in Italy.

3 Data

Post-event data included in the analysis refer to 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 (Molinari et al. 2019, Molinari et al. 2020).
- *Sardegna*. The Sardegna Region (Insular Italy) suffered severe impacts and losses due to floods occurred in November 2013 following heavy thunderstorms and bad weather conditions. Collected data refer in particular to the city of Olbia (Northern-East Sardegna).

- *Secchia*. The flood occurred in the province of Modena (Northern Italy), in January 2014 (Carisi et al. 2018), and was caused by an embankment breach along the river Secchia. Data refer to three municipalities: Bastiglia, Bomporto, and Modena.
- *Enza*. The territory of the Emilia Romagna Region (Northern Italy) was affected by severe weather conditions in the period 8-12 December 2017; in particular, the Enza river breached the embankment in the municipality of Brescello, flooding the town of Lentigione (Regione Emilia Romagna, 2018).

Table 1 summarises the available information for the various case studies. In detail, data referring to hazard and damage were collected, for each affected company (i.e., micro-scale level). The former come from the hydraulic simulation of the flood events, providing the perimeter of the flooded area and the spatial distribution of the water depth, for each case study. For further details about hydraulic modelling see Amadio et al. 2019, Scorzini et al. 2018, Carisi et al. 2018, Gatti 2016.

The latter derive from the declarations filled in by citizens after the flood, claiming for national compensation. In this regard, the information collected for the various case studies is different, for two main reasons: (i) case studies refer to different years and regions, with different regulations and standards for data collection, and (ii) collected data were previously pre-processed by the different authorities (from local to regional) in charge of damage compensation. In Italy, although the recording of damage suffered in case of any natural disaster by public and private structures is required since 1992 (Law 225/1992) (Pogliani et al. 2021), only in 2013 (with the D.L. 93/2013)the National Civil Protection Authority introduced criteria to standardise and homogenise post-event reports. Thus, for the event of Lodi, which occurred in 2002, the damage survey was conducted in a “non-standardised” way, with ad-hoc forms developed by the Municipal Authority; however, it was possible to access the original papery forms compiled by citizens, containing detailed descriptions of both the affected economic activities and the damage types (Molinari et al. 2019). For the case of Secchia, after the event, activities owners were asked to fill in the standardised forms to quantify the compensation demand (Carisi et al. 2018); the requests for compensation are fully available on the website of the authority (www.regione.emilia-romagna.it/commissario/alluvione/2016/).

Data regarding the case studies of Enza and Sardegna were instead obtained in tabular form, the so-called “C tables”, that are standardised tables developed by the National Civil Protection Authority for damage survey to economic activities. For these reasons, only for the events of Lodi and Secchia it was also possible to examine more in detail the types of occurred damage, as shown in Appendix.

The main information reported in the claims is the cost incurred by the activities owners to fix the damage. Depending on the case studies, this value is indicated for different elements characterizing the activity, which we aggregated into three main damage “components”: structure, equipment, and stock. Structure identifies the building with the internal systems necessary to its functioning (e.g., electrical or heating system). Equipment refers to machinery, furniture, vehicles, and tools necessary for functioning of the business. Stock refers to raw materials, semi-finished and finished products. The choice of the three components is coherent with previous studies (Grelot and Richert, 2019, CGGD, 2018, Kreibich et al. 2010, Schoppa et al. 2020, Booysen et al. 1999). In fact, it is expected that damage mechanisms are different among structure, equipment, and stock, thus methods to assess their damage may differ.

Another available information is the type of the affected activities, in terms of NACE code. Although the use of the NACE nomenclature to represent the vulnerability of an activity has been questioned (Molinari et al. 2019, Kreibich et al. 2010), in this study, we decided to maintain this information to classify activity types. This allows indeed to exploit statistical data on the business sector elaborated by ISTAT, that are often organised through the NACE code, and to obtain a description of the activity that is shared at the European level (Paprotny et al. 2020, Bremond et al. 2018).

In this regard, Table 2 shows the types of activities present in the dataset. In Lodi and Sardegna flooding events most of the affected activities were commercial, i.e., G code. In Secchia, the manufacturing sector (C code) was the most affected (27% of the total) followed by the commercial sector with 21% of activities. In Enza event, 33% of affected activities belonged to the construction sector, while 17% of the activities were in the commercial and manufacturing sectors. The analysis of the entire dataset reveals instead that 30% of the flooded activities were commercial, 17% construction, 15% manufacturing, 10% accommodation and food service. Still, data analysis focused only on some NACE categories (Table 2). In detail, category A (agricultural, forestry and fishing) that refers to the agricultural sector was not investigated as agriculture is often considered a separate field in risk analysis (Merz et al. 2010). Similarly, the categories D (electricity, gas, steam, and air conditioning supply), E (water supply, sewerage, waste management and remediation activities) and H (transporting and storage) were assigned to the sector of infrastructures, while the categories O (public administration and defence, compulsory social security), P (Education), Q (human health and social work activities) and partly S (other services activities) were considered part of the public sector and strategic infrastructures, and then neglected. The remaining categories (i.e., B, C, F, G, I, J, K, L, M, N, R) were included in the economic activities sector. Despite of the multiplicity of activities categorised as F (Construction), this category was neglected from a detailed investigation, because of its complexity compared to other activities. Indeed, it includes both offices, warehouses and building sites, that cannot be associated to a “typical” economic activity configuration of one/some premises with contents. The category of the real estate activities (L) was also neglected, because the damage and the exposed value could refer to the several properties owned or managed by the business, that could be spread in the territory. The NACE categories B and R have very few data, so we decided to not investigate them for statistical reasons. The categories J (information and communication), K (financial and insurance activities), M (professional, scientific, and technical activities) and N (administrative and support service activities) were aggregated in a unique macro-category named “Office”, since it was assumed the office configuration as prevalent. The categories G (wholesale and retail trade), C (manufacturing) and I (accommodation and food service activities) were considered as distinct macro-categories renamed for simplicity “Commercial”, “Manufacturing” and “Restaurant”, respectively. It is worth noting that damage to the investigated categories (Manufacturing, Commercial, Restaurant and Office) is responsible for about 65% of the overall damage observed in the case studies. Table 3 shows the average damage and the standard deviation for the analysed categories of activities, to supply an idea of the order of magnitude of observed damage and of data dispersion.

Other information reported in the claims relates to the address, which was used to geo-localise the activities, the number of employees (only in the Secchia claims), and the surface of the activity for the majority of claims. In addition, GIS based-tools were applied to derive the footprint area of the building in which the activity is located, by processing information on localisation included in the regional topographic geodatabases (i.e. the footprint areas of the buildings).

4 Method

Data analysis aimed at understanding what happened in terms of physical damage to economic activities during the floods, to provide a characterisation of the impacts and to investigate damage to economic activities exploring the main damage explanatory variables.

A rough and essential conceptualization of damage has been used as reference model in the analysis (Eq. 1). Each component of damage (i.e., structure, equipment and stock) was considered individually and expressed as a function of three significant variables: activity type, activity size and water depth, identified in the literature among the most explicative of damage (Schoppa et al. 2020, Paprotny et al. 2020, Merz et al. 2010, Penning-Rowsell et al. 2005).

$$D_{component} = f(activity\ type, water\ depth, activity\ size) \quad (1)$$

Three kinds of analysis were performed, on different samples of the dataset, according to the information available for each case study and the objective of the analysis. In any case, outliers were removed before implementing the analysis; in particular, damage values higher than the 75th percentile+1.5 (75th percentile – 25th percentile) were neglected. The percentiles were computed on the damage value in €/m^2 differentiated per category of activity.

In the first analysis, we intersected the information about the activity type with information about damage to the three main components previously identified (i.e. structure, equipment and stock) in order to observe if there were similar trends in the different case studies and to compute the average portions of each damage component in the total damage, for activity category (Fig. 1). The latter was computed as the weighted average on the amount of data per case study.

Regarding the relation with water depth, data were divided per components and classes of water level. The latter were defined to choose significant intervals for the expected damage mechanisms. For instance, the definition of a unique water level class between 0.20 m and 1 m is not useful, as a lot of materials (both equipment and stock) might be positioned at different levels in this range, and then most of the damage would be concentrated in this class. On the other hand, choosing too small intervals means considerably reducing the amount of data in each class. Indeed, classes are limited at 1.5 m because there are little data for higher water levels.

Fig. 2 shows the mean damage expressed in €/m^2 for classes of water depth, differentiating by damage component. The mean damage was computed, for each class, as the sum of the damage divided by the sum of the surfaces of the affected activities in that class. As case studies refer to different years, damage data were revaluated to the year of the most recent event (2017), by considering the variation in the consumer price index supplied by ISTAT.

Finally, the relation between damage and activity size was investigated for each damage component (Fig. 3), whereas activity size refers to the activity surface.

5 Discussion

Fig. 1 shows the results of the analysis performed on the activity types and damage components, highlighting that damage composition, for each activity type, shows some common peculiarities in the case studies. The graphs for Commercial show a very similar behaviour in all events: about half of damage is related to stock, 30% to equipment and 20% to structure. A similar behaviour is described in Gissing and Blong (2004) for the flood that occurred in the commercial district of Kempsey (Australia), where damage to building was accounted for 15% and to contents 85% of the total. Even though damage to stock often represents the main portion of damage to commercial businesses, assessing its value is one of the most demanding challenges. The appraisal of the exposed value and the potential damage to stock must consider the variability of goods constituting the stock, the variability of their costs, and the variability of the amount of stock in different periods of time (during the day, the week, or in specific seasons). However, based on the achieved results, if damage to structure and equipment is known, it is possible to estimate the order of magnitude of damage to stock as well.

With respect to the other categories, also the Manufacturing shows similarities in all case studies. Damage to equipment is the most important component: it covers 44% of the total, stock covers 40% and structure covers the smallest part (16%). The category Restaurant shows that costs mainly derive from damage to equipment while damage to stock is less important. For this category, Lodi and Enza case studies are however very unrepresentative because of the low number of data available for the analysis. Concerning Office, most of costs are caused by damage to equipment with a mean damage of about 50% of the total. Lodi and Enza show a different trend of damage, due to the low amount of data.

For the “Office” category, considering that most of offices are located in civil buildings, a suitable strategy to assess damage to structure could be adapting models developed to assess damage to residential buildings. Indeed, damage assessment to the residential sector is based on more developed and well characterised models if compared to those applied to the economic activities (Molinari et al. 2019, Hasanzadeh Nafari et al. 2016).

With respect to the relation of damage with water depth, Fig. 2 shows an increasing trend of damage, in particular when it is not classified per activity component (i.e., total damage). Weakest trends observed for damage components may be linked to the low quality of data, related to both damage and activity surface. The former was derived from citizens’ declarations that could use different criteria to assess the costs; the latter was partly derived by citizens’ declarations, and partly computed as the entire area of the building where the activity is located, which may not coincide with the real activity area. Moreover, many activities declared a null damage (or did not declared damage at all) for some damage components (i.e., structure, equipment and stock). These null values were taken into account in the calculation of the average damage, as we could not speculate on their justification (e.g., whether it was actually null or, for example, paid back by insurance companies). We also tried to investigate the relation between damage and water depth per activity category (not shown here), but no trend was visible in this case as this operation implies significantly reducing the number of data available in each class. Similarly, the analysis of Gissing and Blong (2004) on the relationships between water depth and damage to contents and buildings did not highlight any significant correlation between the variables, although in that case the total damage was considered. Other studies showing increasing trends, as Kreibich et al. 2010, are characterised by a high number of data or do not distinguish among activity types or damage components.

With respect to the relation with the activity size, graphs in Fig. 3 confirm the expectation that damage increases with the activity surface and that the activity size is a significant variable in computation of damage magnitude.

5.1 Usability of results

Results shown in the previous sections represent a valuable knowledge for a first estimation of damage to economic activities in the Italian context.

Table 4 summarises the main findings of the analysis as reference damage values that can be used to assess the order of magnitude of damage in case the modeller knows, or not, the surface of the activities. Indeed,

Table 4 provides reference damage values expressed in €/unit or €/m^2. The reference values “1.a” were computed as the ratio between the damage (sum of equipment, stock and structure) and the number of activities for the categories Manufacturing, Commercial, Restaurant and Office, while the value “1.b” as the mean damage for all the economic activities in the dataset (NACE Code B, C, F, G, I, J, K, L, M, N, R, see section 3). Analogously, damage values “2.a” and “2.b” were computed as the ratio between the damage and the sum of the surface of the activities. Damage per component (i.e., structure, equipment and stock), in both cases “1.a” and “2.a”, was derived by multiplying the damage by the percentages in Fig. 1. The reference values “3” can be used in case both the surface of the activity and the water depth are known. For this scenario, the table supplies the expected damage for different ranges of water depth, without differentiating by component and activity type, because a clear relation between damage and water depth was visible only for the total damage (Fig. 2).

Table 4 represents, in practice, a solution for a rough estimation of flood damage to economic activities in the Italian context. We implemented a simplified approach for verifying the consistency of results and the estimation bias, applying the model to the original case studies: Lodi, Secchia, Sardegna and Enza. Only Manufacturing, Commercial, Restaurant and Office are considered for the simulation and only activities with information about water depth and surface were used in the analysis. Table 5 shows the results of the analysis, comparing simulated and observed damage in total terms.

Table 5 shows that knowing the surface of the activities improves the damage estimation for most of the case studies. In fact, damages simulated with values “2” are more similar to the observed damage than those with values “1”. Damage of Sardegna is underestimated using reference damage expressed in €/m^2, while that of Enza using reference damage in €/unit. For Sardegna, the average damage values in €/m^2, calculated with data used for the validation, are significantly higher than the reference values, probably due to the low value of surface that characterizes the activities in this case study. For this reason, damage of Sardegna activity is underestimated using the reference values “2”. Differently, the case study of Enza contains data with high values of damage and surface, but they are considerably fewer if compared to the other case studies. For this reason, they have a lower weight in the computation of refence values and the damage is strongly underestimated using the reference value “1”, that does not account the surface.

Table 5 shows that the information about the activity type (reference model “a”) does not improve damage simulation in all case studies (e.g., for Lodi event, the simulations “2.b” is better than simulations “2.a”). Still, Table 6, that compares observed and simulated damage per activity category, without distinguishing among the case studies, shows that the information about the activity type tends to improve the results. Damage in the scenarios “1.b” and “2.b” was computed using the same reference values per activity type. The reference values “3”, which consider the water depth, provide similar results to the values “2”, since both models consider the activity surface. However, reference values “3” could be useful when mitigation measures must be defined/designed as they enable to assess the damage for different ranges of water levels.

Fig. 4 compares instead point values of observed and simulated damage, for two reference simulations, to give a picture of estimation uncertainty. Scatter plots in Fig. 4 show that, for the single activity, the damage could be significantly over or under-estimated. It implies that reference values can be used for estimating the overall damage to all affected companies, but they are not recommended for the estimation of damage at the microscale.

6 Conclusions

The collection, analysis and comparison of data performed in this study provide new significant knowledge on damage to economic activities in Italy, which allow increasing the real capability of defining potential damage scenarios. The study supplies empirical evidence of the most frequent damage types and the most important components of damage per activity type, which are stock for Commercial, equipment for Manufacturing and Restaurant, and structure for Office. Results of such an analysis can be used to infer the composition of damage in future events, according to the type of impacted activities, and then to identify which components to target for protection and mitigation actions. Moreover, the knowledge of damage composition allows to appreciate the portion of the total damage that can be assessed with available tools and the portion that cannot. For instance, if we have models to assess damage to structure and equipment for trade activities, we are aware that we are modelling only half of the expected damage.

The main result of this work is however represented by Table 4, which supplies reference damage values in two main implementation scenarios corresponding, respectively, to whether the activity size is known or not. The assessment of estimation error (Table 5) shows that the scenarios that consider the activity surface (2.a, 2.b and 3) give coherent results and lead to an improvement in estimation accuracy; however, when small enterprises are considered (as in the Sardegna case study), underestimation is possible.

Table 4 can be used as a first approach to assess the order of magnitude of potential damage, still, it is necessary to test obtained results in other real case studies, whose data are not used to compute the reference damage values, to evaluate their reliability/uncertainty, before actually delivering the results to decision makers. Future studies will be addressed to enrich the set of observations to verify the robustness of obtained results.

This study did not analyse damage as a function of all the significant variables (activity type, water depth, activity size) put together, due to the limited number of data with all the required information. Still, collected data could be processed by a different type of analysis (not implemented in this study), such as machine learning techniques, to identify new patterns or trends in the data. Collaboration with other research groups and further surveys could help to increase the richness of the dataset and to experiment with different data analysis techniques.

Results obtained from this research supply then key knowledge on flood damage mechanisms to economic activities in the Italian context as well as a simplified and quantitative representation of the damage. Such information can be used for a first assessment of damage in quantitative terms, to define damage scenarios in risk mapping or cost-benefit analysis, and as the starting points of more sophisticated modelling tools.

Finally, the research leaves a legacy of many questions and propositions for the future, highlighting the need to continue investigating in this research area, towards more comprehensive and complete flood risk analyses.

Appendix

For the events of Lodi and Secchia, it was also possible to examine more in detail the types of occurred damage. Damages reported in claims were assigned to the components structure, equipment, and stock and the frequency of each damage type was computed. With respect to Lodi, all the 89 claims were analysed (Molinari et al. 2019) (Table 7). With respect to Secchia, only 28 claims were investigated reporting the partition of the costs per components and a description of loss types (Table 8). For the other case studies, the individual claims were not available, but only the summary table with the reimbursement information, therefore this detailed analysis was not possible.

Table 7and Table 8 list different types of damage documented in the claims for Lodi and Secchia case studies. The frequency is the number of claims in which that type of damage is declared, the percentage is the frequency divided by the total number of claims (89 for Lodi and 28 for Secchia).

The data analysis of Lodi (Table 7) highlighted that the most frequent type of damage to structure refers to internal plaster and walls (approximately 49%), followed by damage to doors (12%), while the most affected installation was the electrical one (approximately 33%). With respect to the equipment, 55% of activities suffered losses to furniture, 38% to instruments for sale or provision of services, and 31% to materials to carry out the activity. Finally, damage to goods mainly referred to final products or products for sale (with 38%). Table 8 shows that in Secchia claims the most frequent damage to structure was to finishing. Regarding damage to equipment, 60% of activities needed to repurchase new tools and about 50% to repair and to dispose damaged items. With respect to stock, most activities suffered losses of semi-finished and finished goods (29%). Moreover, Secchia claims recorded costs related to technical expenses (as administrative costs, costs for professional consulting, etc.) in almost half of the activities. Such costs were not explicitly recorded in the Lodi claim forms. Still, the Secchia case study highlighted that they can be not negligible. This analysis can suggest self-protection behaviour for the enterprises. For instance, to reduce the frequency of damage to furniture it is suggested to use resistant material, such as metal, or to avoid damage to finished products, it is desirable to place them to elevated positions.

Statements And Declarations

Acknowledgements

The authors acknowledge with gratitude Giulia Pesaro, Scira Menoni and Guido Minucci (from Politecnico di Milano) for their first analysis of Lodi data and their fruitful suggestion during the development of the work.

Funding The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Competing Interests The authors declare that they have no conflict of interest.

Author Contributions MG, DM and FB contributed to the conceptualization of the research, of the methods of analysis and to the interpretation of the results. Data collection was performed by DM, MG, FC, AD, SS and MZ. MG implemented the analyses. MG and DM wrote the first draft of the manuscript. All authors contributed to the interpretation of results and to the review of the text.

Data availability Data coming from the compensation forms compiled by citizens are confidential. The results of damage modelling are available upon request.

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Tables

Table 1- Information about the case studies and the economic activities affected by floods.

Case study	Event date	Source	Form and level of processing	N° of records with the following information					
				Damage	Water depth	Activity type	Number of employees	Surface in the form	Localised in topographic DB
Lodi	Nov-02	Municipality	Paper - original	88	77	87	-	-	83
Sardegna	Oct-13	Region	Digital - partly filtered	637	240	514	-	480	153
Secchia	Jan-14	Region	Digital - partly filtered	226	226	201	105	-	142
Enza	Dec-17	Region	Digital - partly filtered	46	46	42	-	30	46

Table 2- Number of activities per NACE code in the case studies and in the entire dataset.

Categories	NACE code		Lodi	Sardegna	Secchia	Enza	Entire dataset
Manufacturing	C	Manufacturing	50	15	55	7	127
Commercial	G	Wholesale and retail trade	165	36	42	7	250
Restaurant	I	Accommodation and food service	66	4	13	2	85
Office	J	Information and communication	7	0	2	1	10
	K	Financial and insurance	3	2	1	0	6
	M	Professional, scientific and technical	40	5	10	1	56
	N	Administrative and support services	12	1	1	0	14
Other activities	B	Mining and quarrying	3	0	0	0	3
(not considered in	F	Construction	87	8	30	14	139
the analysis)	L	Real estate	15	2	19	3	39
	R	Arts, entertainment	7	3	1	0	11
Infrastructures	D	Electricity, gas, steam	2	0	0	0	2
	E	Water supply, sewerage	1	0	3	0	4
	H	Transport and storage	11	0	10	3	24
Public sector and strategic infrastructures	P	Education	8	1	1	0	10
	Q	Human health and social work	13	2	3	2	20
	S	Other services	24	8	10	2	44
		Total	468	84	191	42	785

Table 3 - Average damage and standard deviation of observed damage data per activity category (without outliers).

	Average damage [10^3 €]	Standard deviation [10^3 €]
Manufacturing	107.5	191.0
Commercial	56.2	113.0
Restaurant	33.3	49.8
Office	25.5	30.6
All activities	72.1	321.7

Table 4 - Reference damage values

Unit of measure		Average damage				
[€/unit]	1.a	*Activity type*	*Structure*	*Equipment*	*Stock*	*Total*
		Manufacturing	21600	47520	38880	108000
		Commercial	14000	15120	26880	56000
		Restaurant	15180	14520	3300	33000
		Office	9430	10810	2760	23000
	1.b	No information				72000
[€/m^2]	2.a	*Activity type*	*Structure*	*Equipment*	*Stock*	*Total*
		Manufacturing	15	33	27	75
		Commercial	20	22	38	80
		Restaurant	55	53	12	120
		Office	29	33	8	70
	2.b	No information				67
[€/m^2]	3	*Water depth [m]*				*Total*
		0.0-0.3				45
		0.3-0.6				80
		0.6-1.0				90
		1.0-1.5				115

Table 5 - Comparison between observed and computed damage per case study.

		Comparison of damage				Simulated /Observed damage			
		Lodi	Sardegna	Secchia	Enza	Lodi	Sardegna	Secchia	Enza
N° data		55	106	76	17				
Observed damage 10^6€		2.2	3.7	7.1	4.9				
Simulated damage 10^6€	1.a	3.5	5.2	5.9	1.2	1.6	1.4	0.8	0.2
	1.b	4.0	7.6	5.5	1.2	1.8	2.1	0.8	0.3
	2.a	3.7	2.4	7.9	4.3	1.7	0.7	1.1	0.9
	2.b	3.2	1.9	6.8	3.8	1.5	0.5	1.0	0.8
	3	3.6	2.4	8.4	5.5	1.7	0.7	1.2	1.1

Table 6 - Comparison between observed and computed damage per activity category.

		Comparison of damage				Simulated/Observed damage			
		Manufac.	Commercial	Restaurant	Office	Manufac.	Commercial	Restaurant	Office
N° data		71	107	35	41				
Observed damage 10^6€		10.0	5.9	1.0	0.9				
Simulated damage 10^6€	1.a	7.7	6.0	1.2	0.9	0.8	1.0	1.1	1.1
	1.b	5.1	7.7	2.5	3.0	0.5	1.3	2.4	3.3
	2.a	9.3	7.2	1.0	0.9	0.9	1.2	0.9	1.0
	2.b	8.3	6.0	0.5	0.9	0.8	1.0	0.5	1.0
	3	9.1	8.7	1.0	1.3	0.9	1.5	0.9	1.5

Table 7 - Type and frequency of damage to economic activities in Lodi claims (Molinari et al.2019).

Damage component	Damaged elements	Frequency	%
STRUCTURE	external plaster & coatings	8	9
	internal plaster & coatings	44	49
	Floor	16	18
	doors	11	12
	Windows	1	1
	Gates	3	3
	electrical systems	29	33
	heating systems	8	9
	telephone systems	6	7
	water systems	1	1
	sanitary systems	2	2
	other systems	1	1
EQUIPMENT	Furniture	49	55
	office equipment (computers, printers)	26	29
	materials for carrying out the activity (stationery, linen, etc.)	28	31
	instruments for sale or provision of services	34	38
	machinery for productive enterprises	6	7
	service facilities of sports facilities	2	2
	loss of contracts	1	1
	other non-compensable damages	12	13
	unidentifiable property	7	8
	Vehicles	10	11
STOCK	stock for production (as packaging, spare parts, uniforms)	13	15
	raw materials	5	6
	semi-finished products	7	8
	finished products/products for sale	34	38

Table 8 - Type and frequency of damage to economic activities in Secchia claims.

Damage components	Declared costs	Frequency	%
STRUCTURE	Costs for structural works (building and system works)	1	4
	Finishing (building and system works)	13	46
	Technical expenses (technical, geological, administrative)	13	46
EQUIPMENT	Supply of new goods	17	61
	Costs for disposal	14	50
	Costs for repair	15	54
	Transport costs	3	11
	Test costs	2	7
	Technical costs	15	54
STOCK	Repurchase of raw and ancillary materials	1	4
	Repurchase of semi-finished and finished goods	8	29

Figures

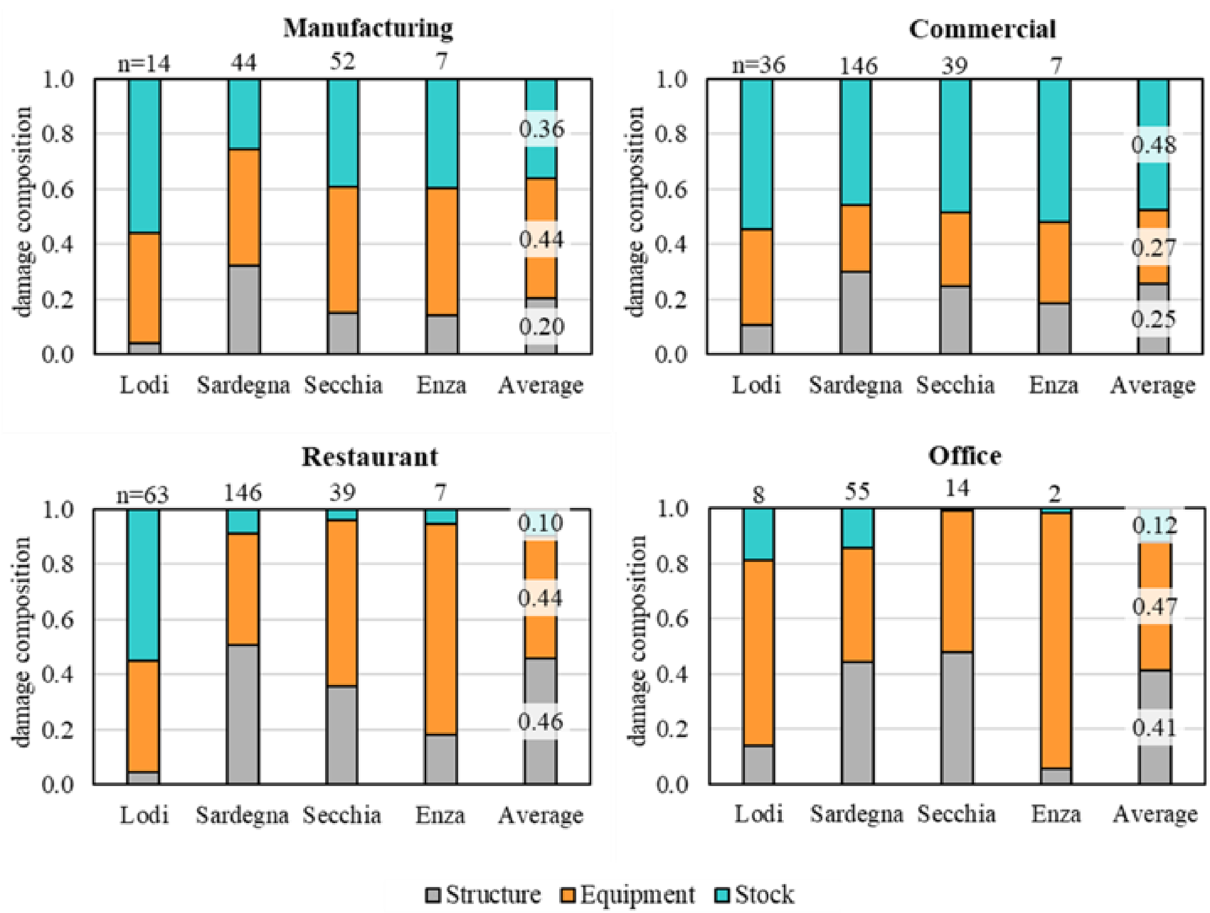

Figure 1

Damage composition for macro-categories of activities and average composition. n=number of data for each class.

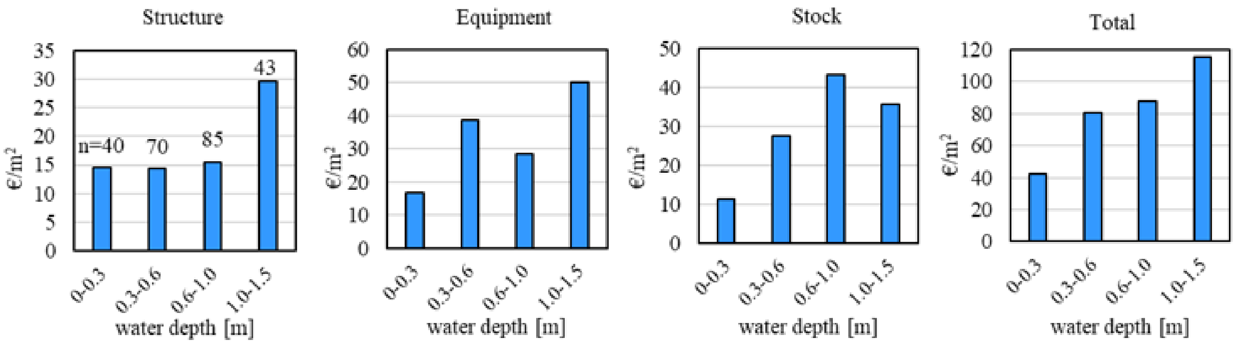

Figure 2

Mean damage against water depth classes for all activity types. n=number of data elements for each water depth class.

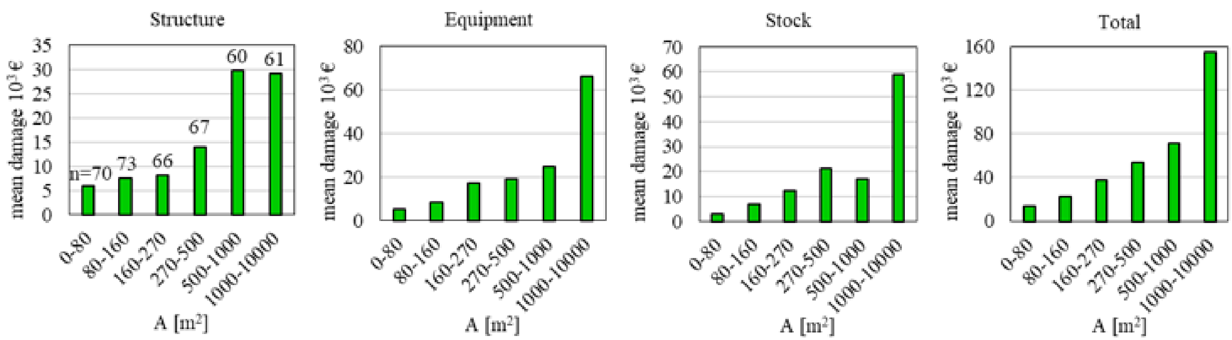

Figure 3

Mean damage against activity surface classes for all activity types. n=number of data elements for each class.

Figure 4

Scatter plot between the observed damage and the simulated damage by the reference values “2.a” and “2.b” for the categories Manufacturing, Commercial, Office and Restaurant aggregated