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Discussions

Reporting flood damages: a model for consistent, complete and multi-purpose scenarios

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Abstract

Effective flood risk mitigation requires that the impacts of flood events would be much better and more reliably known than is currently the case. Available post flood damage assessments usually supply only a partial vision of the consequences of the floods as they typically respond to the specific needs of a particular stakeholder. Coherently, they generally focus (i) on particular items at risk, (ii) on a certain time window after the occurrence of the flood, (iii) on a specific scale of analysis or (iv) on the analysis of damage only without an investigation of damage mechanisms and root causes.

This paper responds to the necessity of a more integrated interpretation of flood events as the base to address the variety of needs arising after a disaster. In particular, a model is supplied to develop multi-purposes complete event scenarios. The model organizes available information in the post event according to five logical axes. This way, post-flood damage assessments can be developed that (i) are multisectoral, (ii) address the spatial scales that are relevant for the event at stake depending on the type of damage, i.e. direct, functional, systemic, that has to be analyzed, (iii) consider the temporal evolution of damage, and finally (iv) allow to understand damage mechanisms and root causes. All the above features are key for the multi-usability of resulting flood scenarios.

The model allows, on the one hand, the rationalization of efforts currently implemented in ex-post damage assessments. On the other hand, integrated interpretations of flood events are fundamental to tailor and optimize flood mitigation strategies, as corroborated by the implementation of the model in a case study.

Keywords

ex-post flood damage assessment, complete event scenarios, flood damages, flood reports, flood damage databases

1. Introduction

In the context of the decennial World Conference organized by the United Nations (UN) in Japan in March 2015, the Sendai Framework for Disaster Risk Reduction (UN, 2015) was approved as a guidance for all UN countries that committed to improve the way they are dealing with risk governance. Among its guiding principles the following ones are of particular interest for this paper: (i) the call for mainstreaming disaster risk reduction in all societal sectors, (ii) the requirement to develop follow up mechanisms to assess the effectiveness of risk mitigation policies and programs, (iii) to build back better after disasters and (iv) to reduce human suffering and disaster losses according to measurable indicators in the coming years. Those objectives require that the damage and losses due to natural hazards are much better known than is currently the case. In fact, to mainstream disaster risk reduction in all societal sectors it is important to be able to show how the latter are actually impacted and damaged by natural hazards; therefore a multi-risk, multi-sectors understanding of societal vulnerabilities and losses suffered in individual events is needed. To assess whether or not risk prevention policies are effective, monitoring the evolution of encountered damage in the course of time is key. To build back better, one has first to analyses why the damage has occurred, what have been its main root causes, including the characteristics of the natural triggering phenomena and the vulnerability of exposed assets and systems, according to what has been labelled as "forensic investigation" (IRDR, 2011; De Groeve et al. 2013).

It is not by change therefore if there is an increased interest in the enhancement of methods and tools to collect and analyze damage and loss data and, specifically, in the definition of procedures and methods to be followed in a coherent, and possibly standardized, way to produce post-disaster impact appraisals. Australia, for example, has issued a decade ago guidelines to assess losses due to natural hazards' impacts (EMA, 2002), though we were unable to find examples of comprehensive damage reports. In the Recovery Plan after the Queensland floods in 2010-2011, damage to infrastructures has been accounted for and described in detail but it has not been appraised in an independent document devoted to the comprehensive and multi-sectoral analysis of the overall flood impact. King (2002) describes the experience developed in rapid post-event assessments at the University of John Cook; however, in this case, the assessment developed mainly as a "research oriented" activity, limited to the immediate events aftermath and with the main focus on social impacts.

Another relevant example, that we also took as a reference for our own activity, is provided by the Post Disaster Needs Assessments (PDNA) (GFDRR, 2013) developed initially by the United Nations Economic Commission for Latin America and the Caribbean (UN-ECLAC) and then improved through the collaboration of several international entities, such as the World Health Organization (WHO), the Pan American Health Organization (PAHO), the World Bank, the Inter American Development Bank, the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Labour Organization (ILO). The PDNA is made by two parts: the DALA (damage and loss assessment) and the Needs Assessment and is meant to be adopted in large disasters where international aid is required. There are several examples of applications in Latin America and Asia and a few in Europe. Several floods have been reported according to the PDNA standards, for example, in Pakistan for the 2010 flood, Nigeria for the 2012 flood and Serbia for the 2014 flood. The most relevant feature of the PDNA methodology is that it covers in a comprehensive fashion all sectors and provides an overview of how the disaster has impacted society and assets. Yet it is a methodology that has been mainly thought for international relief in developing countries, where needs are only partially deriving from the damage caused by the disastrous event, as they are often pre-existing in terms of sanitation, access to public services and utilities. There is also a time scale issue as the PDNA is mostly concentrated at rapid appraisal after disasters and has been far less used for monitoring damage during the longer recovery time.

In Europe, significant effort has been put in the last year into the improvement of damage data collection and appraisal capability at the national level, partly because of the need to respond to European and international risk reduction programs (e.g. Floods Directive, European Solidarity Fund, Hoygo Framework for action), partly as a consequence of the economic crisis. In fact, the latter has forced governments to spend more carefully and become more accountable for their expenditures, including after disasters. This is certainly the case in Italy, where local and regional governments have produced much better damage assessment reports than before to access national aid and where the National Civil Protection has been increasingly introducing standards for improved and more comparable reporting.

In other European countries, comprehensive ex post-flood reports have been produced to fine tune the analysis of the losses and impacts on multiple sectors to identify key lessons and weaknesses to be addressed by national policies. This is the case for the Pitt Report after the 2007 Severn flood in the UK (Pitt, 2008), and for the various "return of experience" reports that have been produced in France after severe storm and flood events (Agence de l'Eau Artois-Picardie, 2006; Direction Territorial Mèditerranée du Cerema, 2014). In the French case, such effort is grounded on the national legislation requiring to issue risk prevention plans at the municipal scale including also the analyses of past cases, setting state of the art of mitigation measures at sustainable costs (see Hubert and Ledoux, 1999) and linked to the national insurance system against natural calamities. Those reporting efforts, though, are still carried out as single spot initiatives and are generally ancillary to the development of recovery and mitigation plans so that they do not constitute an independent effort of representing the multidimensionality of damage and losses. Further, they are seldom presented as multisectoral, as they address specifically one sector only (Ministère de l'Écologie et du Développement Durable, 2005; Direction Territorial Méditerranée du Cerema, 2014).

Summarizing, post-event damage assessments were not developed so far to respond simultaneously to the needs of different stakeholders through a predefined, agreed upon common procedure.

In such a context, this paper responds to the need of developing post-flood damage and losses assessments that are (i) multisectoral, (ii) address the spatial scales that are relevant for the event at stake depending on the type of damage (e.g. direct, functional, systemic) that has to be analyzed and (iii) consider the evolution overtime of damage that may be suffered or gain relevance as the time passes. In this paper, a model for representing and analyzing flood damage is discussed, showing how it is able to address the multiple purposes for which losses data are collected; purposes that can be synthetized in the following: damage accounting, disaster forensic and improved risk assessment as suggested by the EU expert working group on disaster damage and loss data (De Groeve et al. 2013), and also responding to the affected communities needs, as the PDNA does, particularly in terms of losses compensation.

By adopting the model, a much more extensive and comprehensive overview of the different types of damages that affect communities and territories as a consequence of floods is possible, contributing to understand why the damage occurs and how it can be remediated reducing pre-event vulnerabilities. We have called such overview a "complete event scenario" (Menoni, 2001) that depicts not only the immediate, direct, physical impact of a triggering event, but also the indirect, systemic consequences across space and time that are mainly due to the high interdependency and interaction of systems in urban and regional environments. In order to produce such a complete event scenario, a formalized and structured reporting model accounting for damage data collection and analysis is necessary. Furthermore, an agreed upon model is essential in order to produce damage reports that are comparable for events occurring in different times and in different areas as well as for upscaling the information to higher levels, such as national and global.

The model has been actually implemented in real cases, after the floods that affected the Umbria Region in November 2012 and 2013 and that constituted a unique real life laboratory to test the model. The Umbria reporting system has been the result of a joint work of researchers and professionals, including beyond public officials (i.e. the regional civil protection in primis), also volunteering technical experts such as builders, architects, and engineers, local stakeholders (municipal officials) and the private sector (businesses owners and lifelines providers). It has also been mentioned as a good practice by the EU expert working group on disaster damage and loss data (De Groeve et al. 2014).

2. Material and Methods: a model for complete event scenarios

As explained in the introduction, a model to develop complete flood scenarios is presented and discussed here below. Such scenarios depict available knowledge on observed impacts, incurred damages and costs in terms of maps, tables and graphs, usually included in a report.

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After the occurrence of a flood, different stakeholders have different requirements in terms of "significant" knowledge about flood effects (Molinari et al. 2014 c). For example, rescue teams need to know the observed physical impacts in order to define priorities for intervention; public administrators require information on the monetary loss for victims compensation and decisions about reconstructions. With a longer-lasting perspective, local authorities or private agencies (like utilities or insurance companies) are interested to know damage root causes and mechanisms in order to define risk mitigation strategies. In order to optimize available resources and avoid inconsistent duplications of data, multi-purpose reports are then desirable that meet the needs of all possible stakeholders.

It is sensible that the way in which information is structured within a report influences the multi-usability of resulting scenarios. To this aim, the proposed model organizes available knowledge according to five logical axes:

1. Exposed sectors; observed impacts/damages must be reported for all affected sectors (i.e. people, critical services and infrastructures, economic activities, properties - including residential buildings and cars, environment and cultural heritage) in order to supply a comprehensive view of flood impacts and, coherently, mainstream flood risk reduction in all societal sectors (see introduction). Besides impacts/damages to the different exposed sectors, costs due to emergency management (like sandbags, volunteers reward, evacuation, etc.) must be reported as they can represent a significant share of the total loss to the affected community.
2. Types of damage; not only physical damages (being tangible or intangible) due to the contact of water with exposed items must be reported. The disruption of functions due to physical damages can be even more important than the damage itself, for both the return to normalcy of affected communities and in economic terms (Menoni et al. 2012). Moreover, it is often the case that physical or functional damages are not due to the direct contact with flooding water but to damages to other interconnected systems/items. Root causes and damage mechanisms change in the two scenarios.
3. Spatial scales of analysis; they depend on the objective of the analysis and on the types of damage under consideration. It is possible that the scale of the analysis for a particular type of damage differs than the scale at which the damage manifests and/or is surveyed. In the model, three spatial scales of analysis are considered: (i) the level of individual item (like a person, a building, a road or a factory), (ii) the municipality level and (iii) the meso-macro scale (like a province, a region, a country).
4. Temporal scale of the analysis; it depends on three main factors. First, the type of damage under consideration; some damages are evident by nature some time after the event, like physical damages due to humidity or business disruption. Second, knowledge requirements to support the emergency, recovery and reconstruction phases, including information needs to accomplish administrative commitments (like loss accounting). At last,

the availability of data counts which is strictly linked to the previous two points and also to other factors like skills and possibility of collecting data.

5. Variables; reported information must refer not only to the damage itself but also to its explicative variables in terms of hazard, exposure, and vulnerability of affected assets and systems. This information is crucial to understand damage causes and mechanisms in order to create more resilient societies (i.e. to build back better as suggested by the Sendai Framework for Disaster Risk Reduction). When possible, damages must be described in terms of both physical units and monetary values. Physical measures are undisputable while associated monetary values depend on the estimation method, underlying assumptions, stakeholders, etc.

The proposed model is portrayed in Table 1. In the table, only three logical axes are considered: exposed sectors, types of damages and spatial scales of analysis; types of damage are identified for each exposed sector, whereas possible scales of analysis for each type of damage (and sector) are indicated.

As regards damage types, they are almost the same (i.e. physical damage, functional damage and physical or functional damages due to systemic interconnections) for every exposed sector, with some exceptions.

In the case of population, referring to functional damage is meaningless. However, besides physical damage to individuals it is important to catch the impacts of the flood on the affected communities: the number of evacuated people, psychological distress, unemployment or loss in salary due to damage at economic sectors, lack of services because of damage to critical infrastructures or public goods; the last two categories can be actually considered as systemic damages. As regard properties, an additional type of damage has been added to the "standard" ones i.e. the properties loss of value because of the occurrence of the flood. This has been observed several times in the past and may represent a significant share of the total damage associated to properties.

As regards spatial scales of analysis, the table highlights those scales at which the analysis supplies significant results, for each sector and type of damage. Where up-scaling does not modify the nature of information, only the minimum scale of the analysis is marked. For example, physical damages are typically analyzed at the level of individual items; at upper scales, the physical damage to a certain sector is simply the sum of individual damages. On the contrary, the analysis of functional damages at the various spatial scales may supply different information. For example, the functional disruption of an hospital (i.e. a public service) has different impacts on the society when analyzed at the level of the individual hospital, or within the network of municipal and regional hospitals; the functional disruption of all the firms of a certain industrial district has different effects on the economy when analyzed at the level of single firms or at the whole district level, taking into account its importance for a municipality or a region.

Some exceptions to the above general rule can be observed in the table. The minimum scale of analysis of physical damage to people should be the individual level. However, information on injured and dead people is usually available at the level of municipality; accordingly, both individual and municipal scales are marked. The same stands for physical damage to cars (i.e. a property). Physical damage to environment and cultural heritage can be analyzed instead at the whole range of scales as some environmental and cultural goods have big extension like in the case of rivers, parks, etc. From another point of view, in economic terms, the physical damage to a city is not simply the sum of individual damage at all its artistic goods as the value of the whole city has been lost.

The level of disaggregation of each logical axis must be defined at the beginning of the analysis and may differ from the one here proposed. For example, insurance companies could be interested in the knowledge of damage at component level, like damage to pavements, doors, windows and plants within a building. Trade associations could be interested to know damage at each economic sector (manufacture, craftsmanship, trade, tourism, etc.). Civil Protection officials would have a general overview of flood impacts at different moments, soon after the occurrence of the flood. Researchers may be interested to know a very detailed set of damage explicative variables which is usually not considered by other stakeholders. Table 1 has been designed so as to meet requirements of local authorities.

The implementation of the model itself, however, does not guarantee the definition of multi-purposes scenarios. In order for the model to be successful, a coordinator of the scenario production process is required, which has a general vision of available data and required analyses to meet all stakeholders needs.

Such a role can be assumed by public administration services with an ad hoc mandate. With respect to this, Civil Protection agencies are well positioned because of their direct involvement in the emergency and recovery phases after a disaster and because of their preferential links with stakeholders (i.e. data owners and users).

3. The complete event scenario for the November 2012 flood

The model described in the previous section has been applied to analyze and report damages due to the flood that hit the Umbria Region in 2012. The region is located in central Italy (Fig. 1) and covers 8456 km^2 with a population of 883000 inhabitants (source: national statistical office, 2011).

The event was the consequence of a widespread, high-intensity storm with rainfall exceeding in most locations a return period of 200 years, and leading various rivers exceed the alarm and flooding discharge thresholds. Depending on the location and river basin, the flood event lasted for several days or few hours, assuming the typical features of riverine or flash flood respectively: the persistence of almost steady water in the first case and high velocity flows with significant sediments load in the second. Observed discharges in the plain area correspond to a return period of 100 years for the main rivers (Paglia and Nestore).

58 of 92 municipalities were affected during the event, and in particular the municipalities of Marsciano, the hamlet both of Ponticelli (Città della Pieve) and Orvieto Scalo (Orvieto). The monetary value of damages occurred in the whole

Region was about 115 M€, corresponding to 0.6 points on the regional GDP. This figure is emblematic of the real impact of the flood on the regional economy. To compare, damages occurred in Germany after the Elbe flood in 2002 correspond to 0.7 points on the national German GDP.

Data for the post damage assessment have been mostly acquired from local authorities and utility companies which collect such information to accomplish existing practices related to compensation. Damage to the residential and industrial/commercial sectors were instead surveyed on the field, working side by side with the regional Civil Protection (see also section 4).

Table 2 maps collected information, according to the structure proposed by our model (see Table 1).

Depending on the particular damage under consideration, four outcomes were observed: (i) information on damage is available in physical units, (ii) information on damage is available both in physical units and monetary terms, (iii) damage did not occur, (iv) information on damage is not available. In terms of data availability, the resulting picture highlights that information on functional and systemic damages is hardly available. Moreover, problems of data availability arose whereas data comes from private owners (like in the case of some infrastructures). The monetary value of damage is usually available for physical damages while it is usually unknown for indirect and intangible items (like people and environment). Generally, a good coverage of required data is observed thanks to the implementation of the RISPOSTA procedure for data collection (Molinari et al. 2014 a, Molinari et al. 2014 b, Ballio et al. 2015) which is consistent with the model proposed in this paper (see Sect. 4 for an in depth explanation).

The complete event scenarios for the 2012 flood is summarized in Appendix A where Table 2 has been filled in with a brief description of observed damages; monetary values reported in the appendix refer to the regional expenditure to reimburse incurred damages.

A description of the complete flood scenario is beyond the scope of the paper. Interested readers can refer to the appendix; moreover, a report is available for Italian speaker (Ballio et al. 2014). Rather, the scenario is here used to demonstrate how the information structure proposed by our model (i.e. the five logical axes) supports an integrated interpretation of the flood event that, in its turn, meets several stakeholders' needs. To this aim, the 2012 flood event is analyzed in the following sub-sections according to some of the logical axes of the model. Their discussion in terms of multi-usability of resulting scenarios is included in Sect. 4.

3.1 Analysis by exposed sectors

Information on the distribution of damages among the different exposed sectors is key to prioritize interventions and to tailor future mitigation strategies (i.e. towards those sectors that were mostly affected in the past). Figure 2 displays such information for the 2012 flood. The industry sector was the most affected by the event together with infrastructures. This was expected as the Umbria flood plains are mainly characterized by small villages and/or industrial districts. Emergency costs were also relevant because of the multi-spots nature of the flood event which required to dislocate emergency services in the whole region (see also Sect. 3.5). Although the impact to the agriculture was not as high as that to industry, it represents an important share of the total loss due to the presence of several agricultural activities in the flood plain areas. The damage to residential buildings and cultural heritage is the less significant.

It must be pointed out though that the relative damage to sectors shown in Fig. 2 has been computed based on the full reported damage obtained from initial surveys and declarations of impacted municipalities, industries, lifelines providers. This is not a trivial remark; in fact even speaking about the monetary losses, one has to be careful regarding what type of value is actually considered. The case of the industrial sector is particularly emblematic in this regard. The total self reported amount of losses reported by entrepreneurs was as large as 48 M€; however, only part of it was eligible for compensation given the aid provided by the Government for the 2012 event. In particular, in order to be eligible, companies needed to demonstrate a certain financial solidity and to commit not to close their activity for a period of five years. Also, only damaged structures, machinery, and technical equipment were eligible, not raw material or finite products that counted for significant share of the total damage, especially in large commercial surfaces. Given those conditions, the total amount of around 10 M€ was considered as eligible loss for the industrial and commercial sector.

3.2 Analysis by variables

The analysis of both damages an their explicative variables (i.e. hazard, exposure and vulnerability) is crucial to understand damage mechanisms and root causes. As an example, physical damages to the residential sector are discussed in the following. From this perspective, the 2012 flood event was analyzed in terms of:

- occurred physical damages, distinguishing between damage to structural and non-structural components, such as windows, doors, walls and contents, including technical equipment (i.e. plants).
- Flood parameters at buildings locations; in particular, the flood depth both inside and outside walls, the duration of the flood, and the presence of contaminants and /or sediments (see Fig. 3).
- The basic exposure/vulnerability features of affected buildings like typology, year of construction, size, height, number of floors, existence of basement and attached areas (see Fig. 4).

- Mitigation actions taken during the warning period and prior to the event like sandbagging, moving of contents, use of pumps.

The analysis highlighted that the most damaged component is plaster. Windows and doors were damaged only in the case of long lasting floods or high velocity floods. Pavements were usually not damaged but in the case where water proof materials were not used (e.g. wood). Technical plants were mostly not affected as they were placed above the flooding level. Whereas damages to plants were observed, the electrical plant was the most affected. Contents (furniture, appliances, etc.) were always affected although some people stated they move contents in a safer place after receiving the flood warning by the Civil Protection. The same counts for vehicles.

3.3 Analysis by spatial scales

By analyzing damages at the different spatial scales, it is possible to investigate the occurrence of the different types of damage as well as their effect on the affected communities, again with the final aim of tailoring risk mitigation actions, both in the emergency and recovery phase. Herewith, damages to the electrical supply system are commented on, as an example of an analysis by spatial scales.

Coherently with our model (see Table 1), physical damages were analyzed at the level of individual items. This allowed pinpointing damages to several electrical cabins as well as the fall down of trellis and cable which caused the disruption of the service in many areas. Functional damages were instead investigated at upper scales. By looking at the regional scale, it was possible to identify, for example, those municipalities in which an electrical disruption occurred (see Fig. 5). At the municipality scale, electricity disruption was analyzed in terms of the temporal evolution of users without electricity (Table 3), causes of disruption, actions implemented to reduce the discomfort to people and so on.

The assessment at upper scales allowed also investigating systemic damage. In particular, we observed that the restoration of the electricity infrastructure was difficult because of physical damage to roads, causing the inaccessibility of damaged items. This, in turn, increased the duration of service disruption (i.e. functional damage).

3.4 Analysis by time scale

The importance of considering the time scale is certainly very evident in the industrial and commercial sectors. In fact, industrial activities that we surveyed directly at certain time intervals (ten days and one year after the flood), reported damage due to humidity seven months after the event. In particular humidity that had infiltrated into the electrical equipment damaged engines in a weigh station for construction debris; several activities reported health problems for workers staying all day in very humid rooms affected by mold. As for the functional damage, all interviewed entrepreneurs reported that full activity was back only in March, that is five months after the disaster. In this period they had to ask for unemployment support for their workers.

But also in the case of the power system mentioned in the previous section, the time scale mattered. In fact, at least in the city of Orvieto, damage to the electrical network was significant and required a whole year to be repaired. Figure 6 shows the damaged industrial area of Orvieto, including the electrical components that were flooded. Cabins and pylons had to be reconstructed an relocated from the areas exposed to flood risk, which required time spent also for getting permissions for the new locations and re-designing that part of the network. In the meantime powerful generators were serving residential and industrial customers in order to guarantee the continuity of service.

3.5 Further significant damages

Besides corroborating the importance of an integrated interpretation of the flood as suggested by the model in Sect. 2, the definition of the complete event scenarios for the 2012 flood brought into light the occurrence of some types of damages that are hardly commented/discussed in the literature. This section briefly report on them, in particular as regards damages to environment, lack of services and civil protection costs.

Regarding environment, the flood event affected a natural park (i.e. the Oasi of Aviano) causing both physical damages to the recreational structures (e.g. bird-watching houses, path bridges), and to fauna and flora. The flood event caused also damage to hydraulic networks such as riverbanks and levees. To be noted that indirect damages to the local ecosystem may be evaluated only some years after the occurrence of the event, as ecosystems require long time to reach equilibrium. Functional damages were also observed as recreational activities of the natural park were disrupted for one month. Besides damages to the natural park, the contamination of several green areas was detected because of industrial toxic waste, especially in the industrial area of Orvieto. It is important to stress the significant of costs required by toxic waste disposal (see Appendix A).

With regard to public services, the Orvieto hospital was inaccessible for 12 hours on the day of the flood due to disruption to the road network (the hospital is connected to the city center by a bridge that was affected by the flood). Moreover schools were closed for several days in the affected municipalities.

At last, civil protection costs were significant, because of the multi-spots nature of the flood event. In order to manage the emergency, one regional emergency and 14 municipal emergency rooms were opened and contextually 15 tactical operation centers were activated, 45 volunteer organizations were involved for a total amount of 500 volunteers. A total of 255 families were evacuated from 11 municipalities, in particular from the municipality of Marsciano and Todi.

4. Discussion

The proposed model overcomes limits of existing reports focusing on a certain time span (like in the case of PDNA reports), on a specific scale (like "return of experience" reports), on the only "damage" variable (like reports presently produced by Italian authorities) or on a specific sector (like reports by insurance companies). In particular, the model allows the production of complete event scenarios that meet different stakeholders' need by analyzing data according to different logical axes. This integrated interpretation of the event, in its turn, widen the spectrum of possible risk mitigation strategies.

Examples supplied in Sect. 3 are emblematic, from this perspective. For example, to define and tailor risk mitigation strategies at the regional level, important information can be inferred by analyzing damages to the different exposed sectors. Figure 2 highlights that the reported damage for the residential sector is less relevant than usually thought of. Indeed, most of risk assessments consider only or mainly damages to the residential sector, for which several models are available; damage to industry and infrastructure (which instead play a major role in our case study) are hardly considered or estimated with high degrees of uncertainty (see, e.g. Merz et al. 2010, Meyer et al. 2013). Our experience suggests that, in certain contexts, damage estimates based on current typical practice are biased towards those sectors for which modelling capacity exists; as a result, effectiveness of risk reduction strategies grounding on such estimates is questionable.

From another point of view, the analysis of the different types of damage allows accounting for functional and systemic damages. In fact, analysis' results can be used by a variety of actors, both in the emergency and in the recovery phases.

Information on functional damage to the electricity supply system can be used, for example, during the emergency by both utilities owners/managers and Civil Protection, to prioritize interventions and to support disconnected users.

On the other hand, information on functional and systemic damage can be used by risk managers to tailor reconstruction activities towards not only the reduction of physical damage but also the avoidance of services disruption and indirect damage. Indeed, although often discounted by present damage assessment (especially when they are conducted ex-ante), functional and systemic damage may represent an important share of the overall damage, with important outcomes also in terms of societal impacts. For example, functional damages to industries had important consequences in terms of profit and unemployment in the 2012 flood in Umbria (see Sect. 3.4) Systemic damages were also significant, leading to the disruption of several public services (see Appendix A).

Another example concerns the analysis of data towards disaster forensic and/or damage modeling. It is evident that an analysis of damage explicative variables like the one in Sect. 3.2 allows investigating damage mechanisms and root causes of the event in depth, with major outcomes on the effectiveness of risk mitigation strategies (in particular, on those that can be implemented at the level of individual item). On the other hand, information on damage causes can be used to increase present skills in damage modeling.

It must be stressed that analyzing root causes means also investigating the effectiveness of mitigation actions implemented before and during the event. Such an analysis proved to be useful in the 2012 flood as it revealed deficiencies of (i) existing flood hazard maps and risk maps, especially for what concern the identification of likely flooded areas, (ii) emergency plans, particularly with regard to the actual response to flood early warnings, and (iii) land use planning, particularly regarding the location of industries in the most hazardous areas. As a consequence, a revision of hazard zones, master plans and emergency plans is in place in some of the affected municipalities.

At last, also the analysis of damages in terms of both physical and monetary values is important, for an integrated understanding of flood impacts. The experience with the Umbria flood in 2012 suggests that available monetary values hardly correspond to the real damages. Sometimes, monetary values refer to the public expenditure to reimburse incurred damages (as those reported in the appendix) which typically is only a portion of the total damage (see Sect. 3.1). Other times, reported costs refer not only to the damage itself but also to the expenditure for improving pre-existing situation, for personnel, for ex-post analyses and for survey. Without the information on the physical damage, it is not possible to distinguish between real damages and other costs. This is crucial, especially when damage assessment is performed to access the European Solidarity Fund that only cover real damages (i.e. the expenditure to recover the pre-disaster situation). The analysis of damage in physical units supplies then unambiguous scenarios that can be used as the base for different economic evaluations. Still, the translation of physical damage in monetary terms is presently a matter of debate (see e.g., Handmer 2003; Downtown and Pielke 2005) that goes beyond the scope of this paper.

From another point of view, the structure of the model in Sect. 2 and the field case study clearly show that the development of complete event scenarios requires lots of data, coming from different sources and being characterized by different level of detail and accuracy, sometimes including sensitive information. Considering the present (un)availability of flood related data (see, e.g. Merz et al. 2010, Meyer et al. 2013), it is likely that most of knowledge required by the analysis is lacking or that available data are not comparable. For this reason, a procedure for data collection should be shared among all possible stakeholders (i.e. data owners, data collectors and data users), to be applied in case of flood. An important requirement of such a procedure is to "produce" data that are compatible with their use for defining multi-purposes scenarios.

Moreover, the development of proper ICT tools supporting the whole process (i.e. from data collection to analysis) is crucial, in order to ease as much as possible the management of data. On the base of ICT tools, a model of data is required defining data of interest, their format, the temporal and spatial scales at which data can be collected and analyzed as well as relations among them, and data owners. In fact, such a model represents the structure of enhanced

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flood damage databases as advocated for in the introduction. The definition of the model of data must be shared with data collectors and users in order to effectively support their needs. The RISPOSTA (Reliable InStruments for POST event damage Assessment) procedure for data collection, storage and analysis (Molinari et al. 2014 a, Molinari et al. 2014 b, Ballio et al. 2015) is a best practice in this direction in that: (i) it allows the acquisition (i.e. collection and storage) of all information required to develop complete event scenarios, (ii) it produces consistent data although deriving from different sources and (iii) it is based on a model of data so that information is structured coherently with the reporting requirements (i.e. the logical axes) identified by our model.

It is evident that the whole process (from data collection, to data storage and analysis) requires significant resources in terms of time, people and technological assets (Molinari et al. 2014 a). However, two considerations can be made in this regard.

First, present practices entail a "waste" of resources. As discussed in the introduction, most of required data are already collected and analyzed after floods but for specific purposes, linked to the needs of the different stakeholders. This could lead to the situation in which the same "damage/impact" is analyzed several times but in non homogeneous ways (e.g. at different scales, formats). On the other hand, when a comprehensive picture of flood impacts is required (as in the case of local authorities asking for a declaration of the "state of emergency"), the lack of homogeneity implies huge efforts in terms of data pre-processing, especially if available data and their features change from event to event.

Second, the path towards "consistency" in data collection, storage, analysis and reporting identified in the paper is actually a learning by doing process. Required efforts decrease with experience. This was evident in the development of the complete event scenario for the flood that hit the Umbria Region in November 2013 (ongoing activity). Indeed, another event occurred in the region, just one year after the one analyzed in Sect. 3 and with similar features (with respect to both event intensity and observed impacts). The event has been used as a further stress test for both the RISPOSTA procedure and the model in Sect. 2. So far, the analysis of the 2013 flood event implied a significant reduction of resources compared to those involved in 2012, as analysts were familiar with practices developed for data collection and analysis.

In other words, a rationalization of resources is here proposed which, in the long run, should lead to a "saving" with respect to the present situation.

Conclusion

This paper responds to the necessity of an integrated interpretation of flood events as the base to address the variety of needs arising after a disaster; among them: prioritizing interventions, damage accounting and compensation, risk assessment and disaster forensic towards effective risk mitigation strategies.

To this aim, a model is supplied to develop multi-purposes complete event scenarios. The model organizes available information in the aftermath of floods according to five logical axes. This way, post-flood damage assessments can be developed that (i) are multisectoral, (ii) address the spatial scales that are relevant for the event at stake depending on the type of damage, i.e. (iii) direct, functional, systemic, that has to be analyzed, (iv) consider the temporal evolution of damage that may be suffered or gain relevance as the time passes, and finally (v) allow understanding damage mechanisms and root causes. All these features are key for the multi-usability of resulting flood scenarios.

The possibility offered by the model of producing scenarios which meet different stakeholders needs is the main innovative contribution of the research. Existing flood reports typically focus on a certain time span, on a specific scale of analysis, on the analysis of damages without an investigation of root causes, or on a specific sector. The model proposed in the paper widens the spectrum of possible interpretations of data and, as a consequence, of resulting actions.

Still, the successful implementation of the model requires the knowledge of a huge amount of data that may not be available. A procedure for data collection should then be defined, and shared among all possible stakeholders, to be applied in case of flood.

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Table 1: The structure of the model according to three main logical axes: sectors, types of damage and spatial scale

EXPOSED SECTOR	TYPE OF DAMAGE	SPATIAL SCALES OF ANALYSIS		
		Individual item	**Municipality**	**Meso- Macro-scale (Province, Region, Country)**
Population	physical damage	X	X	
	evacuated people		X	
	psychological distress	X		
	unemployment, loss in salary, etc.			X
	lack of services		X	X
Infrastructures (installations and lines)	physical damage	X		
	functional disruption		X	X
	physical and functional systemic damage		X	X
Public Services	physical damage	X		
	functional disruption	X	X	X
	physical and functional systemic damage		X	X
Economic Activities	physical damage	X		
	functional disruption	X	X (district)	X (district)
	physical and functional systemic damage	X		
Private properties (residences and cars)	physical damage	X	X (cars)	
	functional disruption	X		
	physical and functional systemic damage	X		
	loss of value		X	
Environmental and cultural heritage	physical damage	X	X	X
	functional disruption	X	X	X
	physical and functional systemic damage		X	X
Civil Protection	costs of emergency services		X	X

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501 Table 2: Coverage of required flood information for the 2012 flood event in the Umbria Region

EXPOSED SECTOR		Type of damage	SPATIAL SCALES OF ANALYSIS		
			Individual item	**Municipality**	**Meso - Macro scale (Province, Region, Country)**
Population		physical damage	!!!	✓	
		evacuated people		✓	
		psychological distress	✓		
		unemployment, loss in salary, etc.			✓
		lack of services		✓	✓
Infrastructures (installations and lines)	**Roads**	physical damage	✓€		
		functional disruption		✓	✓
		DDIS(*)		!!!	!!!
	Railways	physical damage	✓€		
		functional disruption		!!!	!!!
		DDIS(*)		!!!	!!!
	Electric lines	physical damage	✓€		
		functional disruption		✓	✓
		DDIS(*)		✓	!!!
	Water and sewage	physical damage	✓€		
		functional disruption		!!!	!!!
		DDIS(*)		!!!	✓
Public services	**Schools**	physical damage	✓€		
		functional disruption	!!!	✓	×
		DDIS(*)		!!!	!!!
	Health and care services	physical damage	×		
		functional disruption	×	×	×
		DDIS(*)		✓	×
	governmental services	physical damage	✓€		
		functional disruption	×	×	×
		DDIS(*)		!!!	!!!
Economic activities	**Agriculture**	physical damage	✓€		
		functional disruption	!!!		
		DDIS(*)	!!!		
	Industries and commercial activities	physical damage	✓€		
		functional disruption	✓	!!!	!!!
		DDIS(*)	!!!		
Properties (residences and cars)		physical damage	✓€	!!!	
		functional disruption	✓		
		DDIS(*)	✓		
		loss of value		!!!	
Environmental and cultural heritage	**Environment**	physical damage	✓€	×	✓
		functional disruption	✓	×	×
		DDIS(*)		✓€	×
	Cultural Heritage	physical damage	✓€	×	×
		functional disruption	×	×	×
		DDIS(*)		!!!	!!!
Civil Protection		costs of emergency services		✓	✓

Legend	
✓	information on damage is available in physical units
✓€	information on damage is available both in physical units and monetary terms
×	damage did not occur
!!!	information on damage is not available

502 (*) DDIS = physical damage and functional disruption due to damages to other interconnected system
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Table 3: Users without electricity during the 2012 flood in Umbria: temporal evolution per municipality

Municipality	Time of the day									
	12 Nov 2 pm	**12 Nov 6 pm**	**12 Nov 8 pm**	**12 Nov 10 pm**	**13 Nov 7:30 am**	**13 Nov 11:30 am**	**13 Nov 4 pm**	**13 Nov 7 pm**	**13 Nov 9 pm**	**14 Nov 10 am**
Attigliano	14	2	2	2	2	2	2	2	2	2
Orvieto	512	425	188	188	131	131	131	-	-	-
Deruta	277	2	113	-	-	-	-	-	-	-
Umbertide	27	27	-	-	-	-	-	-	-	-
S. Venanzo	93	-	-	-	-	-	-	-	-	-
Città della Pieve	64	-	-	64	64	64	64	64	40	20
Ponte S. Giovanni	15	-	-	-	-	-	-	-	-	-
Marsciano	-	300	-	172	16	16	16	-	-	-
Gualdo cattaneo	-	111	111	-	-	-	-	-	-	-
Perugia	-	96	-	-	79	79	79	-	-	-
Todi	-	-	-	44	189	189	189	189	189	189
Citerna	-	-	-	101	-	-	-	-	-	-
Perugia	-	-	-	-	79	-	-	11	6	-
Spoleto	-	-	-	-	77	77	-	-	-	-
Massa Martana	-	-	-	-	77	-	-	-	-	-

Figure 1: The case study area

512 Figure 2: Distribution of damage among the different exposed sectors for the November 2012 flood in Umbria

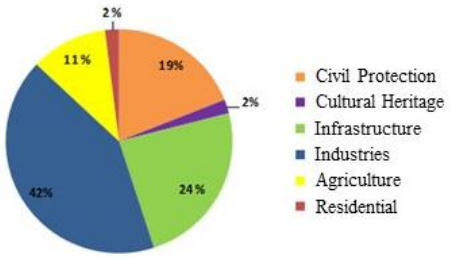

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Figure 3: Sediments' distribution in Marsciano

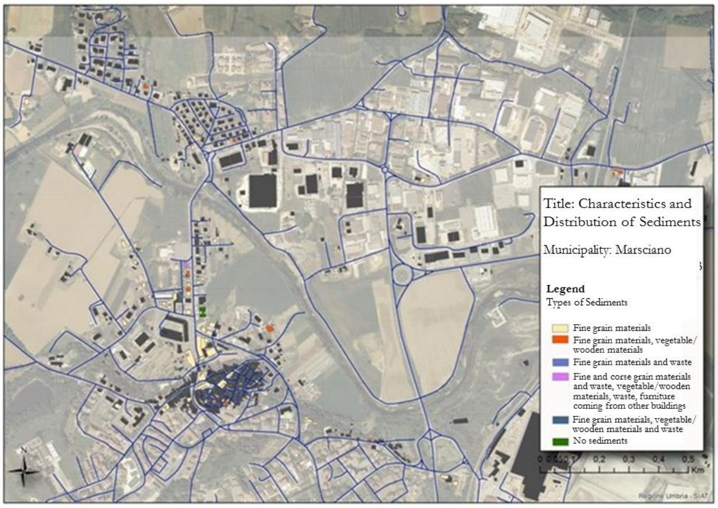

Figure 4: Features of flooded building in Città della Pieve: (a) typology of the structure, (b) year of construction

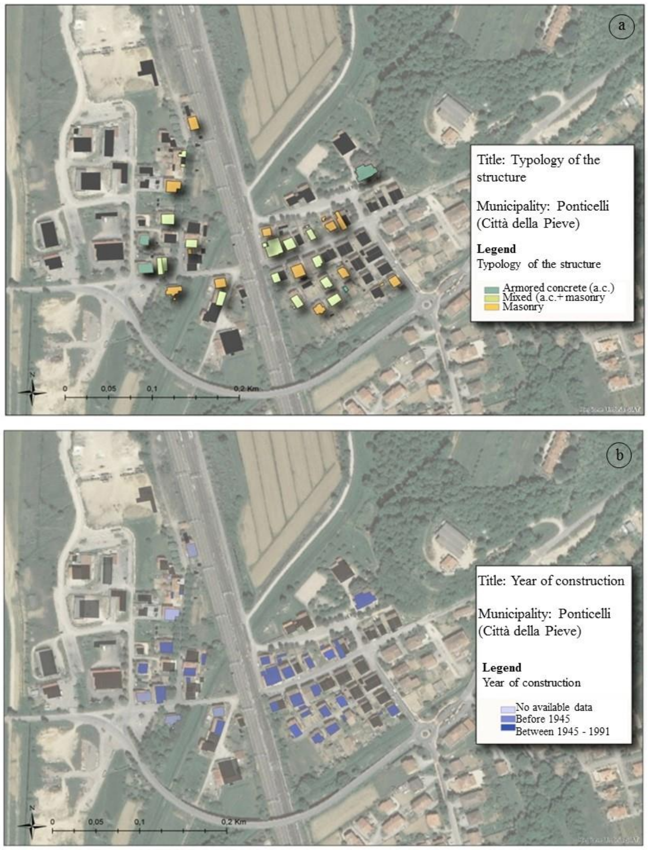

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Figure 5: Overview of electricity disruption at regional level: interested users and duration of the disruption per municipality

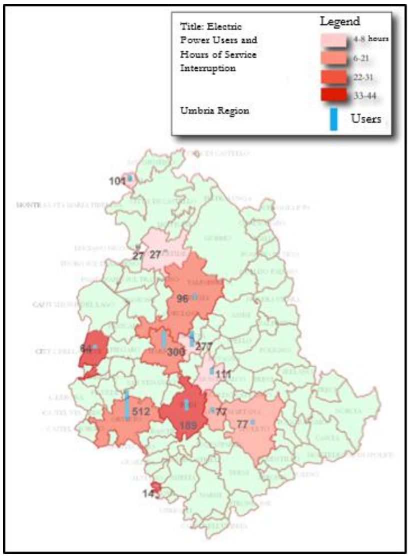

Figure 6: Electrical lines and transformation rooms, economic and industrial activities hit by the November 2012 flood in Orvieto.