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Cascading impact chains and recovery challenges of the 2024 Valencia catastrophic floods

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Abstract

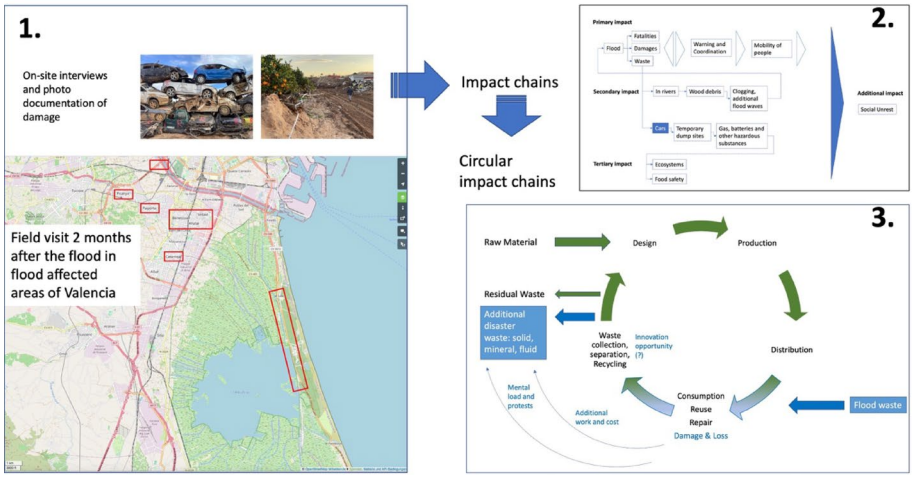
In the Valencia Region, in Spain, 228 lives were lost after catastrophic floods in October 2024, locally named "DANA". Additional losses and damages occurred in the recovery phase, which were documented by a field visit two months after the flood. The methodology consisted of empirical research and theoretical impact chain frameworks. Interviews with key informants, such as experts, affected citizens, and industry, identified key focal problems, which included damaged vehicles, disaster waste management, and losses in agricultural production. Additional impact chains emerged, such as potential soil contamination, on groundwater, and ecosystems such as the Albufera Lagoon, and impacts on the food system and agriculture. The resulting conceptual frameworks allow for better cross-sectorial and sustainable cooperation to mediate those cascading impact chains in the further recovery. The examples of Valencia were also compared with other international cases, such as the German 2021 flood disaster, in terms of disaster and waste management. The main conclusions are that, next to direct flood damages, especially waste management and potential long-term contamination, are problems in the recovery process. And on the scientific and management side, gaps in cross-sectorial collaboration must be mitigated, based on a better perception of impact chains and interrelations. An international audience of researchers, policy makers, industry, and affected people can better understand how disaster, waste, and food safety interrelate through cascading impacts in the medium- and long-term after a disaster.

Article Highlights

- Over 200 lives lost and management problems persist, 2 months after the floods in Oct 2024 in Valencia, Spain
- Flood damage and recovery problems documentation and analysis
- Impact chains development
- Integration of flood disaster impact chains with circular waste management

Keywords Disaster risk reduction, Waste management, Circular economy, DANA, Damage and loss, Ecosystem risk, Food security

Graphical abstract



1 Background

Hydroclimate volatility refers to fluctuations and extremes in precipitation, evaporation, and river flow patterns. This volatility is projected to rise beyond historical levels in a warming climate due to intensified precipitation and evaporation extremes. In a moderate emission scenario, hydrologically intense years in major global river basins may triple. In a high warming scenario, extreme dry-to-wet transitions could quintuple across global land areas [1, 2]. However, climate change is not the only cause of catastrophic flood events; it is also a combination of physical, psychological, and socioeconomic factors [3]. Under this context, the floods in the province of Valencia and other parts of Spain at the end of October and beginning of November 2024 attracted worldwide media attention [4]. Weather warnings were issued from 7.30 am, but the official evacuation alert by the Autonomous Government was issued at 8 pm [5]. There were more than 220 fatalities, accusations of failure to warn, questions of blame between the regional and national governments [6], and failure in many other aspects [7]. By the time of writing, a judge investigating the case claims that many deaths could have been prevented with the correct warning message sent in time, as has been the case in other similar floods [8]. In Spain, events of similar magnitude have historically occurred, even with a higher death toll. Besides, similar catastrophic floods have also been registered in the Valencia Region, originating from cut-off lows, a primary driver of extreme precipitation in the Mediterranean Region [9, 10]. "DANA" refers only to the weather synoptic situation, not the flood, but it is widely used in media reports and by the people in the region.

In 2024, from 27 to 30 October, heavy rainfall fell in the mountainous regions around Valencia, triggered by a cut-off low system fed by the warm temperatures of the Mediterranean Sea. This system remained static for hours, generating an unprecedented rainfall register at the headwaters of Turia and Poyo rivers, ca. 800 mm [10]. The result was that a massive flood was moving downstream, delivering water and sediment over the coastal alluvial plain of Valencia, a depositional geomorphic unit with a sediment accretion of ca. 20 m in the last 11,000 years [11], evidencing the geomorphic footprint of flash floods. The flood completely inundated the alluvial plain area where orchards had historically coexisted with flood hazards. However, the industrialisation and the

intensification of agriculture since the middle of the twentieth century involved a profound land-use change, increasing the vulnerability to river floods [12] and, consequently, the devastation.

The scientific literature on the 2024 flood disaster in Valencia is still limited due to the short time since the floods. However, there are publications covering historic and recent flood maps, the development of historic floods and flood protection in Valencia since floods in 1776, and changes in city layouts [13]. Another study analyses the 2024 flood impacts and coping strategies of schools and psychological support for pupils and staff [14]. Finally, another publication addresses urgent arbovirus surveillance and control after flooding in Valencia [15].

Before the floods, technical studies were carried out for the Valencia Region, especially concerning the 1957 flood on hydraulic aspects [16] or planning processes [17].

The legal basis for disaster management in Spain has been analysed for several dimensions, including climate change adaptation, urban growth, including vulnerable groups, psychological support, and waste management [18]. Several studies have been conducted after a 2019 flood, which was also caused by a cut-off low, in Murcia and the province of Alicante [18, 19]. Flooding situations and contributing factors have been analysed using spatial information for 2016 and 2019 cut-off low events and overflowing wadis and canals [20].

Waste management in the context of flooding was analysed after cases in New Zealand in 2010 and Japan in 2011 [21], including guidelines and strategies [22] in the USA [23], South Korea [24, 25], and Thailand [26]. Flood risk due to waste accumulations was analysed using qualitative methods for European areas like Austria [27], as well as in India [28]. The importance of waste management following flood disasters has been evaluated concerning screening, landfilling, shredding, material separation, and related costs in Italy [29]. Additionally, the treatment of stormwater in urban environments through bioremediation, macrophages, and nutrient recovery represents a relevant aspect of solid waste management [30]. Moreover, hazardous toxic waste generated by disasters is not limited to flood events but is also a critical concern in the consequences of wildfires, as recently exemplified in Los Angeles 2025 [31].

The flooding in Valencia at the end of October 2024 is also particularly interesting, as the city was not affected because it was already partially protected after the devastation of a catastrophic flood in 1957. In the 1960s to 1970s, a flood channel was built to protect the capital by diverting the main river flowing through the city [13], generating an underestimation of the flooding potential and consequences [3]. As a result, part of the metropolitan area of Valencia, located in the southern part of the flood defence channel -the Horta Sud county- was severely flooded by extreme discharges, land-use changes, and the wall-effect of the Túria diverting flood channel. The residents reported that they were surprised as it had not rained in the area (oral communication with local residents, January 9 and 10, 2025), adding to the problems with warnings and alert coordination between the different administrations involved in emergency management [32]. This is a common topic in disasters which affect many citizens, such as the L'Aquila earthquake in Italy in 2009, the floods in Mallorca in 2018 or in Germany in 2021, or the urban fires in Los Angeles in 2025 [33–36]. On the other hand, it is also typical of such flood events that the area is rather linear and, despite its dimensions, creates a world of affected

citizens living next to unaffected citizens, often separated only by individual blocks of buildings.

This study investigates the documentation of damage traces observed on-site following the October 2024 floods in Valencia, analysing impact chain recovery challenges to enhance post-disaster management. It further examines how cross-sectorial disaster response and circular waste management can be more effectively integrated to create synergies in recovery efforts. Two months after the event, the study assesses the damage, recovery processes, and associated challenges based on material collected from field visits, including photo documentation, interviews with citizens and experts, and workshops. The objective is to identify disaster impact chains and emerging interdisciplinary research needs, focusing on waste and disaster management. By providing a detailed account of the situation, this research supports future comparative studies of recovery phases while improving the understanding of disaster damage patterns. Special attention is given to the interconnected impact chains of settlements, land use, waste management, water, and ecosystems, highlighting key areas for further empirical and conceptual research on disaster impact dynamics.

The guiding research questions of this article, which also structure the paper, are:

RQ1 Which traces of damage can be documented on-site for the case of the 2024 October floods in Spain, in the case of Valencia?

RQ2 Which impact chain recovery problems can be analysed and used to help improve the aftermath management?

RQ3 How can cross-sectorial disaster management and circular waste management concepts be better integrated to create synergies in the recovery?

This study adopts a structured approach to analysing Valencia's damages and reconstruction processes, framed within a conceptual model of direct and secondary disaster impact chains. Key challenges and unresolved issues are identified and systematically examined through chains of effects, providing a comprehensive perspective on their interconnections and potential solutions. The analysis highlights critical gaps and areas for improvement, ultimately contributing to a broader understanding of disaster recovery dynamics. The specific research gaps of disaster impact dynamics addressed in this paper are missing empirical insights into the interconnections of flood damage, waste, and longer-term impacts. The novelty of this paper lies in the documentation of the flood damage, starting recovery, and waste management challenges in the Valencia region. Another contribution is a framework illustrating the general interrelations between floods and disasters, waste management, and food security. The applied framework contributes to the existing literature in disaster risk reduction by applying it to the specific disaster case of October 2024.

2 Method and data collection

2.1 Empirical data collection

A field mission was conducted from 8 to 11 January 2025 to gather information, assess needs, and document the damage after the flood. It was organised by a circular economy and waste management cluster based in Valencia. The cluster comprises various experts

in waste management and recycling companies and the Polytechnic University of Valencia. Based on the experience gained in Germany in 2021 with waste management, German experts had been identified online and invited to join the knowledge exchange mission. The German experts were a circular economy consultancy, a waste manager from the Ahr Valley municipality, and a professor from a technical university in Cologne. During the visit, on-site inspections of damaged areas, discussions with experts from the waste management sector, authorities involved in disaster management, researchers, and affected citizens took place. The verbal communication with affected citizens and experts, and photos of damages and recovery efforts are documented in this article, in a volume addressing a larger general audience, and in three languages [37]. Specific methods included interviews with key informants, guided site visits, discussions with affected citizens and civil society organisations, and focus group discussions with experts. The participants consented to the documentation and dissemination of the information and the use of the photographic material in written form. Persons that served as key informants, and their acronyms used in this article are Salvador Ortí (SO), Jose Sainz (JS), Teresa Moyano (TM), Stephan Müllers (SM), and Eveline Lemke (EL). The areas visited are, in chronological order of the visit on site: Picanya, Paiporta ("Ground Zero"), Alfafar, Massanassa, Sedaví, Catarroja, Albufera Lagoon (Fig. 1).

2.2 Direct, secondary damages and impact chain conceptualisation

The main method part of this paper and its ambition is to apply the theoretical concept of impact chains, the related dimensions of direct and indirect damages and losses, and primary and secondary impact steps to the case of the Valencia floods. The previous empirical data collection of damage evidence mainly serves to identify the key dimensions of damage that are long-lasting in terms of persistence as an important topic to the public, and visibly on the ground, two months after a disaster. This empirical evidence then serves to construct conceptual impact building blocks. The result aims to inform future quantitative and qualitative in-depth assessments of damages and which interconnections between damage and impact chains need to be analysed further.

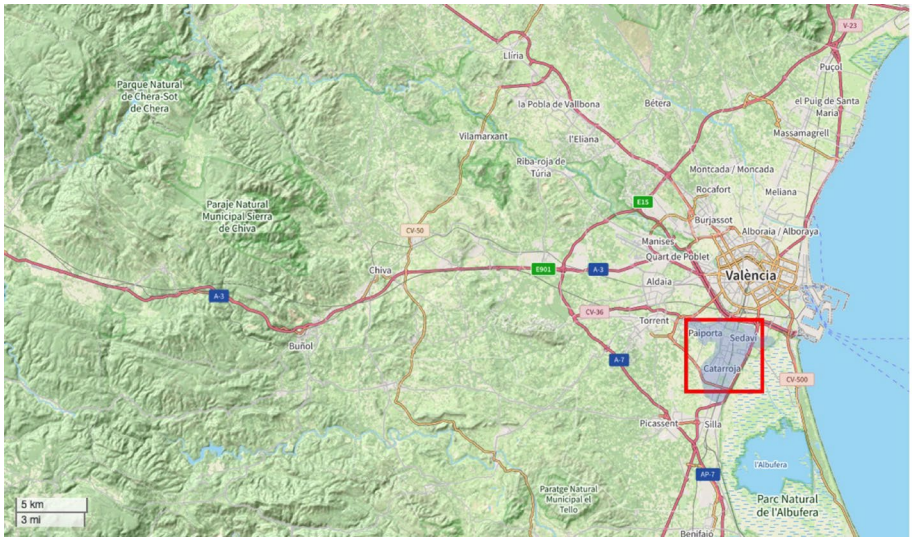


Fig. 1 Map of the Valencia area, field trip and main flooded area visited marked in red box (Source: Open Street Map contributors and Copernicus Sentinel-1 satellite flood area from 31 Oct 2024)

Impact chains are a recent topic of interest, especially climate change [38–40], but also in extreme events, weather, and warning impact research [41]. Different domains of knowledge are often better represented in scientific studies on the modelling side of the hazard and less on the impact side of events, and there are cascading interdependencies between multiple sectors being affected. Floods such as those in Valencia 2024 are unfortunate for the affected population and therefore need documentation and analysis to improve their situation, as well as for those non-affected or in other countries, since follow-up disaster events are likely to occur. Such events also serve as real event laboratories to identify and document individual impacts on people, the economy, ecology, interlinkages, and important patterns of follow-up cascading impacts [42]. The ambition is to identify those cascades and react before they can create further damage. One prominent example from the study is hazardous substances from car wrecks seeping into the ground, potentially affecting ecosystems and, later on, the food chain.

As a theoretical background, this study draws upon impact chains, pathways, cascading or compounding effects, and related narratives and storylines from the climate change impact research community [42, 43]. This work follows this literature and defines impact chains as a sequence from triggers (heavy rain) to hazards (floods), leading to multiple primary, secondary, and tertiary impacts: direct and indirect damages and their repercussions. A combination of narratives, scenarios, fault tree diagrams, and pathway visualisations used in areas such as resilient energy scenarios [43] guides the research design of the method steps applied in the present paper. The authors complement this with intersectoral research of blue, green, and grey infrastructure, especially interdependency modelling of complex adaptive systems within critical infrastructure [44–46]. In flood-related research on natural hazards, the study further separates notions and concepts of loss and damage into direct and indirect damage types [47, 48]. Primary, secondary, and tertiary impact steps are found in natural hazards research, as well as in critical infrastructure and other fields [46].

A working framework is created to structure the key findings of damages and recovery problems identified in the field. This framework is used as a first structure for this paper (Table 1). After that, the conceptual framework is improved in a reflection, considering transferability to broader topics such as waste management and other areas.

3 Results

3.1 Insights into damage and processes

The following results are based on the field visit observations of the lead author, complemented by media and literature sources. Key informant sources are provided for specific individual statements.

Table 1 Method steps in the paper

Steps	Methods	Data	Section
RQ1: Damage documentation and analysis	Empirical: Field visit, key informants, street interviews with affected residents, expert workshops	Written documentation, photos	3.1 & 3.2
RQ2: Impact chain development and examples	Conceptual: Impact chain graphs and description, pathway, narrative	Empirical data from step 1, literature	3.3.1
RQ3: Concept integration and example application	Primary to tertiary impact chain, circular economy cycles	Literature	3.3.2

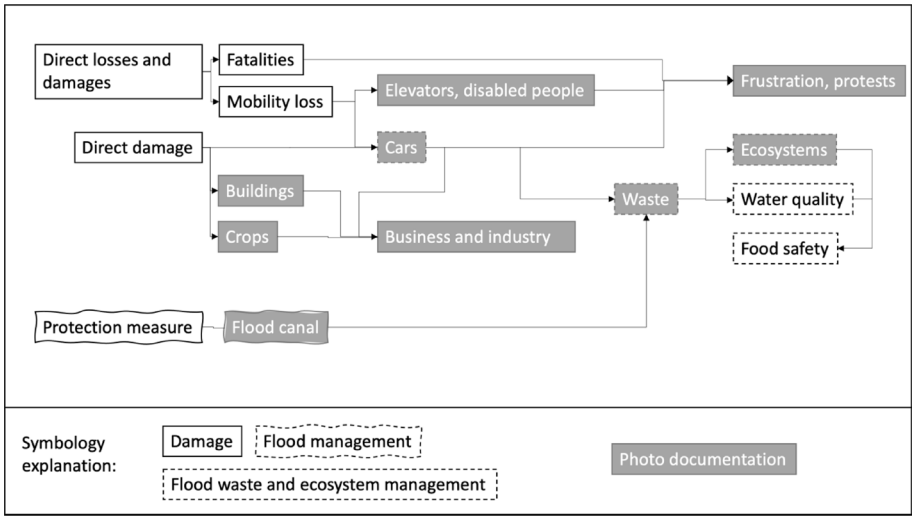


Fig. 2 Working framework of the chain of impacts observed during the field trip, as a structure for the following damage documentation

Fig. 3 Canal/"barranc" in Paiporta (photos: Fekete, 8. Jan. 2025)

The losses and damages are structured according to direct and indirect damages. The graph visualises the different examples of loss & damage observed and documented in the following text (Fig. 2).

3.1.1 Visible signs of damage

People reported they were surprised because the main flood did not come via the flood channel but via tributaries, such as artificial irrigation or drainage channels, while also highlighting that the hydrological regime is predominantly ephemeral, with most of the fluvial network becoming active primarily due to Hortonian overland flow. Over time, rubbish and waste accumulated in these canals. Debris, reeds, wood, and solid waste from these canals were collected at the waste collection points of the flood. As in other flood events, the debris clogged the drains and caused additional flood heights and waves. The drainage channel of the Túria River served its purpose, protected the city centre, and discharged the flood into the Mediterranean Sea. However, the Barranco del Poyo overflowed its banks due to a combination of the heavy rainfall in the remote headwaters' mountain areas, the convex topographic features of the downstream alluvial area and the Turia deviation canal, mainly causing the flood of the affected areas south of the city centre of Valencia (Fig. 3).

Quantifying the losses and damages precisely two months after the event was difficult. The search for bodies was still ongoing, as people were still being reported missing. As a result, the same areas, such as cars, needed to be searched repeatedly, meaning they needed to be labelled as verified to ensure that the situation could be managed (oral com., SO). Some disabled residents were stuck in their apartments since the elevators have not been repaired yet (oral com., TM). Ten thousand elevators are damaged in the area, and 8,000 are in residential buildings [49]. The visual documentation with photos of the affected areas showed signs of damage, such as closed shops and locked entrances. Some houses and riverbanks were still covered in debris and dust. However, the clean-up work was already clearly visible, and it was difficult to see flood marks or damage on the road when driving past. Flood marks could be seen up to 2 m high in houses, interiors, or garages.

Two months after the flooding, in another affected area, Catarroja, the pumping out of cellars, the cleaning of streets, and the presence of civil defence and the military were even more visible than in Paiporta and other areas. The floodwater had reached 1.5 m, and many underground floors of apartment blocks had been flooded. Concerned citizens on the street said that some emergency services stopped pumping water out of private homes, which upset them. In talks with other stakeholders, we heard that this might be since some of the underground car parks are unregistered in the official cadastre.

Private initiatives and volunteers still distributed food and other items to those affected. The military, which initially only had cleaning and security duties, was also involved in these tasks. Citizens reported that communication with the police and the army had significantly improved due to the floods. Some of the military personnel returned for the third time because the help they provided to the people motivated them.

Many people perished in cars, many cars (>120,000) were damaged, also creating waste disposal problems [50, 51]. There are many underground car parks, typical of constructing residential areas in Spain, which were flooded. The damaged cars were then piled up in the collection centres and checked by volunteers and the Emergency Military Unit (UME is the acronym in Spanish), which was responsible, alongside a civil defence unit, to ensure that no bodies were left in the cars. Damaged cars are a visible sign of flood destruction due to their deformation and muddy hulls (Fig. 4).

The main problem is that the insurance company requires detailed documentation of the car damage. Some had parked their cars on the street during the flood, but after the

Fig. 4 Car wrecks with signs for being searched for dead bodies (R = Reviewed, X + 2, checked two times) (photos: Fekete, 8 Jan. 2025)

Fig. 5 Car wrecks lifted and pressed into transporting trucks, and lithium batteries on the ground on scrapyards pose potential soil contamination (photos: Fekete, Catarroja, 9.1.2024)

Fig. 6 Damaged and mud-covered orange trees (photos: Fekete, 10 Jan. 2025)

flood, they were taken away to scrap yards without being informed. The owners, therefore, no longer know where their cars were. And without photos and documentation of the costs, they could not receive compensation from the insurance company. Some owners reportedly drove 60 kms to the scrapyards. More problems with hazardous materials in the cars were visible at the scrapyard, such as lithium batteries from mobile phones lying on the ground next to the vehicles. Also, caterpillars lifted some cars, and gas and other liquids were leaking (Fig. 5).

Many orange and fruit orchards were still covered with mud and flood debris (Fig. 6). Agricultural losses are an important factor in the area, as the Valencia Region produces 2/3 of Spain's orange production, and Spain is one of the leading exporters of oranges to the world [52].

The recovery plan of the provincial government of Valencia lists estimated budgets needed for the rehabilitation of infrastructure and living conditions [53]. Tourism is an essential economic factor in the region, and the Valencia Region Tourist Board announced two months after the flooding and before Christmas that tourists are welcome and normality has returned to the region [54]. This fact certainly applies to the unaffected areas and the entire city centre of Valencia. Hotels, restaurants, and other

services are still being operated. Many people in the region report that the floods affected colleagues or relatives. Between 10–20% of the affected companies were suspected to need to close after the damage [55], and a similar number of people from the business community were said to be affected. On-site conversations with the people revealed that the floods affected up to 40% of their staff.

A civil society group (TM) member showed us a residential area in Catarroja and explained that residents were now afraid of dangerous dust and contaminated soil. The mud had already covered some of the grass in the parks, but underneath, it was uncertain for people what health effects the groundwater could have.

In addition to the general damage assessment, a particular focus of the mission was on waste management. Waste is now an important issue and concern during the flood recovery phases. Firstly, because the first main phase of response and reaction, namely cleaning up homes and accounting for casualties, is now moving into a phase of rebuilding and reopening businesses and daily life. Signs of solidarity and gratitude can be seen in the affected streets. Compared to the events in Germany in 2021, it is interesting to note that there are no house dryers. Cellars are also no longer being pumped out. This fact is due to the climatic conditions, according to locals. However, it may also be a factor of knowledge about the health effects of affected or even contaminated building structures. In Germany, even after the summer flooding and mild conditions, it was crucial to dry out the moisture in the affected houses to avoid health effects due to mould or weathering of building materials.

3.1.2 Flood waste management

Disaster waste management (DWM) accounts for approximately 27% of a natural disaster's total cost [56]. Poorly designed or executed DWM threatens environmental security and public health [21] and hinders rapid disaster recovery [23]. After the floods in Valencia, disaster waste (DW) had to be removed and taken to the two mechanical biological treatment (MBT) plants located near Valencia (10 km approx.). These MBTs belong to the public official waste collection centre (EMTRE, the acronym in Spanish language) and regularly manage waste (excluding selective waste collection) from 45 municipalities (645.000 t/year). However, after the torrential rains, the MBT plants were turned off for some days because, in one case, the accesses were flooded, and in the other case, there was no power supply. In addition, transporting disposal waste to the controlled landfill was impossible because the roads were closed, and a bridge collapsed. Setting up a makeshift military bridge took one month, allowing road communication to the landfill. The DW kept arriving at the MBT plants during such a time (2.500 t/day), almost collapsing the facilities because treating all the DW was impossible, and final residues from the treated fraction could not be taken to the landfill. In this scenario, the Generalitat (Regional Government) authorised the deposit of DW in quarries in nine municipalities in the province of Valencia, which have offered their facilities along with ten other spaces for vehicles. This decision was an exceptional measure provided for the Waste Management Law 7/2022 to ensure public health and safety in cases of natural disasters. Allowing avoidance of bureaucratic barriers in DWM to increase authorities' power in decision-making is frequent when disasters occur [57], representing the ongoing dilemma between hurrying up to solve immediate problems and the risk of generating worse long-term consequences.

Meanwhile, in the affected areas, regular municipal waste was impossible to manage because debris and vehicles blocked the streets, the collection trucks were either towed away or rendered unserviceable, and most bins disappeared or collapsed due to the excess weight as they were overflowing. Thus, public companies managed DW in the affected municipalities with their heavy machinery in collaboration with environmental agents. They collected DW and stored it in large metal containers provided by the EMTRE, thirty local stacking areas, and four intermediate transfer points. This way, vans collecting debris stopped going to the MBT plants, avoiding traffic jams that hinder waste trucks from working efficiently. The Generalitat announced that they will activate the last phase of the Waste Plan to progressively empty these stacking points and intermediate transfer points by January. The objective was to let private companies specialise in the complete waste management cycle (from collection to treatment and final disposal in authorised landfills) properly manage DW, allowing municipalities to perform regular waste operations as before the crisis's advent.

Apart from the MBT plants, the EMTRE manages 26 Eco-parks (a selective waste collection facility where citizens can deposit materials free of charge that have no place in traditional containers) scattered along the entire province of Valencia. After the floods, most of them were devastated by flooding due to their location in flood zones. The fact that unaffected areas in the north of the ground zero deposited voluminous waste as if nothing had happened did not help alleviate the massive influx of waste to the treatment plants. In this line, technicians also asked for more coordination from the command outposts, which were overwhelmed. In this regard, waste managers demand the presence of an expert in waste management in the Integrated Operational Coordination Center (CECOPI, the acronym in Spanish language), which centralises decision-making for the total management of the emergency.

Another burden that was difficult to manage was the immense quantity of canes and logs. In a few weeks, 13.400 tons of this waste were collected only from beaches, representing more than 50% of the pruning fraction generation for all metropolitan areas in one year. This type of waste is now being screened, large logs are being shredded to reduce the waste density, and sand is being filtered to be replaced on the coasts.

Special mention merits the Albufera Natural Park, an ecosystem protected by the European Union with an area of approximately 211 Km^2, of which some 150 Km^2 are dedicated to rice cultivation, which is crucial for the region's biodiversity and has been seriously affected by the floods. The arrival DW in the northern zone was estimated at 85.000 m^3, of which 1,500 m^3 from irrigation ditches had already been removed in December, together with some 2.5 tons of plastics. In December, PreZero began the removal of hazardous waste, removing an accumulated 18 m^3. Another critical issue is that after floods, the volume of sediment at the bottom of the lake is estimated at 700,000 tons, which means about 46,000 truckloads of debris. Floods caused in one day the usual 30-year volume of sedimentation, which raises the debate as to whether it is necessary to drain the lake bottom, which has been increased by 6 cm. In addition, the collapse of several sewage treatment plants is causing the arrival of untreated urban water, which further aggravates the disaster impact. Although samples are being analysed and results point to a recovery of conductivity and suspended matter values before floods, much work remains ahead to safeguard the health of the ecological jewel of the Valencian community. Experts claim that the fact that local, regional, and state administrations are

involved in its care hinders the global vision it needs, generates a lack of coordination, and slows the execution of corrective actions.

Finally, more than 120,000 damaged vehicles after the floods [55, 58] generated a significant economic, environmental, and emotional impact in the affected areas. The emergency solution consisted of accumulating them in some 70 camps set up by the municipalities. Some chaos in the initial vehicle management and the fire in one of these camps showed that this temporary solution required urgent measures. Thus, the urgent approval of a Royal Decree made it possible to regulate the transfer of these vehicles to 138 Authorized Vehicle Treatment Centers (CATV) in Valencia after receiving a prior appraisal by insurance agencies. However, in January, only about 40,000 vehicles were removed, at a rate of approximately 1,000 vehicles per day. Therefore, the Generalitat plans to accelerate the removal rate to 5,000 vehicles per day by incorporating scrapyards nationwide. This measure will increase costs but reduce the environmental impact of wrecked vehicles by allowing their controlled decontamination before they are scrapped.

The expert workshops organised by the Waste and Circular Economy Cluster and the Project Management, Innovation, and Sustainability Research Center (PRINS) at the Universitat Politècnica de València (UPV) discussed the improvements to be introduced in the region regarding waste management. The main conclusion is that, despite having expertise in waste management, sorting, recycling, and waste assessment and revaluation, its application is not widespread in the region. Although many well-known companies offer these services, most municipalities continue to landfill waste that has the potential for reuse, recycling, or other types of recovery, representing a massive waste of resources. The waste management system is based on the autonomy of the municipalities and regions, which makes it challenging to have a reproducible standard for the whole state. This fact makes generalizing a disaster action plan difficult since it must always be adapted to the existing systems and regulations in the affected areas [24]. In the case of floods, the waste management system is severely affected by the increase in volume (800.000 tons in Valencia floods, almost double what the metropolitan area produces in one year), the heterogeneity of the waste, and the presence of hazardous waste, which stresses the waste treatment system and makes waste disposal even more difficult. As a result, the recovery and return to normality phase are slowed down. Valencia is not an exception, as this circumstance is common in almost all urban areas affected by flooding. In most reported cases, there is a lack of a plan to deal with natural disasters, and those that exist are outdated [23]. Considering that for emergency services, sustainable waste management remains in the background [18] and that there is a general lack of training for waste treatment [59], the result leads to inefficient disaster waste management, worsening the safety, hygiene, and recovery of the affected areas.

Regarding DWM, the experts concluded that (1) the relevance of DWM and the potential issues arising from it is still undervalued, (2) it is mandatory to include DWM within the emergency management planning, (3) waste experts must design a preventive plan to deal with DW including: predicting volume of DW, planning waste collection and transport, designating temporary storage areas, selecting treatments and final disposal methods, (3) finance the DM plan with the annual allocation of a budget including the provision of resources and updated equipment, (4) define roles, participation and responsibilities of the local, regional, and national stakeholders, including affected

citizens and volunteers, and (5) personnel training and capacity building is mandatory to handle proper DWM.

3.1.3 Disaster management and coordination

Disaster management and coordination are essential issues in the areas affected by the flood and the province. The failed warning was the main issue [11, 60] that dominated discussions two months after the flood (oral com, SO). On the morning of the first day of the floods on 29 October, the Spanish Meteorological Agency (AEMET, the acronym in Spanish language) issued a red warning for rainfall accumulations > 180 mm in 24 h as early as 7:30 am [7]. By 10:30 a.m., fire services in the region were dealing with the flooding. By 17:00, the 112 call centres for emergency management lines were overloaded [60]. But it was not until 8:11 p.m. that the regional government issued a warning via mobile phone. At this point, people were already drowning. Later, there were many accusations of mismanagement and delayed reaction, e.g., not responding with a warning, not reacting to the flood, but taking three hours to have lunch with a journalist [61]. And the initial refusal of offers of local and international aid [62]. Days later, however, international rescue organisations from France and Portugal were invited and active in the area [63]. Discussions about apportioning blame were significant in national and international press coverage. For example, five days after the flooding, the King of Spain, the Spanish Prime Minister, and the Regional President visited the affected areas. They were met by protesting people who threw mud at them and destroyed the car of the Prime Minister, who had to leave the area [58]. The situation was heated, and 130.000 people protested on the streets after the flood [64].

Flood management responsibility was transferred from the national to regional governments after floods on October 28, 1982, in the Valencia Province, in early November 1982 in the Catalan Pyrenees, and in August 1983 in the Basque Country in Spain [65]. The Basque, Catalan, and Valencian regions are also known for struggles for autonomy. The city and region of Valencia also have their language (Catalan, officially named Valencian), culture, and understanding of autonomy. National responsibility for flood management was transferred to all autonomous regional governments in Spain after 1983–2013, shifting from pure hydraulic protection measures to a more comprehensive management of environmental hazards [65]. For example, a flood control canal was built after the 1957 flood in Valencia to divert the discharge from the mountains around south of the city center into the sea under the Plan "South" [65]. It was then expanded into a more comprehensive structural plan that covered the entire area, including bridges and housing construction. Flooding and urban expansion, particularly in the Horta Sud, followed over a more extended period, with specific proposed mitigation plans that were not enacted [66]. It is a catchment area with runoff that flows into the Mediterranean Sea, as well as a large lagoon and ecosystem area. This ecosystem area has been increasingly converted into agricultural plantations and industrial and residential areas. Plans for hydrological management of structural measures to improve the existing systems have been proposed since 2008 in a novel approach. Still, many have been idle, due to the economic crisis beginning in 2008 [65]. A disaster management unit for general disaster management purposes was proposed. Still, after the elections, the new government of the current administration decided to cancel the idea about a year before the floods to save costs [67]. A similar issue is coastal defence against coastal flooding. Under the

new government, it has been discussed that the officially existing 500-m zone should be reduced to protection of only 100 to 200 m [68]. Tourism is important, and many hotels are being built directly on the region's beaches.

3.2 Analysing the underlying problems

3.2.1 Why do innovations in waste management get stuck?

And why does circular thinking not become more prevalent after disasters? In science, disasters often offer change opportunities [69, 70]. In the Valencia floods in 2024, landfills and vehicles were an important emotional cornerstone for people's recovery two months after the disaster. Therefore, we explored how to transfer knowledge from the waste management experience after the floods in Germany in 2021 and how to adapt it to the local situation in Valencia. Therefore, the main part of the field trip and the investigation involved many discussions with key informants from the waste management sector and civil society organisations. They pointed out that modern recycling, waste separation, and other techniques are generally in place, and several companies have come together under the umbrella of the Clean Waste Cluster to support themselves. However, despite existing European regulations, the region lacks enough support to move away from simple landfilling to more modern approaches. DANA crisis and European regulations led the Generalitat to plan the construction of three incineration plants with waste energy recovery by 2030, which will be located in each of the three Valencian community provinces. In this line, three bulky waste management facilities to promote waste reuse and recycling are also planned for 2030.

Salvador Ortí (SO) is a Municipal Services Management Systems consultant and the Spanish Clean Waste and Circular Economy cluster CEO. He believes the most modern waste management, separation, or recycling techniques are known, but no efforts have been made to comply with current European laws and regulations. Nor do municipalities have specialized waste management units. He says another issue hindering rapid adaptation to innovations and environmental requirements is the long duration of current contracts between public administrations and private waste management companies. On the other hand, during the guided tour, Salvador Ortí learned from local workers that the local authorities are also active in this area to maintain the existing waste treatment system. However, new contractors with more modern approaches are available. Regrettably, due to scheduling problems, administration representatives couldn't attend the organized workshops at UPV to give insight into these issues.

Salvador Ortí mentioned that other Spanish regions are already further ahead in waste management innovation. Communities such as Cataluña, Madrid, the Basque Country, and the Balearic Islands already have incineration plants. The Balearic Islands are leading in waste management because of the demand for tourism. Recycling and consideration are key as the Balearic Islands generate a lot of additional waste from tourists, and tourism expects clean beaches (oral com., SO). This fact aligns with reports of beaches being cleaned within days in Málaga after the floods of 2024 [71]. In Valencia, some reports suggest that the cleaning of the beaches was still ongoing, as a key informant told us during the field trip, because the municipality has not yet fully decided on the process. However, some entrepreneurs are already active in waste recycling, such as in recycling high-value plastics (oral com, JS). It is a material that can be used for better building materials that are exposed to the sun for longer than wood, for example, which

must be preserved with additional substances. There are also some remarkable projects and innovations, such as Urbaser and Recycleye's first investment in AI waste sorting in the Valencia plant in Algímia. A robot guided by AI collects recoverable materials at the end of the sorting process to prevent them from ending up in landfills. Recycling in treatment plants such as Recimed in Villena (Alicante), which guarantees the correct treatment of non-hazardous waste, or the waste treatment centre in Vall d'Alba (Castellón) that ensures the management of hazardous and non-hazardous industrial waste, are other good examples of advanced waste management in the Valencian community.

To summarise, a mixture of barriers, lack of insight, and need for innovation explains why waste management is still traditional and does not rely on more modern waste separation or recycling techniques and ideas. There is, therefore, still a long way to go before recycling becomes part of the circular economy.

3.2.2 Flood waste is not suitable for recycling

It was also found that upcycling flood waste is more difficult and, therefore, even less attractive (oral com, JS). Solid waste must be cleaned of a lot of sludge, and drying this can be very resource-intensive, consuming water and labour. For high-quality plastic recycling, for example, this extra process is economically inefficient (JS).

Another example is the actual recycling of vehicles in Valencia. At one of the scrap yards, we observed car wrecks stacked on each other so liquids could seep into the ground; see Fig. 4. We also observed car wrecks being transported on a lorry without the gas tanks having been emptied first, leaving the smell of gas and oil in the air.

These two examples, recycling problems with sludge solid waste and handling cars and hazardous substances, show that severe floods stressed WM even more. In this line, the experts who dealt with waste management in Germany in 2021 also found that all recycling and the careful handling of hazardous substances were overtaken by the dynamics of the clean-up work (oral com, EL, SM). Many street volunteers were highly motivated and quickly took the empties from the houses to the landfills. However, some furniture could have been cleaned, and some even could be offered to carry out voluntary cleaning work [72]. Overall, the dynamics of the volunteers and the cleaning process in Germany also meant that the usual recycling and sorting practices were not followed. In the Spanish situation, too, the floods did not fall within the window of opportunity that was seen for the introduction of new techniques in waste management. At a political and economic level, waste management in Spain has a tradition of prioritising economically efficient handling over other recovery issues (oral com, SO).

Destroyed vehicles were also a significant issue in Germany, as around 50,000 cars were damaged [73]. Loss of mobility and vehicles is an important topic for media coverage in other events, such as the L.A. urban fires in 2025 [74].

3.2.3 Lessons to learn for an international audience

The floods in Spain in 2024 triggered worldwide attention mainly due to the high death toll and accusations of flawed management and warning. This fact is a recurring theme in many other cases worldwide [75].

A comparison to floods in Germany in 2021, as one prominent example, helps to identify common and recurring themes in catastrophic flood events. Similar floods occurred in Germany in July 2021 and claimed over 180 lives [8]. The flood disaster attracted

global media attention for alleged failures to warn, and court cases and commissions of enquiry continued for two years after the floods to investigate failures in emergency management coordination and administration. The federal states and other institutions produced a series of lessons learnt studies highlighting the need for improvements in coordination and communication and better involvement of volunteers, among other aspects [76, 77]. The Ahr Valley has become the 'poster child' for flooding in Germany, as most fatalities occurred in that region, covering around 40–60 kms. The situation was special due to the relatively long and narrow valley, its geomorphology, and the built-up infrastructure in the floodplain [78]. However, it should be noted that fatalities and damage also occurred in nearby areas, valleys, and in urban and flat regions. Although they were not the centre of media attention, they also occurred in other federal states in western Germany and eastern and southern Germany. Neighbouring countries such as Belgium and France were also affected by the floods, and the total area affected is comparable to that in Spain [79]. The total amount of precipitation in Germany was lower, reaching 100 to 150 mm within 24 h in the valleys, for example, with maximum values of 200 mm, while in Spain, up to 491 mm fell within eight hours [10, 80].

The weather in the coastal area of the Valencia Region is comparatively mild, even in winter. In January 2025, the temperature ranged from 16° to 23 °C during the day and 9° to 11 °C at night, which was exceptionally warm. However, this was exceptionally warm, not representative of every year. In Germany, winter conditions were between -5 °C at night and 5 °C during the day. As a result, even six months after the floods in Germany, the dryers were still running in the houses the following winter, which was not observed in Valencia.

Valencia was the worst-affected area and will be the 'poster child' for the so-called "DANA" flood in Spain in 2024, just as the Ahr Valley was for the 2021 flood in Germany.

Previous studies following floods in 1976 in the USA, for example, already stated that there are two types of disasters following a flood; after the direct damage, a perceived disaster of failed management often can occur [81].

Another pattern recurring after major disasters is that floods often have already happened in the same area in the past, such as in Valencia in 1957, 1984, or as recently as 2022 [82]. In the Ahr valley, floods happened some 80 years before to the same extent, and in 2016 to a lesser extent [78].

The recovery in Germany is not yet complete and will continue. A comparison of the two cases is also important for an international audience, as the events and allegations of failure are similar. Comparing the two cases can also help decision-makers and experts in both regions better understand future improvement opportunities.

3.3 Development of governance structures based on chains of circular processes

3.3.1 Development of impact chain pathways based on key focal problems identified

Based on the findings from the field interviews, discussions with key informants, and focus groups, we summarise some key examples of how to explain better, visualise, and develop impact chains. To do this, we use a tried-and-tested approach: we combine narratives, scenarios, fault tree diagrams, and pathway visualisations [43].

We start by selecting key narratives from the insights documented above. This fact makes it necessary to repeat the information from above in a comprehensive manner. We then transfer this into a graphic of a fault tree flowchart. This flowchart illustrates

a chain of effects with secondary effects and a circular feedback loop that shows why certain techniques, such as better waste management, must be introduced to avoid additional hazards or risks in the future. Finally, we highlight future development scenarios and pathways to help decision-makers and audiences understand different paths of choice or indecisive behaviour.

Cars are an example of the chain of effects of disasters and waste

Vignette or narrative description:

> *"Cars were identified as one of the main damaging factors in the Valencia floods. The floods damaged an estimated 120,000 cars. The daily lives of residents and businesses have been affected by the lack of cars and mobility to continue daily tasks. For the people who have lost their cars, this means an additional economic and emotional burden. More than two months after the flooding, they are still trying to locate and identify their wrecked cars, often taken off their streets without their knowledge. They now need photo documents to take out insurance. The car owners are exerting pressure and demanding that the scrapping companies at least declare the value of the raw material when scrapping the cars. When the cars are disposed of, they are piled up in several scrapyards in an area that stretches up to 60 kilometres in the Valencia region. The stacked cars are already causing damage, and hazardous substances from gas and oil are seeping into the ground, potentially contaminating groundwater, which can have unpredictable consequences for drinking water, crop cultivation, or other areas. Introducing more innovative waste management would include locating car wrecks and identifying and separating solid waste into recyclable and other raw and hazardous materials. This fact could prevent long-term pollution and provide more emotional and economic clarity and support to people who have lost their cars."*

This narrative or vignette described above can also be translated into a flowchart; see below (Fig. 7).

We want to emphasise that car wrecks are only an example of a specific damaged good. However, they are important for many of those affected now and offer a good starting point for better understanding and communication. Similar topics could also

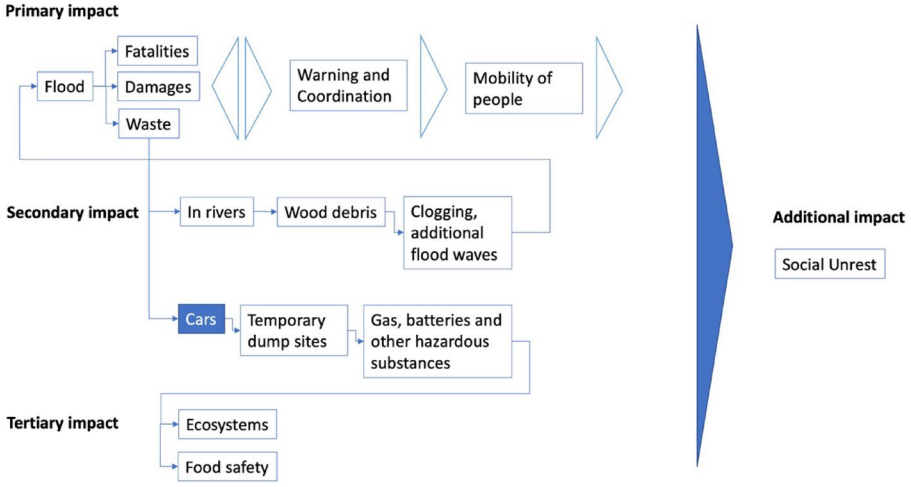


Fig. 7 Impact chains of flood damage at the example of car wrecks

be selected, and the same methodological and logical approach could be applied. Other example topics could be orange plantations and sensitive ecosystems such as wetlands.

Orange plantations are an example of the chain of effects of disasters and waste

Example narrative:

> *"Orange tree plantations are an important economic factor for the Valencia region. Like khaki plantations or rice fields, they were flooded in 2021. Oranges are a good example because two-thirds of the orange harvest in Spain is produced in the Valencia region for export, and Spain is the largest exporter of oranges in the world. In many countries, such as Germany, oranges from Valencia are particularly well known and could be used to symbolise flood damage. During the excursion, it was noted that many orange plantations were still covered in flood debris. In addition, many orange trees and plantations were located near temporary or permanent landfill sites. This fact creates an additional risk of contamination from wind or water transport of hazardous substances from the sludge-covered solid waste or wrecked cars and lithium-ion batteries mixed in with the solid waste."*

Additional problems could arise from the sludge taken from the Albufera lagoon for the orange plantations in the north of Valencia, which were not directly affected by the floods. As a large part of the flood debris washed into the lagoon, it should be checked whether certain areas with nearby villages to the far north of the lagoon, which border the urban area, could be contaminated. This is because the sludge from the lagoon is used as fertiliser and transported to the orange plantations.

Figure 8 expands on Fig. 7 and shows the additional impact chain connecting car wreck induced hazards of soil, groundwater, fertilizer, orange plantation contamination, and finally, food safety.

Figure 9 shows a map of a major ecosystem in the region that could be directly affected by this impact chain: the Albufera lagoon, a major tourist destination (Fig. 9).

3.3.2 Holistic governance approaches to introduce innovation

One idea that emerged as a possible approach to introduce innovation in the future was suggested in the group's discussions. As in many other disaster cases, a holistic

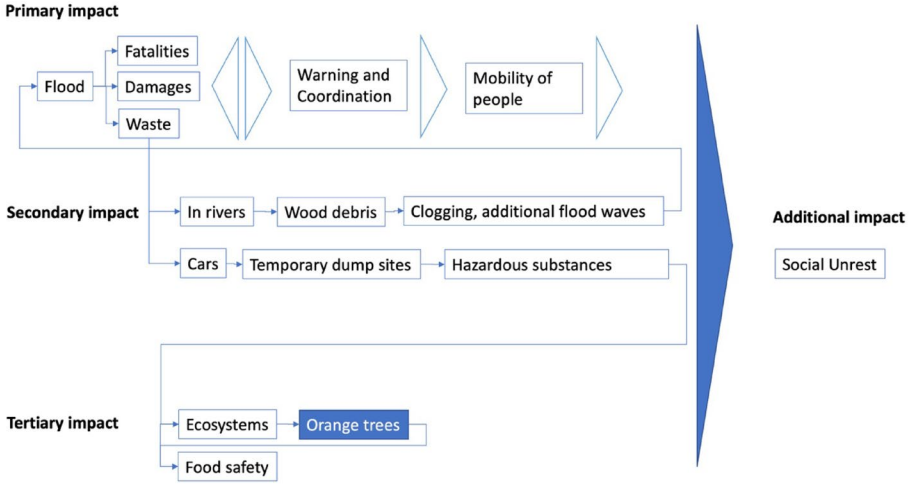


Fig. 8 Impact chains of flood damage at the example of orange trees

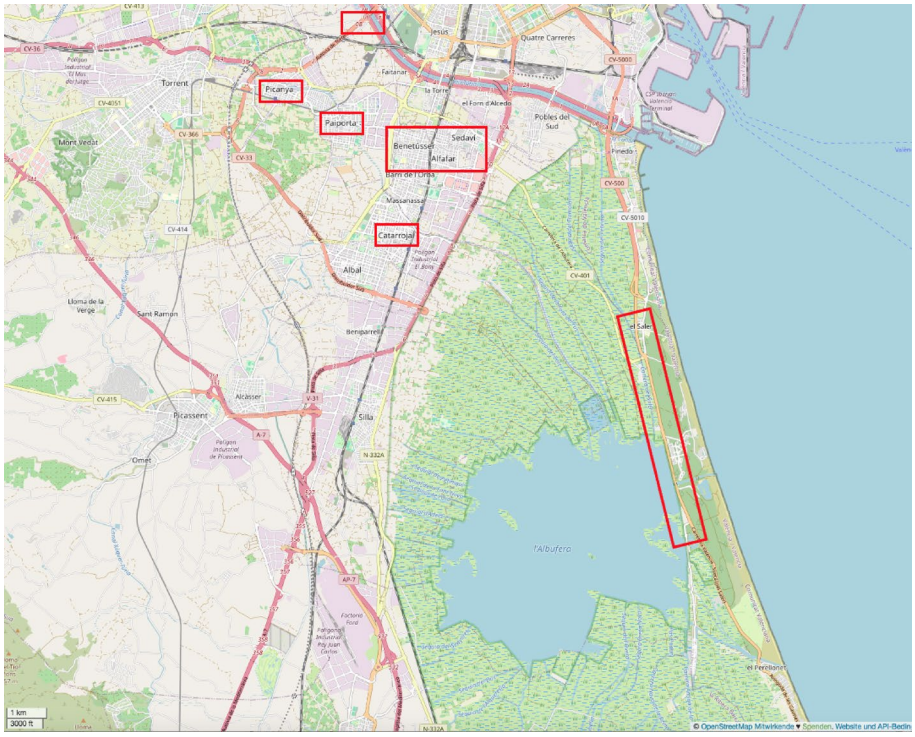


Fig. 9 Contamination risk for the Albufera lagoon is visible through the many tributaries from the residential and industrial areas that enter the lagoon. Locations of the field visit are marked with a red box. (Source: Background map is from the Open Street Map contributors)

approach is called for, thinking of multiple actors, all-hazards, or even a whole-of-society approach [83, 84]. This means that not only existing waste managers need to be integrated into training programmes to change their techniques and management habits to more modern or circular approaches. Of course, they need to be trained, but other stakeholders must also be trained to support this and ultimately make it work. Now, what certain experts could already do with such techniques, resources, and knowledge is not supported by local authorities or has no basis in regulations, and it is also not known or welcomed by customers or citizens. Therefore, local and regional authorities also need training and more knowledge, resources, and regulations. Also, the people and customers of waste need a basic understanding of the techniques and the benefits of better waste management. A wide range of educational measures is therefore required. They must address all these groups individually and in a standard scheme to integrate the needs and requirements of the stakeholders and their ways of thinking. Without this integration, there will be no leverage effect without mutual understanding. As an example of transfer work between science policy and the public, taken from current research, there are so-called climate adaptation managers in Germany. These are employed by local authorities to promote the introduction of climate change adaptation techniques in the community and work together with various departments in the city, as well as with companies and people in the communities. However, training such individual multipliers is not enough, as we know from the German study [85]. Such multipliers are 'lone wolves' who often lack support for their newly created department and positions from the more established and recognised departments. It is therefore vital not only to introduce their positions but also to create an environment and ecosystem of support within

the municipality and a connection with the local waste management companies, such as disaster and emergency management, as in the project case in Germany.

To create a plan for multi-stakeholder, multi-level, and multi-sector cooperation, it is first important to develop schemes that help to understand the interrelationships in governance.

We suggest that it is advisable to overcome silo thinking, both politically and in terms of reorganising thematic areas. Emergency and disaster management need to be better integrated. These, in turn, need to be better integrated with urban planning and flood management. Waste management, in turn, must be better integrated across sectors with water management and agriculture. Tourism should also be integrated into this picture, as should education and governance (Fig. 10).

As we know from projects in Germany, it is difficult to bridge such silos even in the day-to-day work of local authorities. It is therefore not surprising that it is often not known how to do this and that even interdisciplinary clusters such as the Clean Waste Cluster have yet to recognise needs and opportunities arising from collaboration with, for example, water management. If waste management cannot be improved on its own, perhaps it could be in conjunction with tourism, agriculture, and industry, as key drivers of economic development in the region. Jointly, they could finally create an awareness of how important it is to think this "circular" and more sustainable (Fig. 11). The Circular economy knows conceptual integrations of the whole process from raw material to recycling in waste management [86, 87]. Similar depictions are used in disaster management contexts to introduce new topics or agilely deal with unexpected stressors, such as extreme events or climate change adaptation into everyday processes, known as "planning P" processes [88].

Figure 11 shows that flood waste modifies the usual circular waste management process. It brings new loads of waste that often overwhelm local waste collection and recycling. Flood waste includes vegetation and soil washed away, damage from buildings, interiors, cars, and fluids such as oil, chemicals, and sewage. In addition, additional

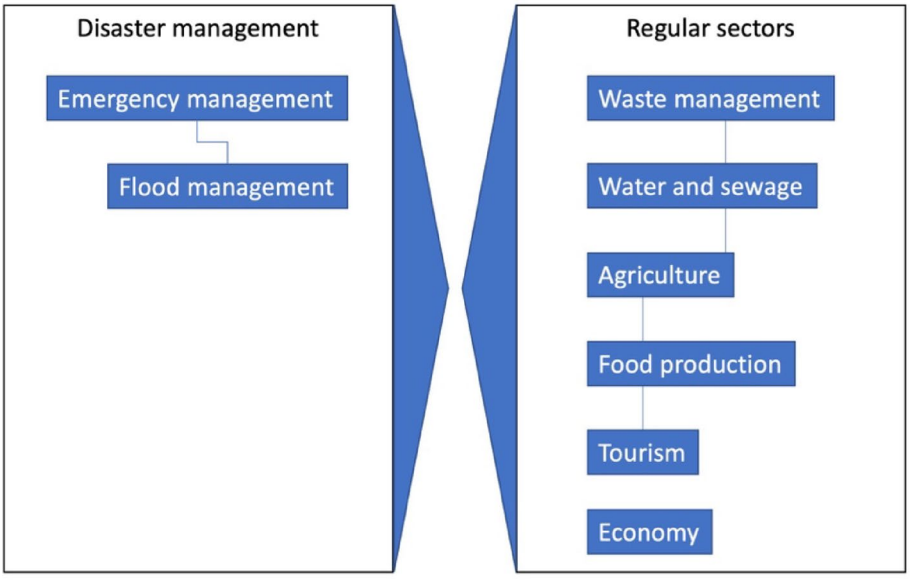


Fig. 10 Cross-sectoral areas of cooperation as an opportunity to promote holistic and systemic thinking and approaches

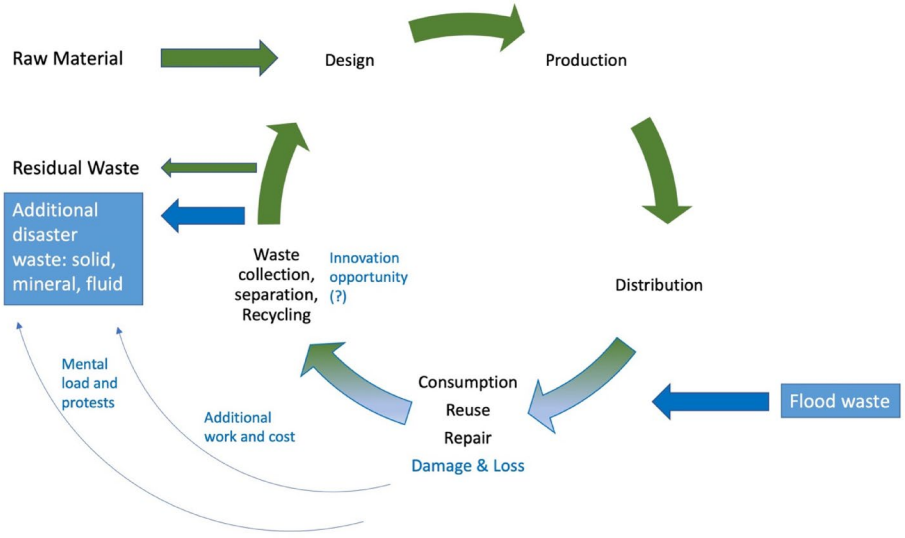


Fig. 11 Integration of the flood impact on disaster waste production into circular economy waste management

loads or feedback loops emerge, such as extra work and costs for the professional waste management industry, affected people, businesses, and authorities. It also adds another repercussion cycle of psychological stress, dealing with losses and damages while busying with waste such as cars as visual reminders of the disaster over months after the event, problems with lost vehicles, and the process behind this fuels anger and protests. The disaster could also be an opportunity to introduce new recycling processes into a waste management system that traditionally relies on landfills. However, these innovation processes can also get stalled due to multiple additional loads and overlaps with other processes of high relevance, such as cleaning and reconstruction.

4 Discussion

4.1 Urban flood management, the dyke effect and the double-edged sword of protection

The floods in Valencia are important for international attention because of the existing urban flood defences. After the 1957 floods, Valencia introduced an extensive urban flood defence system by constructing an artificial flood channel and diverting the main river directly around the city to the south [65]. This meant that the central part of the city was protected during the floods of 2024. However, following the canal's creation, urban development and the growth of small villages into large towns [89] created exposure conditions for residents who were flooded in the 2024 flood. In addition, many lives were lost due to the Spanish construction of many underground car parks. The high number of damaged vehicles not only occurs there but also symbolises this potential threat to future populations.

In a sense, this is a large-scale example of what is known as the levee effect, developed after studies in the USA, finding that more flood protection paradoxically increases flood risk [90, 91]. A feeling of security can arise after the well-intentioned construction of an urban defence measure in the form of dams, drainage channels, or similar. Growing neighbourhoods need constant flood management and protection plans updated according to the urban development. The many drainage channels that crisscross the area have caused most flood damage in the southern parts. Like wadis [20], they are mostly inconspicuous for lay people, since they run dry, exacerbating the runoff effect

problem. People are unaware of the potential risk of flooding, and in many countries, these riverbeds are even used for daily transport. An additional problem is that it is a low-lying area, and people in such wadis or irrigation canals are unaware of flooding because it often does not even rain in their area when the flood comes. The flood waters come from nearby or distant mountainous regions at high speed without any natural warning signs. For Valencia, this could mean that urban planning needs to extend a protection system, such as the Turia river channel, and create a costly measure for the southern and other growing areas. It is crucial to consider the areas not affected last time, as they may be more surprised next time. The "next valley problem" is similar to the "not in my backyard" problem [92] and applies to many areas around the world that have been affected before.

On the other hand, other urban planning measures, such as permits for underground car parks, must also be considered overall. The positive examples of supermarkets or furniture shops that sell their goods on mezzanine floors and have ground-level parking spaces could be an option. However, this must be accompanied by a good and reliable warning system so people do not get stuck in their cars.

This study example strikes at least two aspects. The first is that Valencia has a unique protection system: a large river completely diverted around it. This protection divides the city into a protected central part that is not affected by floods and a southern part that has over 200 fatalities.

The second oddity is the waste and recycling system. From an outsider's perspective, as a tourist in the city centre and the southern parts, waste separation and collection are visible. There are many online sources for Valencia City to engage actively in waste recycling activities, including using modern AI technologies. Valencia was the "green city" in 2023, or "the greenest city in Europe", a program and campaign to boost its image towards more sustainable and green thinking and urban environment, based on its usage of AI, renaturation, sustainable mobility, emission reduction, wetlands, innovative recycling, noise reduction, water management, and coastal wave energy generation [93]. Valencia is therefore not different from cities like Berlin in Germany, with similar visible signs of waste recycling and online and media campaigns. Both examples teach a lesson about a highly developed city, including visible signs and existing activities. However, severe gaps in complete implementation chains and mentality exist in certain urban environments or situations, such as in the aftermath of flood disasters. Lessons learned studies are just emerging in this field, for example, guidelines written about flood recovery and waste management after the floods in 2021 in Germany [94]. Waste managers in Valencia have learned other lessons, and joint findings and calls pointing at specific gaps have been promoted and published [37]. These lessons include better recognizing flood waste management relevance, awareness, personnel training, and scientific monitoring and evaluation. It also includes damage documentation, self-help guidelines for affected people, and recognition of similarities in risk governance systems between countries with federal structures.

In this scenario, DWM requires a specific kind of innovation, apart from technological innovation. After natural disasters, waste management demands innovation in defining processes, procedures, regulations, and management of decentralized yet well-planned decision-making. Thus, the most influential innovation currently addressing DWM is a management and organizational innovation, based on a new process definition, to

be resilient and agile under sustainability and the circular economy precepts. According to the results of [95], the most significant barrier to be addressed to improve DWM is the legal one. In Valencia, there are more than 95 different regulations, including national, regional, and local, when dealing with a natural disaster, making it challenging to implement. Thus, the required innovation involves resolving first the legal framework to simplify it and make it operational from the outset. Next, innovative actions would be focused on design procedures and processes to improve DWM in each phase, into which crisis management is divided: mitigation, preparedness, response, and recovery. It has been proven that being proactive and having a DWM plan favorably impacts the effectiveness of recovery processes, leading to significantly reduced costs [23]. Drawing this DWM framework in which it is defined who does what, when, in coordination with whom, and how requires a lot of organizational and management innovation, as polymakers and managers have to face a multi-level, multi-agent, multi-sector, and multi-expert systemic problem. Management innovation is imperative in Valencia and many other countries because the topic is much broader and prevalent. As the literature used here shows, waste management problems follow disasters in flood situations in Italy, the USA, South Korea, or after the tsunami in Japan. It indeed can be found in many other events in other countries. Therefore, this topic is an essential problem worldwide that needs to be urgently addressed.

4.2 Solidarity and protest

The affected people showed a great sense of solidarity and an innovative character. They have set up cleaning and neighbourhood help schemes or school programmes with local universities (oral com, TM), [14]. Efficient solutions to the problem of car wrecks are also being created, such as online apps. Still, many signs hanging in the windows of working cars indicate that they should not be accidentally taken for towing. So, the capacity and activity for innovation are powerful in the area, and the local citizens' initiatives were also engaged during the field trip. They could be an important lever to initiate long-term improvement measures after the end of the main restoration efforts. Better waste management could be an area that should, at best, be linked to other tasks related to flood preparedness or multi-hazard readiness and preparedness. For example, the region has droughts, wildfires and coastal hazards, which all need to be considered.

A major problem that has already been identified in many media reports and during the field trip is the high level of protest and pressure created due to the failed measures. The failure to provide adequate warnings and accept foreign aid continues to affect the regional authorities' cooperation and acceptance of responsibility. In the case of Germany, it was similar, as the court cases and hearings have reduced the availability of those responsible to the authorities and increased their reluctance to share findings openly. Sharing flood damage data and other data for scientists was also minimal due to the ongoing legal proceedings, which dragged on for two years. Only a few severely affected cities with no fatalities were slightly more open to sharing data or taking responsibility from the public. However, this was also due to several other factors, such as personal courage or political attitudes in Germany. It is, therefore, not surprising that this exists in a similar way in Spain. We have experienced ourselves that it was not possible to meet with the local authorities. The unwillingness to speak out in media interviews, to take responsibility for innovation in waste management, or to take any other form of

visible action that could go wrong in disaster relief are the main problems that still exist in Valencia two months after the flood. This hesitation is probably even greater due to the political protests in the autonomous region of Valencia, and perhaps in Spain, compared to countries such as Germany. Hundreds of thousands protested in Valencia after the floods, and the continued accusations and pressure on the regional and national government are striking and different from other events and countries where public protest does not have this scale or publicity. This fact has been channelled in orderly and regulatory forms, such as court hearings or inquiry commissions in Germany. In Valencia, we also saw a lot of graffiti and protest posters in the tourist city centre, cursing local and national government representatives. It is a city with protests, posters, and graffiti due to the gentrification problem and rising housing prices. So, even before the flood, civil society had a lot of tension, not only because of the political parties but also because of the conversion of shops and flats in the city centre into tourist accommodation.

In comparison, before the floods, there were no such protests and public unrest at that scale in the larger affected regions in Germany, such as the Ahr Valley. Therefore, it is a sensitive issue that will also contribute to the recovery after the floods in Valencia. In this situation, it seems more challenging to introduce improvements in emergency and disaster management, flood management, and waste management.

It is essential to calm the heated public unrest, dissatisfaction, and blame. Suppose this continues to drive decision-makers to hide or maintain the status quo, linear thinking, and simple pre-existing practices. In that case, it will prevent any improvement for the next flood event. It is an important and unpleasant message in any case, but especially here, similar flooding can happen in Valencia every year. It is unnecessary to attribute it to climate change; the cold drop had already occurred in the same area in 1957 and more recently, although not as severely. There is not a lack of general expertise, but a lack of public awareness in the sense of recognising that this is a difficult task for society as a whole and across sectors. An everyday basis must be created for this task that allows for such innovations and measures, which often do not immediately lead to economic improvements. But sticking with the status quo is recreating the same situation exposed to before the floods. International bodies like the United Nations call for "building back better" [96], but this rarely happens. Be it after the tsunami in the Indian Ocean, Germany after the floods, or elsewhere. Buffer zones on the coast affected by the 2004 tsunami were problematic or later retracted [97]. In Germany, almost all houses have been rebuilt in the same place, and many more are built in flood zones yearly.

After decades of work, researchers have devised a seminal document about the disaster they coined: "Knowing better, but losing more" [91]. So, it is not enough to pass on knowledge and educate people; it must also be recognised as a question of coordination and hidden societal struggles over values [98]. Therefore, realizing that all this is ultimately linked to political parties and social unrest is necessary. It takes courageous individuals and groups who dare to make unpopular and novel attempts. During the field trip, we saw that such courageous individuals, even when affected or criticised, set up voluntary groups of various kinds or even expert networks in the private sector and took matters into their own hands that usually are the task of scientists, non-governmental organisations, or other institutions. Therefore, the flood story in Valencia is a story of both despair and hope. Things have stalled and reverted to their previous state, and there seems to be no flood or waste management improvement. However, some individuals

and groups of experts are already driving innovation in this area. Perhaps blueprints can be created in this or other areas to help other regions affected by flooding, pollution, or other hazards.

5 Conclusions

The most important results of the damage documentation show that the affected areas are recovering two months after the floods in Valencia. Some of the damage is still visible, some invisible. Persistent problems are often hidden, but vehicle wrecks are an essential issue. This is an example of the intertwining of mobility, waste management, and satisfaction with clean-up and management in the sense of a more sustainable and holistic perspective. Public protest and dissatisfaction hinder the region's improvements, actions, and dialogue. Scientific moderation can generate communication through science-policy-citizen dialogue and educational explanatory material in circular impact chains and narratives. A better systematic understanding between the wastewater, agriculture, and flood management sectors can be a starting point.

Entrepreneurs and those affected can drive innovation in post-disaster recovery. A general realisation of the reconstruction mission is that communication and networking in the affected province still need to be expanded. This applies to the media discussion between the government and administrative structures. Establishing further networks, e.g., in the private sector, is also necessary. While experts in the circular economy, for example, are involved in a network, they still need to approach companies and authorities in neighbouring areas, such as water management, and join forces with them. This is because linking waste and water management could be an important lever in convincing the public and authorities of the risks of depositing hazardous substances in landfills. Landfill sites are utilised because they are relatively cheap, and the issue of waste is currently not on the agenda of the economy or in the minds of administrators and politicians. However, after the immediate damage and effects of the floods, contaminated groundwater and drinking water would pose a longer-term health risk in the region. Clarifying this link through cross-sectoral cooperation between waste and water management could be a significant improvement in the region, not only for post-flood consequence management but also for an overall improvement in health risks through better waste management and environmental monitoring. It is also important to expand the networks between the private sector and the scientific community, as much of this is already known and documented by scientists in the region. For example, there is a cluster for such research at local universities. Then, the authorities also need to be better involved and work with the scientific community and the private sector, which also has a lot of expertise in this area.

It is helpful to consider the benefits of external experts from other countries in the recovery process. A key benefit of external experts is the knowledge exchange at similar events, and they are often an incentive and an opportunity for local experts from different fields and disciplines to meet and exchange ideas. Disaster and flood management liability is a sensitive topic that makes it difficult to propose solutions from the outside. This is because the external experts are not from the region, and it could also be questionable why other countries and experts are proposing something based solely on their own experience. However, it is also often the case that external experts are used to justify the plans and actions of local authorities. This can be problematic when the justification

is shifted to external experts, who are blamed for interfering in regional affairs. However, engaging more in knowledge transfer and sharing to drive change is also always important, especially in areas stuck in development or discussion.

Another study limitation is that the methodology relies on individuals and key persons, even in focus group discussions. This could lead to other sources and opinions being underrepresented, which could be the opposite of a confirmation bias. For example, many car owners may have no problem determining their costs or receiving compensation from the insurance company. But the concerned citizens we met at the dump may be the ones who were not satisfied. So, the situation, the places concerned, and the motivations must also be questioned. Therefore, this methodology can only give an impression of the situation and help to develop possible impact chains. Such an impact chain blueprint can help identify and analyse problems. Of course, it is also helpful to document impressions, but a generalised, step-by-step impact chain can help identify gaps and analyse them with additional information, data, and methods.

In conclusion, transferring knowledge between different disciplines and countries is important. Even if disasters are negative experiences that continue to occur, knowledge transfer is an important lever for understanding, recovering from, and identifying the reasons for a standstill and for driving sustainable improvements.

Some recommendations are that it is a common problem and that disasters, floods, waste, and food security need to be better understood in their interconnections, and we think, locally, cross-sectoral, but also within their global interconnections. Also, flood transport is limited in research regarding urban solid waste compared to other contamination studies, as is the uncontrolled presence of waste from disasters in ecosystems. Within disaster risk management, calling for prevention and preparedness is already problematic, but in the aftermath of the Valencia floods, we find that the recovery phase faces equal challenges.

Some areas seem to be easier to improve than others. From an outsider's perspective, the flood in Valencia could be a window of opportunity for implementing innovations in waste processing. Knowledge, companies, and resources exist in the region to introduce recycling and circular thinking. There is also extensive scientific knowledge and a resource background in the area. The main problem seems to be overcoming established structures and economic and political interests. Financial benefits and political benefits could be shown when introducing such new technologies to create more revenue for the people already employed, while also adding revenue for all residents or visitors. Tourism could especially be a key lever in fostering the avoidance of toxic waste and contamination problems. International food markets selling oranges to Europe, for example, could also help to safeguard such impact chain awareness and improvements.

It is more challenging to deal with public protests and criticism of the disaster managers and authorities. Embarking on learning from the disaster and directly channelling this into recycling innovations, and more sustainable general economic production could show a way here. Because, in the long term, economic prosperity and rehabilitation are key. Citizens' involvement already works very well, since volunteer groups are still active in the region, more than six months after the disaster in Valencia. While they still exist due to deficiencies in rebuilding after disaster, they are ready to engage and participate. The problem now is increasingly the lack of visibility of problems. While the streets are cleaned and the houses renovated from the outside, in some affected quarters,

citizens still live from self-organised distribution of goods, and some shops have not yet opened. There are also media reports that citizens are waiting for renovation efforts.

Recommendations can be drawn from similar cases of the German floods in 2021, when, more than three years after the floods, citizens still face similar problems of rebuilding, struggling with insurance, recompensation by the state, bureaucracy, frustration, and prolonged psychological trauma. One key recommendation also provided on-site at the workshops was not to underestimate the long-term recovery duration. Someone coined the term "marathon" to think about rather than short-term recovery within a couple of months.

Another recommendation is how to provide the best leverage to motorize actions. Especially in the heated public protests in Valencia and other cases, we found that disaster management authorities and waste management get stalled due to fears of wrongdoing and public exposure. One lever often heard is the expectation that expertise from outside could point out how to improve things. For example, European regulations would have provided a mandate before the disaster to implement necessary management improvements in many areas, including recycling, disaster, and crisis management. Based on our experience, it is not helpful or can even appear intrusive when experts from other countries or outside call out for improvements and put forward claims of wrongdoing. It is much better when people who are willing to take action and improve things locally are fostered and encouraged with the help of external expertise to build up and drive the recovery themselves. And we also recommend leaving or giving them a voice in documenting wrongdoings, limitations, and gaps. It is also necessary to document this in different formats and languages for audiences suited to the needs of affected people and those in command. In addition, it is undoubtedly essential to have scientifically guided documentation of the damages caused by those actions. Because science can help to distribute such lessons learned internationally, and also find links between sectors and actors that often do not have an opportunity or occasion. Authorities and companies usually must talk to other persons or institutions outside the usual communication chains. Impact chains are, therefore, also highly connected to communication chains.

Future research should examine the different recovery phases and conduct continuous, long-term monitoring and repeated studies. Situations, needs, and empirical data can be retrieved immediately after the disaster, but we also document and find that capturing them after some months is very important. And then again, after some months at least, because the needs change, but certain documentation cannot be made after cars have been removed or all the debris has been cleaned, for example. Future research should also look into flood waste management and identify the interconnections to food security, tourism, and local living conditions. We also think it is important to re-analyse flood protection measures, especially in cities that have made great efforts to redirect the river canals. While those measures help save historic city centres, the high population pressure and urban growth in the past decades after establishing such protection schemes must be observed. And finally, it is necessary to better convince disaster risk management and public authorities of the value of scientific research and the role of moderation and transfer to enable them to find better levers for their actions.

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Data availability
Data available on request from the authors. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The study follows the COPE guidelines. Ethical issues regarding plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been observed by the authors. All participants in this research provided informed consent for using the data collected. They were thoroughly briefed on the study's purpose, the procedures for ensuring anonymity, and the methods for data processing. Participants were also informed of the researcher's obligation to maintain confidentiality, adhering to international ethical standards and the ethical guidelines of the European Commission [50]. Furthermore, the study received approval from the Ethics Committee of CREA (Community of Researchers on Excellence for All), under approval code [20241207]. European Commission. Directorate-General for Research and Innovation. (2013). Ethics for researchers: Facilitating research excellence in FP7. Publications Office. https://data.europa.eu/doi/10.2777/7491. Informed consent was obtained from all individual participants included in the study. All authors and contributors consent to this publication.

Consent for publication
The participant has consented to the submission of the case report to the journal. All authors consent to this publication. Additional informed consent was obtained from all individual participants for whom identifying information is included in this article.

Competing interests
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