Directed Project

A Comparative Case Study of Two Extreme Floods: Rhine - Erft July 2021 & Emilia - Romagna May 2023

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Report Overview

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Executive Summary

Figure 1: Emilia Romagna Flood, Source: Regione Emilia Romagna, May 2023.

This report, A Comparative Case Study of Two Extreme Floods: Rhine - Erft July 2021 and Emilia - Romagna May 2023, was developed within the EU Horizon Europe project DIRECTED. It compares two of Europe's most devastating recent floods in order to extract lessons on preparedness, emergency management, recovery, and resilience. Drawing upon openly available data, academic research, and the unique insights of DIRECTED's Real World Labs (RWLs) in Emilia - Romagna and Rhine - Erft, the study provides an impartial, locally grounded perspective designed to inform policy, practice, and training across Europe.

Key Findings

- Meteorological Extremes: Both floods were triggered by exceptional rainfall. Emilia Romagna received six months' precipitation in 36 hours, while Rhine - Erft was overwhelmed by record - breaking totals of more than 200 mm in a single day. Antecedent conditions - drought in Italy and saturated soils in Germany amplified the impacts.
- Human and Economic Losses: The Emilia - Romagna floods caused 17 deaths, displaced over 36,000 people, and generated damage estimated at €8.8 - 9 billion. The Rhine - Erft disaster, part of Germany's wider 2021 floods, led to 189 fatalities nationally (11 in Rhine Erft alone), billions in insured losses, and catastrophic local destruction, including landslides and sinkholes in Erftstadt.
- Emergency Response and Governance: Italy's centralized civil protection enabled coordinated early warnings, structured evacuations, and clear inter - agency protocols. Germany's federal system revealed weaknesses in coordination, communication, and decision - making between municipal, regional, and national levels, contributing to delays in protective action.
- Volunteer Management and Social Response: In both regions, thousands of volunteers mobilised spontaneously to support evacuations, debris removal, and humanitarian aid. While this community solidarity was critical, it also exposed coordination challenges, safety risks, and the need for better integration of volunteer groups into official response systems.
- Public Preparedness and Drills: Neither region had routine, large - scale public flood drills in place. This contributed to confusion in evacuation processes, especially in Germany. The absence of rehearsed, community - wide preparedness measures limited the effectiveness of warnings and delayed protective actions.
- Data and Technology: Both regions deployed hydrological models, satellite imagery, and GIS platforms. However, interoperability gaps and limited integration of socio - economic and vulnerability data hampered timely, targeted interventions. Real - time information on agriculture, vulnerable groups, and structural damage was particularly lacking.
- Communication and Public Information: Digital platforms and social media supported public

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alerts and situational awareness, but dependence on infrastructure created vulnerabilities. Emilia - Romagna benefitted from a multi - tiered communication framework, while Germany's fragmented system undermined clarity during the crisis.

- Recovery and Financial Mechanisms: Both regions faced protracted recovery. Italy mobilised national and European Solidarity Funds rapidly, while in Germany insurance payouts covered billions but left many households under - or uninsured. These experiences underline the need for comprehensive financial preparedness mechanisms.

Lessons Learned and Recommendations

- Strengthen Early Warning Systems: Expand hydrological sensor networks, integrate soil - moisture and socio - economic data, and ensure information reaches at - risk groups.
- Embed Vulnerability Mapping: Incorporate demographic and social data into evacuation and recovery planning to protect the most exposed communities.
- Enhance Communication Protocols: Establish clearer inter - agency and cross - sector protocols to reduce fragmentation and build public trust.
- Invest in Climate - Adapted Infrastructure: Upgrade defences, integrate nature - based solutions, and improve land - use planning based on updated hazard maps.
- Address Compound Hazards: Plan for cascading risks such as landslides, sediment transport, and flood waste.
- Integrate Volunteer Management: Develop frameworks to harness community solidarity while ensuring volunteer safety, coordination, and alignment with official emergency services.
- Promote Public Drills and Preparedness: Establish community - wide flood drills and preparedness campaigns to strengthen public awareness and capacity for action during emergencies.
- Leverage Real World Labs: Use local engagement and co - production to ground resilience strategies in operational reality.

Conclusion

The floods in Rhine - Erft and Emilia - Romagna reveal the destructive power of climate - driven extremes and the urgency of preparing for compound, cascading hazards. They also illustrate the contrast between centralized and federal governance systems: Italy benefitted from coordinated protection structures, while Germany highlighted the risks of fragmented authority. Both events exposed critical gaps in communication, data integration, financial recovery, volunteer management, and public preparedness.

By situating these local experiences within a European framework, this case study offers practical lessons for policymakers, emergency managers, and adaptation professionals. It also provides a training resource for practitioners, helping them learn from other regions' experiences. Above all, the findings reinforce the need for Europe - wide investment in early warning, interoperable data systems, resilient infrastructure, inclusive governance, structured volunteer engagement, and regular public drills to meet the accelerating challenges of climate change.

Figure 2: Damage Asessment - Source: Regione Emilia Romagna, May 2023

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Abbreviations

ACRONYM	DEFINITION
CCA	CLIMATE CHANGE ADAPTATION
DMP	DATA MANAGEMENT PLAN
DRM	DISASTER RISK MANAGEMENT
DRR	DISASTER RISK REDUCTION
FAIR	FINDABLE, ACCESSIBLE, INTEROPERABLE AND REUSABLE
RWL	REAL WORLD LAB
WP	WORK PACKAGE

1.0 Introduction

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Figure 3: Emilia Romagna Flood, Source: Regione Emilia Romagna, May 2023.

The extreme floods that affected the Rhine - Erft Region (Germany) in July 2021 and the Emilia - Romagna region (Italy) in May 2023 caused loss of life and major damage to people's homes, businesses, assets and the surrounding environment. As with many disasters, the world watched when the peak of the flood and its damages occurred, watching first responders hard at work dealing with the event and then the aftermath, hearing the tears of people as their lives and livelihoods were destroyed. We often see the bravery of first responders, public services and volunteers who work as a team to help those impacted and later start the clean - up and recovery work immediately after the event. The world then moves on to the next event, with little learned by broader society, both at home and even less so, internationally, about the true timeline of events, the underlying causes, the scale of damage that occurred, the impact on people's lives, health and housing in the aftermath, the recovery or the effectiveness of the preparation and management of the disasters. The world forgets quickly, and the cycle repeats itself somewhere else, again and again.

In this comparative case study, we seek to stop and look backwards, to gather information to understand, compare the preparation, management and post - disaster learnings of these two major floods in Europe. This case study is produced as a broad scoping report that brings together available information and draws out learnings and potential areas of future, more formal research, as well as practical considerations and actions in the aftermath of both events. Looking at the events comparatively also allows us to ascertain common issues that should be tackled in disaster planning in the future at local level but also as practical considerations at European scale.

The Emilia - Romagna floods in 2023 and the floods affecting the Rhine - Erft region in 2021 provide valuable insights into the growing threat of climate - driven extreme weather events. Both floods were caused by intense rainfall that overwhelmed local river systems, sadly leading to loss of life, significant damage to infrastructure, agriculture, communities and habitats.

Comparing these events reveals the vulnerability of different regions to similar natural disasters, highlighting the need for effective flood management and climate adaptation strategies. Key areas of comparison include the socio - economic impacts, such as displacement, financial losses, and disruptions to public services and infrastructure, as responses from local governments in terms of emergency management and recovery efforts, as well as communications between actors and the general public both during and after the event.

Furthermore, these floods offer an opportunity to evaluate long - term resilience and adaptation strategies. By studying the differences in flood prevention measures, recovery processes, and policy responses, the comparison can inform future disaster preparedness and climate action. The two cases underscore the urgency of investing in flood mitigation, improving infrastructure resilience, and developing comprehensive emergency plans to address the increasing frequency of extreme weather events. This case study can provide valuable lessons for policymakers, disaster risk manager and responders and communities facing similar risks in the future.

1.1 Methodology

In our analysis of the two events, it has been discovered during the desk - top research of this report, that most academic materials that examine the two extreme events focus on large - scale, regional analysis of the events. Therefore, this report takes advantage of two local, Real World Labs (RWL) in the Rhine - Erft area and the Emilia - Romagna region from the EU Horizon Europe, DIRECTED Project, https://directedproject.eu/ to focus on local level impacts and learnings, thus making the situational analysis more focused on local disaster risk managers and planners, emergency services and disaster impact volunteers. However, at times where information is not as available locally, we have often used broader level information.

As such the case studies can also be used as training materials for disaster management, risk reduction and climate adaptation planning professionals in that viewing the processes in other localities and their variations, will help localities to think more deeply about their own processes and how they may be able to improve them. We will also consider the interoperability of the processes and tools used in the different events within the chapters below to evaluate how well salient information was transferred in and between organisations and whether and how that could be improved. For example: how were the flood risk projections transferred between different organisations, who needed the information, and did everyone get access to the information they required?

We draw upon information of two, not perfectly matched, case studies as one is based on the Emilia - Romagna Region - being informed from the Real World Lab Partners that is led by the Territorial Safety and Civil Protection Agency of the Emilia - Romagna Region (ARSTPC - ER) together with the ARPAE Hydrometeo Service Civil Protection Functional Centre who are responsible for Disaster Risk Reduction (DRR) related to climate risks whereas Rhine - Erft Real World Lab is led by the Erftverband in Bergheim, which is an organization under public law that manages water supply, flood protection, water quality improvement, and wastewater

The Erftverband also manages a network of water quality monitoring stations and collaborates on research projects. Therefore, these entities are not directly comparable, which is a limitation in this case study, however we have attempted to treat the case studies in an equal manner as far as possible given this limitation, again drawing information from many sources, including the academic record and local, regional and governmental records. We wish to sincerely thank these two lead entities for their co - operation. We also need to clearly state that some of the views in this report are made through an impartial analysis and are not the official views of the cooperating authorities. Nonetheless, we hope this report provides some constructive and impartial findings that they may find useful.

Although the comparative case study may, on occasions, be critical of some practices and processes, it is not intended to be a negative reflection, but more as an honest assessment of possible avenues for improvements involving the local stakeholders themselves in our two case study areas, but also to extend the consideration of other disaster risk managers and planners in other areas and allowing them to apply some of the findings in their local areas to improve planning for disaster response and recovery. This report promotes increased openness on the management processes and impacts of such events but also recognises that on some occasions that some information may be withheld by different agencies at all levels, thus in effect hampering the full understanding of events – having said this it is not at all a given that information has been withheld in these case studies. Nonetheless, we will conduct our analysis using the following approach.

For each section of work, our methodology is as follows:

- Initial utilisation of Chat GPT to pull together known sources of information related to the two extreme events – this information and its sources are then carefully checked and verified.

- Utilisation of locally published and grey literature unlikely to be included in the above
- Utilisation of information provided directly from the partners involved in the DIRECTED Projects – Real World Labs
- Definition of a timeline of what happened
- Situational/ Event analysis – linked to topic areas
- Governance and communications – linked to each event
- Comparative analysis of each section/ event
- Identifying interoperability issues where relevant
- Evaluation and recommendations

In this case study we have used a comprehensive approach to case study development using a range of data sources from online AI (Chat GPT) checked and verified, academic papers and local reports and grey literature. We have also used a timeline approach that helps us both set the scene of how the events unfolded and help us understand how critical information, including modelled information flowed before, during and after the event and what information was missing in the public sphere.

Regarding the extent of the two regions in focus, we largely follow the Real World Lab (RWL) definitions of the Horizon Europe's, DIRECTED Project. In the case of the Emilia - Romagna Region, these are its eastern provinces as shown in the map below. For Rhine - Erft it is situated south - west of Cologne, in the federal state of North Rhine - Westphalia. It consists of the Rhine - Erft district and the north - eastern part of the adjoining Euskirchen district that belongs to the River Erft catchment – (see the map in Figure 6, Section 2.2).

We have focused on the flood in the River Erft and some of its tributaries. However, due to information in this specific area being limited, we will often (where relevant) broaden our analysis to surrounding regions. The July 2021 event in Germany extended over larger regions in the west and east of Germany, notably the Ahr valley in Rhineland - Palatinate, which are not covered primarily in this document.

Limitations of this Report include:

- The case studies are not directly equal due to the nature of the Real World Lab lead partners and this should be considered when reading the document.
- The case study draws on published literature and information, as well as contextual information at local level – therefore there may be important information held by other government and local agencies that could impact and improve the results of this report – indeed we hope that this case study encourages greater and open information sharing in the future
- Some of the results have not been scientifically verified by detailed academic research, nonetheless we have reported what is considered correct at local level.

Case Study

2.0 Case Study Area Information Summary

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2.1 Emilia - Romagna Flood Event Fact Sheet

Emilia - Romagna is a region located in the northeastern part of Italy, bordered by Lombardy to the north, Veneto to the northeast, Tuscany to the south, Marche to the southeast, and Liguria to the west. The region stretches from the Po River in the north to the Apennine Mountains in the south. Its diverse geography includes flat plains in the north, which are part of the fertile Po Valley, and rolling hills and mountainous terrain to the south. The coastline along the Adriatic Sea forms the eastern boundary of the region, offering a mix of sandy beaches and seaside resorts.

The floods in Emilia - Romagna in May 2023 were among the worst natural disasters in Italy in recent decades. Triggered by intense rainfall that lasted several days, the region experienced devastating flooding, leading to widespread destruction and loss of life. A summary of the key events and impacts can be found below:

Heavy Rainfall: The Emilia - Romagna floods were caused by two heavy rainfall events. Starting on the evening of May 1, 2023 until May 3, 2023, the territory of the Emilia - Romagna was affected by a hydro - meteorological events of exceptional intensity that led to a serious critical situation particularly in the provinces of Forlì - Cesena, Ravenna, Bologna, Modena and Reggio Emilia.

Further extraordinary rainfall occurred as the result of an intense storm on the 16 - 17th May, 2023 that aggravated the situation as the soils became saturated. Starting on May 16, 2023, the region was hit by extraordinary rainfall - some areas saw six months' worth of rain in just 36 hours. This followed an unusually dry spring, which left the ground less able to absorb the rainfall, worsening the flooding.

The Emilia - Romagna coast was also affected by a concomitant intense storm event that slowed the flow of rivers.

Flooding and Landslides: In addition to flooding, the torrential rains triggered thousands of landslides, cutting off roads and isolating entire communities.

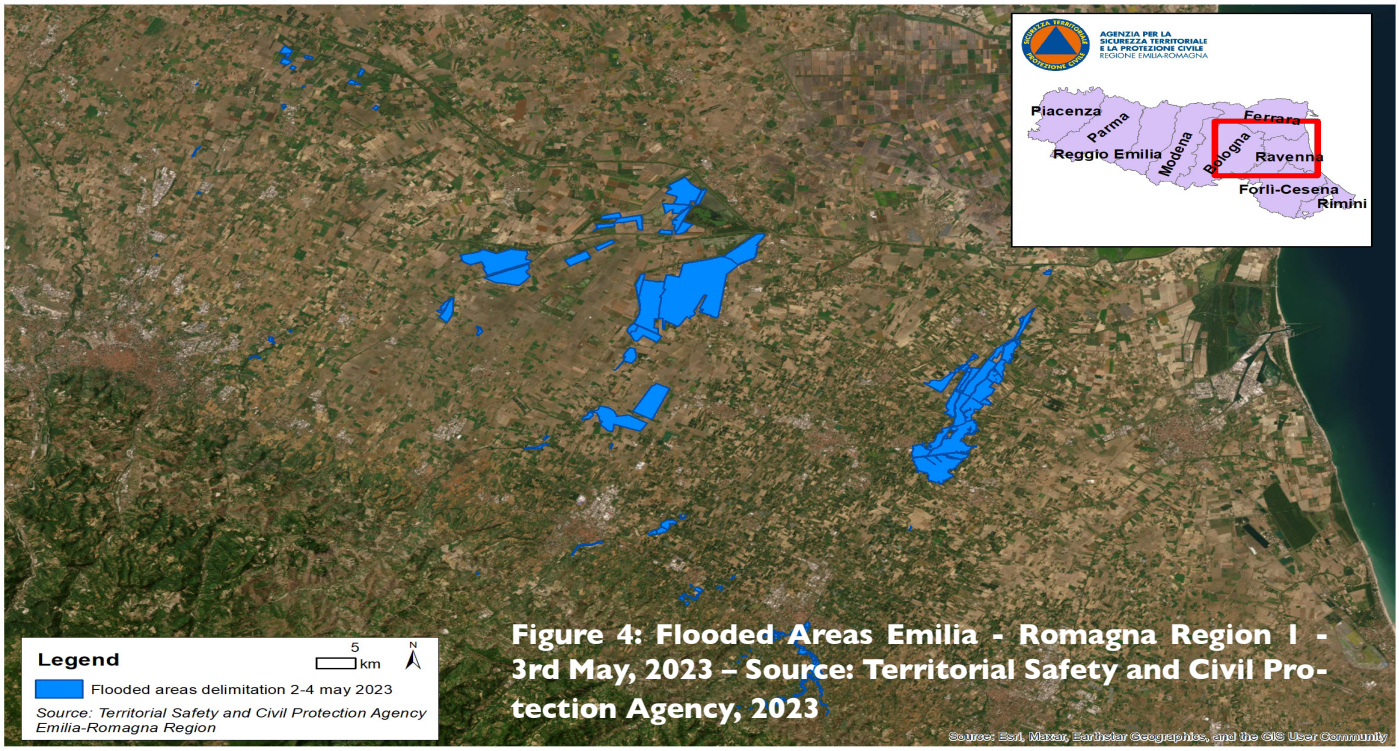

Figure 4: Flooded Areas Emilia - Romagna Region 1 - 3rd May, 2023 – Source: Territorial Safety and Civil Protection Agency, 2023

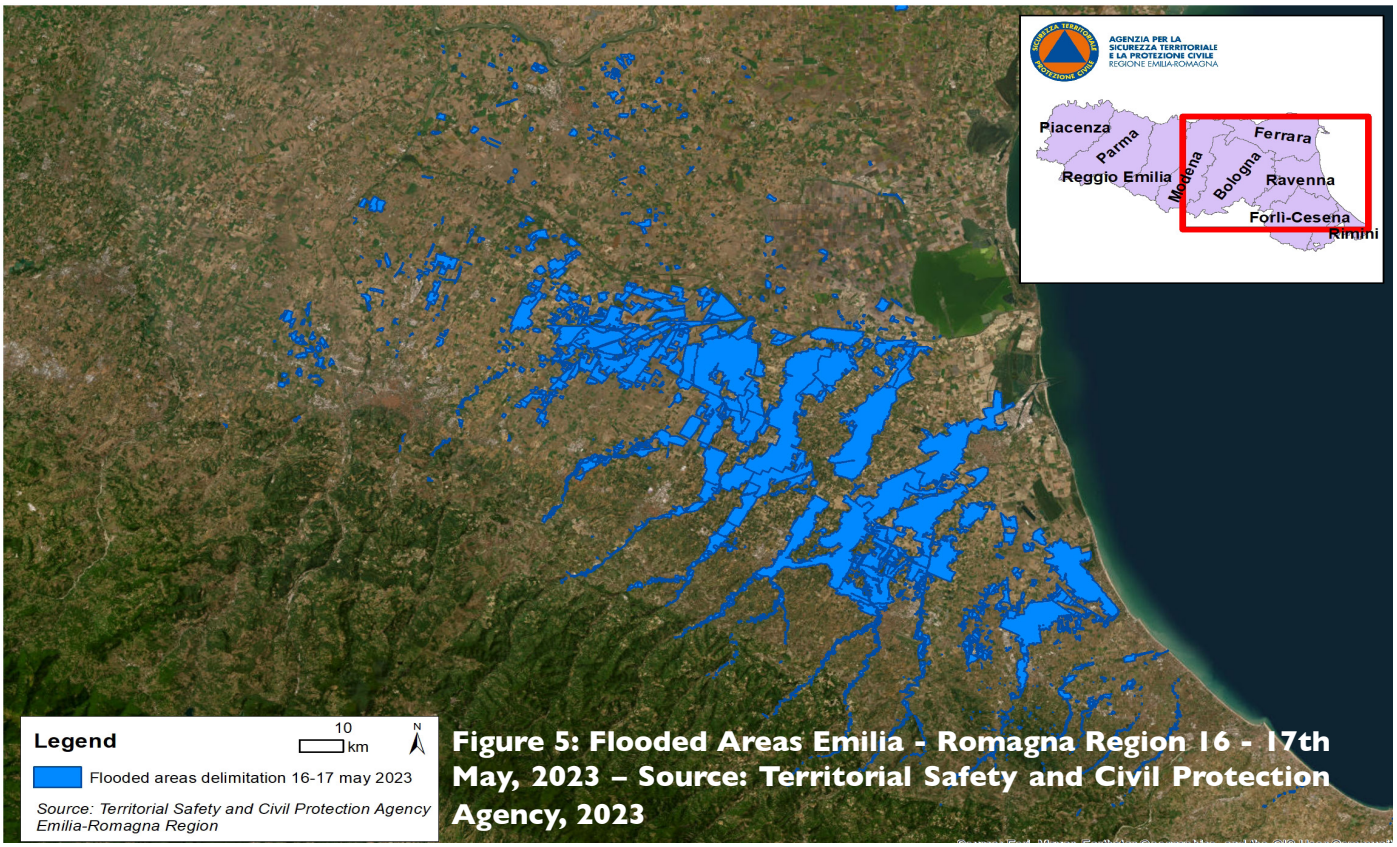

Figure 5: Flooded Areas Emilia - Romagna Region 16 - 17th May, 2023 – Source: Territorial Safety and Civil Protection Agency, 2023

Human and Economic Impact: Death Toll: 17 people lost their lives. Evacuations: Over 36,000 residents were evacuated from their homes. Damage: Thousands of homes, businesses, and farms were submerged or destroyed. Agricultural lands were particularly hard hit, with the fertile farmland of Emilia - Romagna, suffering extensive damage.

Infrastructure and Transport: The 2023 Emilia - Romagna flood disrupted over 600 roads, leading to significant delays in emergency response and supply chain disruptions (Valente et al., 2023) Roads and railways were damaged or blocked by landslides and flooding. Power outages affected many areas, and rescue efforts were hampered by the poor conditions.

Government and Relief Response: The Italian government declared a state of emergency and mobilization of the National Civil Protection Service and allocated around 200 million Euros, for relief and rebuilding efforts. Rescue operations were launched involving the army, emergency services, NGO's and volunteers, but the sheer scale of the disaster made relief efforts difficult. European Solidarity Funds were also mobilized to assist the recovery efforts.

Climate Context: Experts linked the event to the growing impact of climate change. Unusually intense and unpredictable weather patterns, like the combination of drought followed by heavy rainfall, are becoming more frequent, posing challenges for disaster preparedness. The floods of 2023 have indeed had profound and lasting impacts on various regions, both economically and environmentally, prompting calls for enhanced infrastructure and climate adaptation measures. For example, the Emilia - Romagna floods in Italy resulted in initial damage estimates of €8.8 billion, highlighting the region's vulnerability and the need for improved flood defenses (Natural Hazards and Earth System Sciences, 2024).

The most impacted towns Emilia - Romagna Floods (2023):

Faenza: Faenza was one of the hardest - hit towns during the Emilia - Romagna floods. The Lamone River overflowed, inundating streets and homes, leading to widespread evacuations. The town faced significant damage to its buildings and infrastructure, and rescue operations were extensive.

Figure 6: Flooded Roads - Emilia - Romagna Region - Source: Territorial Safety and Civil Protection Agency, 2023

Forlì: Forlì, located near the Montone River, saw major flooding as the river breached its banks. Many homes and businesses were submerged, and several people had to be rescued by boat. The city's infrastructure was heavily impacted, including transportation and power supplies.

Cesena: Cesena experienced severe flooding from the Savio River. The river's rapid rise submerged parts of the city, and residents were evacuated as floodwaters reached homes and streets. Emergency services were deployed to rescue people trapped in flooded areas.

Ravenna: Ravenna, a coastal city, faced significant flooding as rivers and canals overflowed. While parts of the historic city centre were spared, several rural and agricultural areas were badly affected, and rescue operations were conducted across various neighbourhoods.

Lugo: Lugo, situated in the low - lying plains, was also hit hard by the flooding, especially as local rivers overflowed. The agricultural lands around the town were heavily affected, and floodwaters damaged crops, homes, and infrastructure.

Climate Context: Experts linked the event to the growing impact of climate change. Unusually intense and unpredictable weather patterns, like the combination of drought followed by heavy rainfall, are becoming more frequent, posing challenges for disaster preparedness. The floods of 2023 have indeed had profound and lasting impacts on various regions, both economically and environmentally, prompting calls for enhanced infrastructure and climate adaptation measures. For example, the Emilia - Romagna floods in Italy resulted in initial damage estimates of €8.8 billion, highlighting the region's vulnerability and the need for improved flood defenses (Natural Hazards and Earth System Sciences, 2024).

2.2 Rhine - Erft Flood Event Fact Sheet

The Rhine - Erft Region as defined within this case study includes the districts of Euskirchen and Rhein - Erft, composing 21 municipalities in total, which are in the federal state of North Rhine - Westphalia, Germany. The entire area of the Rhine - Erft RWL is part of the ~1.900 km² large Erft river catchment. The Erft rises south of Bad Münstereifel, has a length of about 100 km and flows into the Rhine in Neuss, near Düsseldorf. The Real World Lab is led by the Erftverband in Bergheim.

Figure 7: Extent of Rhine - Erft Real World Lab - next to the city of Cologne, 2021

Germany's 2021 flood disaster revealed critical weaknesses in risk communication and infrastructure resilience (Civil Protection Knowledge Network, 2024). The cascading effects on transportation energy supply, and emergency services have underscored the need for integrated flood risk management strategies (Fekete, 2020).

These floods were part of the larger European floods that affected several countries in mid - July 2021, and among the worst in modern German history. A summary of the key events and impacts is as follows:

Extreme Rainfall and River Overflow:

- In mid - July 2021, a slow - moving low - pressure system brought record - breaking rainfall to parts of western Germany, Belgium, The Netherlands, and other western European countries.
- In the Rhine - Erft district, located in the state of North Rhine - Westphalia, rivers and smaller streams such as the Erft and Swist overflowed after days of heavy rain, leading to severe flash flooding.

Flooding and Landslides:

- Torrential rain caused widespread flooding, particularly in towns like Erftstadt, where a devastating landslide occurred. The floodwaters eroded a gravel pit in Erftstadt - Blessem, causing parts of the town to collapse, swallowing homes, roads, and cars.
- The Erft River burst its banks, submerging streets, houses, and infrastructure.

Human and Economic Impact:

- Casualties: The disaster killed 189 people in Germany overall, with many still missing days after the floods. 11 people lost their lives in Rhine - Erft: 1 in Erftstadt, 2 in Zülpich, 3 in Euskirchen, and 5 in Bad Münstereifel (Thieken et al., 2022b).
- Evacuations: Thousands of residents in the Rhine - Erft district were evacuated from their homes. The landslide in Erftstadt forced a large - scale evacuation due to fears of further collapse.
- Property Damage: Homes, businesses, and infrastructure were severely damaged. The collapse in Erftstadt left entire areas devastated, with parts of buildings and roads disappearing into the ground.

Infrastructure and Transport:

In North Rhine - Westphalia, the July 2021 flood resulted in extensive damage to transportation networks, cutting off entire communities from emergency aid (Thieken et al., 2023). The interdependency of infrastructure systems highlighted the urgent need for resilience planning.

- Roads and bridges were washed away or destroyed, disrupting transport and emergency responses.
- Power outages affected large areas, and communication networks were temporarily cut off in some places.

Government and Relief Response:

- Local authorities, rescue services, and the military were mobilized to aid in evacuations and rescue operations, but the scale of the disaster overwhelmed resources.
- The federal government declared a national emergency and pledged financial aid for the affected regions. Emergency funds were set aside to help the victims rebuild.

Climate Context:

- The floods were a stark reminder of the growing risks associated with climate change. The disaster prompted discussions about the need for better flood management, climate adaptation, and resilient infrastructure.

The floods affecting the Rhine - Erft region, particularly the landslide in Erftstadt, highlighted the destructive power of extreme weather events and emphasized the urgency of preparing for the impacts of climate change:

Erftstadt: This town in North Rhine - Westphalia was one of the worst - hit. A devastating landslide caused by riverbank erosion led to the collapse of several houses and buildings. The flooding from the Erft River resulted in massive infrastructure damage, with roads and bridges washed away. Entire sections of the town were submerged, and the landslide trapped many residents, leading to urgent evacuation and rescue operations.

Bad Münstereifel: Known for its historic town centre, Bad Münstereifel saw extensive damage as the Erft River flooded large parts of the town. The old buildings were severely affected, with streets filled with debris and water. Businesses and homes were destroyed, and it took months for the community to begin recovery efforts.

Weilerswist: Similar to Swisttal, Weilerswist saw major flooding along the Swistbach stream. The local infrastructure, including roads and railways, was heavily damaged, with large areas submerged in water.

2.3 Data Tools Exploited during and after The Event

2.3.1 Emilia - Romagna – Data exploited

During and after the Emilia - Romagna floods of 2023, data and tools played a critical role in flood monitoring, response coordination, damage assessment, and recovery planning. Several technologies, systems, and datasets were used to manage the flood crisis, though certain data gaps highlighted areas for improvement in future disaster responses (European Commission, 2023a),

2.3.2 Early Warning Systems and Real - time Monitoring Tools

Weather Forecasting Models: The Italian Civil Protection Department (DPC) used advanced weather forecasting models, such as those from the European Centre for Medium - Range Weather Forecasts and local meteorological stations, to predict rainfall intensity and potential flood events. These models helped forecast the heavy rainfall that led to the floods, giving authorities early warnings.

Flood Warning System: The Flood Alert System, based on hydrological models, was crucial for monitoring river and stream levels.

The DPC and local authorities utilised real - time data from gauging stations placed along rivers like the Santerno and Bidente to assess water levels and predict when they would exceed critical thresholds.

- Satellite Imagery and Remote Sensing: Remote sensing technologies, including satellite imagery from the European Space Agency (ESA), were used to assess flood extents. Copernicus Sentinel satellites provided detailed flood maps, enabling authorities to track the spatial spread of water and identify the most affected areas (ESA, 2023).

- Geographic Information Systems (GIS): GIS tools were widely used to map flood events, identify flood - prone areas, assess damage zones, and plan evacuation routes. GIS data allowed emergency services to visualise affected areas, coordinating better responses.

- Geospatial Data and Mapping: The platform SaferPlaces was employed by civil protection services during the emergency exploiting its near real - time modeling capabilities, the platform provided actionable flood scenarios including flood extent and water depth to support on - the - ground response, as reported in the national press (SaferPlaces, 2023b).

2.3.4 Post - Event Damage Assessment

- Damage Assessment Tools: Following the flood, authorities relied on drone imagery and aerial surveys to assess structural damage, particularly in isolated towns like Faenza and Cesena. This helped quickly identify damaged infrastructure, including roads, bridges, and buildings (NASA Earth Observatory, 2023).

- Damage Reports and Satellite Data: Satellite imagery from commercial providers like Planet Labs was used to assess property damage, especially for agriculture. This allowed for real - time visualisation of flooded regions, helping both government agencies and humanitarian organisations to plan for immediate relief (European Space Agency, 2023).

- Geospatial Data and Mapping: The platform SaferPlaces has been used with high - resolution imagery from satellites such as Sentinel - 1 and COSMO - SkyMed, in combination with local municipal and civil protection data, to generate detailed flood - depth maps for affected towns (European Space Agency, 2023).

2.3.5 Disaster Relief Coordination Tools

- Emergency Management Platforms: Platforms like Crisis Information Management System (CIMS) helped authorities manage resource coordination during the flood. These systems allowed agencies to track evacuations, deploy rescue teams, and distribute relief supplies.
- Communication Platforms: Social media platforms like Twitter, Facebook, and Instagram were critical in disseminating information in real - time.2.3.6 Post - Flood Recovery and Rebuilding
- Damage Modelling Tools: Following the May 2023 floods in Emilia - Romagna, a range of damage modelling tools were employed to assess economic losses, infrastructure impact, and crop destruction. For example academia performed ex post assessments on the damages using the COASTS GIS - based decision - support system, applied to simulate flood scenarios using hydraulic models such as XBeach and Mike21, helping estimate potential damage across coastal municipalities (Zanuttigh and Pareschi, 2025). In parallel, other researchers developed models to estimate agricultural flood damage using satellite and ground - based data to support local recovery strategies (Montelone, 2023). The insurance industry, through PERILS, also released a detailed economic loss footprint for the event, reporting total economic damages of €9 billion and insured losses of €495 million (PERILS, 2024). These tools provided crucial evidence to guide both emergency response and long - term reconstruction planning.

- Flood Protection Planning: In the recovery phase following the May 2023 floods in Emilia - Romagna, authorities employed geospatial and hydraulic modelling tools to update flood hazard maps and inform long - term prevention strategies. The Copernicus Emergency Management Service (EMS), through its Risk and Recovery Mapping activation (EMSN154), delivered post - event flood extent and depth analyses, along with temporal flood dynamics, which were used to revise local flood - prone zones (European Commission, 2023). These datasets enabled planners to assess vulnerable infrastructure and prioritise mitigation measures.

2.3.6 Emilia - Romagna – Data Gaps Identified

Despite the effective use of various tools and data during and after the Emilia - Romagna floods, certain data gaps were evident, highlighting areas for improvement in flood risk management.

2.3.7 Incomplete or Inconsistent Hydrological Data

- Gaps in Real - time Data: Although gauging stations along key rivers provided valuable real - time data, there were gaps in coverage in remote or rural areas. Some areas lacked sufficient river gauges, and existing data was often incomplete due to equipment failure or technical issues (European Flood Awareness System, 2023).

- Inconsistent Data Integration: The integration of data from various sources, such as satellite imagery, river gauges, and weather forecasts, was not always seamless. The lack of standardised protocols made some information delayed or difficult to interpret in a coordinated manner (European Commission, 2023).

2.3.8 Lack of Granular Data on Vulnerable Populations

- Population Vulnerability Data: There was limited granular data on vulnerable populations in flood - affected areas.

For example, data on age, disability status, or mobility could have been better integrated into emergency response planning, enabling more targeted evacuations.

- Social Vulnerability Mapping: Socio - economic data on low - income households and those in flood - prone areas was lacking, making it difficult to prioritise high - risk communities for evacuation or aid.

2.3.9 Real - Time Damage Assessment

- Delayed Damage Data: While aerial surveys and satellite imagery provided valuable insights, the data was sometimes delayed due to cloud cover, satellite access limitations, or the large scale of the disaster (European Space Agency, 2023).
- Assessment of Non - Visible Damage: Tools for assessing non - visible damage, such as structural integrity of buildings, were limited. Reliance on visual imagery made it difficult to assess the full extent of damage, especially for properties submerged for long periods (NASA Earth Observatory, 2023).

2.3.10 Data on Agricultural Impact

- Lack of Real - Time Crop Damage Data: While satellite imagery helped assess large - scale agricultural losses, more detailed data on crop conditions and soil quality was needed to gauge long - term agricultural impacts.

2.3.11 Communication Challenges in Remote Areas

- Limited Communication in Remote Areas: Despite extensive use of social media, areas cut off due to road or infrastructure damage had limited access to real - time updates.

2.4 Rhine - Erft – data exploited

2021 saw catastrophic flooding across parts of Germany, especially in North Rhine - Westphalia and Rhineland - Palatinate. Real - time data and

However, the scale of the disaster also revealed significant data gaps that affected response efficiency and the effectiveness of recovery efforts (Civil Protection Knowledge Network, 2024)

2.4.1 Early Warning Systems and Monitoring Tools

2.4.2 Weather Forecasting Models

During the July 2021 Rhine–Erft floods, numerical weather prediction models from the German Weather Service (DWD) and ECMWF (via the European Flood Awareness System) correctly forecasted heavy rainfall, although the intensity and timing of rainfall in smaller catchments exceeded expectations, leading to unexpected flash floods. The Bundesanstalt für Gewässerkunde (BfG) contributed by operating a hydrodynamic model linked to weather - service forecasts, incorporating local precipitation and river discharge data to issue 36 - hour flood warnings for Rhine gauges at sites like Speyer and Emmerich (not in Rhine - Erft). Real - time rainfall measurements from local weather stations supported these forecasts, but the extreme event still surpassed earlier modelled scenarios.

2.4.3 Hydrological Models and Flood Warning Systems

The Federal Institute for Hydrology (BfG) and the DWD operated flood monitoring and hydrological models to track river levels, particularly in the Ahr, Erft, and Rhein rivers, which were at the heart of the disaster. Flood monitoring tools, including rainfall - runoff models and real - time river gauge data, helped track the overflow of the Erft River and other tributaries, sending flood warnings to local authorities. However, these tools were often not sufficiently detailed to predict the localized flash floods that occurred in towns like Bad Münstereifel and Erftstadt (Civil Protection Knowledge Network, 2024)

2.4.4 Remote Sensing (Satellite Imagery)

The Copernicus Sentinel satellites provided high - resolution imagery to track the flood's progression in real time (IFRC, 2023). This satellite data helped map the extent of flooding and assess damage areas, especially after the floods had subsided. Aerial imagery and drones were also used by emergency services and local authorities to assess flooded regions, particularly where ground - level access was restricted due to debris or collapsed infrastructure.

2.4.5 Geographic Information Systems (GIS)

Local authorities and emergency services in the Rhine–Erft region utilized GIS platforms during the July 2021 floods to map damage, plan recovery operations, and enable situational awareness. High - resolution flood extent maps - derived from aerial and satellite imagery - were incorporated into ArcGIS StoryMaps (Esri, 2021) alongside field observations, enabling responders to identify affected roads, infrastructure damage, and safe evacuation routes. Additionally, crowdsourced data from social media outlets such as Twitter were integrated into GIS dashboards. An analysis by Moghadas et al. (2023) demonstrated the use of near - real - time Twitter feeds during the flood event to trace spatiotemporal communication patterns and support decision - making in affected localities. Open Street Map edits further supplemented official maps with community inputs, validating road blockages and flood locations, which enhanced GIS situational models.

2.4.6 Damage Assessment and Aerial Surveys

Following the July 2021 Rhine–Erft floods, authorities leveraged aerial surveys - using drones, helicopters, and manned aircraft - to evaluate structural damage to roads, bridges, and buildings. Unmanned Aerial Vehicles (UAVs) equipped with high - resolution cameras were deployed in Erftstadt and Blessem, capturing imagery that was processed into georeferenced orthomosaics and 3D models within minutes. These models supported rapid situational assessment and

guided rescue and relief operations, particularly in areas obstructed by debris or collapsed infrastructure (Surmann et al., 2022). Additionally, German insurers, including the GDV, conducted damage assessments for insurance purposes, reporting insured losses amounting to approximately €7–8 billion from the event, which informed both public - sector and industry - led rebuilding and recovery strategies (Milliman, 2021).

2.4.7 Social Media and Communication Platforms

During the July 2021 Rhine–Erft floods, platforms such as Twitter, Facebook, and WhatsApp were essential for real - time communication and information exchange. Emergency services - like the Deutsche Rote Kreuz - and local authorities leveraged official channels to broadcast evacuation instructions, shelter locations, and safety advice. Volunteers and residents also used crowd - sourced channels to report road blockages, flood depths, and infrastructure damage. A comprehensive social media analysis revealed over 58,000 flood - related tweets during the crisis, highlighting shifts from weather updates to solidarity calls and damage reporting throughout the event (Thiebes et al., 2022). Additionally, geo - social tools have been shown to enable early flood topic detection and improve situational awareness across borders (Kron et al., 2022).

2.4.8 Crisis Information Management System (CIMS)

Local, regional, and national emergency services used CIMS platforms to coordinate relief efforts. These platforms allowed for the real - time tracking of rescued individuals, evacuations, and delivery of humanitarian aid. The system was integrated with emergency shelters, first - aid stations, and donation drives, providing responders with up - to - date information on resource allocation and volunteer management (German Committee for Disaster Risk Reduction, 2022).

2.4.9 Mobile Apps and Digital Platforms

The German government and local emergency services developed dedicated mobile apps to allow affected residents to report flooding, request help, and find shelter locations. For instance, apps like Katwarn and NINA were used to send emergency alerts directly to mobile phones of residents, ensuring that they were informed about the progression of floodwaters and necessary evacuation orders (IFRC, 2023).

2.4.10 Rhine - Erft – Data Gaps Identified

Despite the use of these data tools, several data gaps hindered the speed and efficiency of response and recovery efforts (German Committee for Disaster Risk Reduction, 2022).

- Incomplete or Delayed Flood Warning: Forecasting models underestimated flash flooding, particularly in smaller tributary areas and steep valleys. Some remote areas lacked sufficient hydrological sensors, resulting in gaps in real - time flood predictions (Bundesanstalt für Gewässerkunde, 2021).
- Inadequate Vulnerability Data: There was a lack of granular socio - economic data on vulnerable populations, hindering targeted evacuations
- Limited Real - Time Agricultural Damage Data: Agricultural damage was significant, but real - time data on crop and livestock losses was sparse (GDV, 2021).
- Incomplete Damage Assessment for Buildings and Infrastructure: Many buildings suffered from hidden structural damage that was not immediately visible via aerial surveys.
- Communication Gaps in Remote Area: Mobile networks were disrupted, limiting real - time communication and emergency alerts.

Case Study

3.0 Event Information

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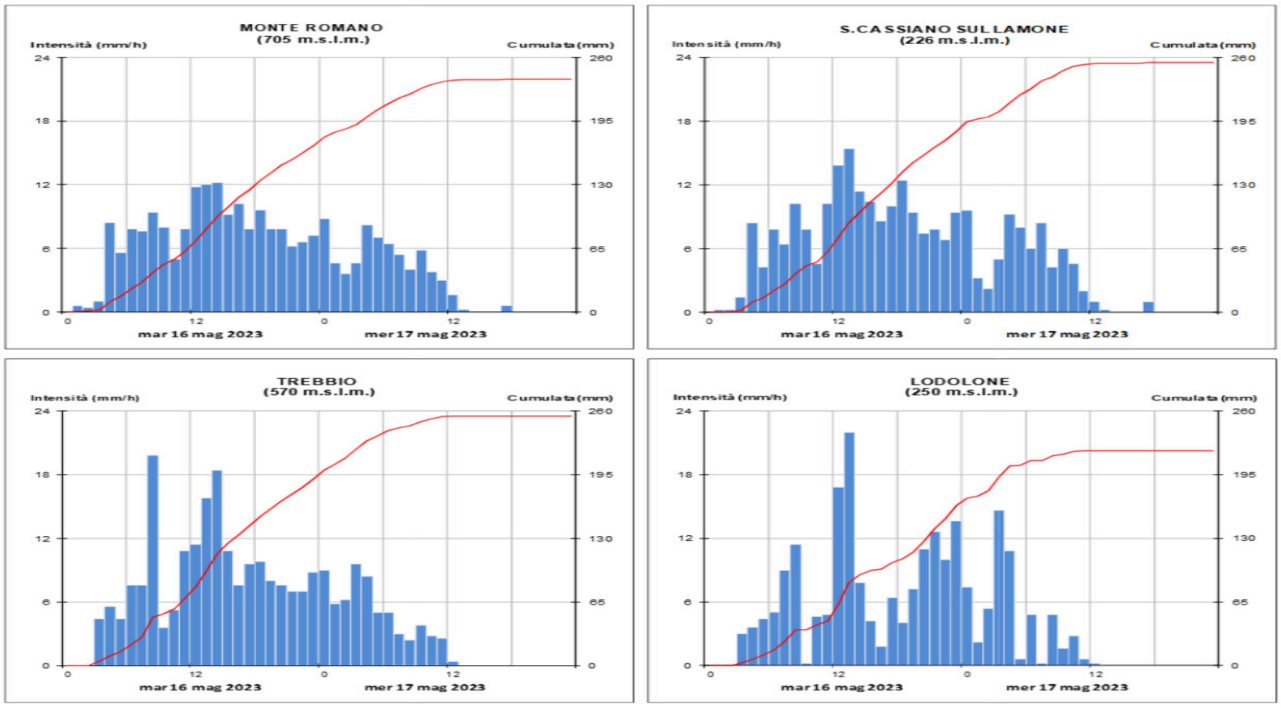

Figure 8: Trend of hourly and cumulative precipitation recorded by the most significant rain gauges in the Lamone basin and its tributary Marzeno (validated data - standard time) – (Source: Regione Emilia - Romagna, 2023a)

3.1 Meteorological and flood event information

3.1.1 Emilia - Romagna meteorological and flood event information

Meteorological Event Information:

Heavy Rainfall: The Emilia - Romagna flood event of May 2023 was driven by two consecutive meteorological systems that brought unprecedented rainfall to the region. Between May 1 - 4, a depression system stalled over the Mediterranean, bringing sustained, widespread rainfall across the region. This was followed by a second, more intense event between May 16 - 18, during which the region experienced 200 - 300 mm of rainfall in less than 48 hours (Regione Emilia - Romagna, 2023a). The event produced rainfalls with return periods exceeding 100 years in several locations, particularly along the Apennine foothills (Regione Emilia - Romagna, 2023a).

The first event saturated the soil, making the second event more destructive. The most affected areas include Forlì - Cesena, Ravenna, Bologna, Modena, Reggio Emilia, and Rimini, particularly along the Senio, Lamone, Montone, Ronco, Savio, Santerno, Sillaro, and Idice rivers (Regione Emilia - Romagna, 2023a).

The second event was fueled by the Mediterranean storm "Minerva," which caused a persistent flow of moist air from the southeast, particularly affecting the Apennine foothills. This convergence of humid air, combined with the topographical effect of the Apennines, resulted in extreme precipitation and flooding across much of Romagna. Rivers such as the Idice, Sillaro, Santerno, Lamone, Senio, Montone, Ronco and Savio overflowed, with water levels surpassing historical highs. Over 23 rivers breached their banks, leading to widespread flooding across both urban and rural areas (Regione Emilia - Romagna, 2023a).

Storm Systems: The flood event was linked to intense storm systems moving across northern Italy, bringing not only prolonged rainfall but also strong winds that compounded the severity of the disaster.

Temperature Fluctuations and Atmospheric Instability: In the days leading up to the May 2023 floods in Emilia - Romagna, exceptional soil saturation from earlier rains combined with persistent low - pressure systems drew abundant moisture from the Mediterranean and North Africa. This created highly unstable conditions that fueled multiple waves of intense precipitation - recording up to 600 mm of rain in parts of the region by mid - May - vastly exceeding

Figure 9: Aerial picture of one of the many breaches on River levees during May, 2023 flood event (Source: Regione Emilia - Romagna)

normal May levels. This dynamical interplay of saturated soils and moist air masses resulted in atmospheric instability and precipitation levels far beyond standard model predictions (Fondazione CIMA, 2023; Resch et al., 2024).

Flood Event Information:

Affected Areas: The meteorological events of 1–4 and 16–17 May 2023 affected a wide portion of the Emilia - Romagna region, generating intense and widespread ground impacts across both hilly and lowland areas. The valley zone was particularly exposed, with floodwaters spreading over extensive agricultural and urban surfaces, highlighting the vulnerability of the plain to extreme rainfall events..

3.1.2 Rhine - Erft meteorological and flood event information

Meteorological Information:

Extreme Rainfall: Between 12 and 15 July 2021, parts of western Germany received 100 to 150 mm of rainfall in less than 24 hours, with some stations in North Rhine–Westphalia and Rhineland–Palatinate recording totals up to 207 mm (Lengfeld et al., 2023). This represented three to four times the July monthly average. Radar data revealed that over 40 mm per hour fell in certain locations, overwhelming drainage systems and causing flash floods.

Storm Fronts: The cut - off low - pressure system "Bernd" remained stationary for several days due to weak steering winds. This led to successive thunderstorms and embedded convective cells over the same areas. These mesoscale features resulted in continuous downpours with cumulative totals surpassing 200 mm, particularly in upland catchments of the Eifel and Sauerland regions (Ludwig et al., 2023).

Ground Saturation: Soil moisture levels prior to the event were already at 90–100% saturation in many parts of the Rhine basin due to a wetter - than - average spring (WWA, 2021). This limited infiltration and accelerated runoff generation, particularly in steep, narrow catchments like the Ahr and Erft, contributed to the sudden rise of river levels and triggered deadly flash flooding.

Flood Event Information: Affected Areas: The most severely impacted areas included Erftstadt - Blessem, Bad Münstereifel, and Schuld, where rivers overtopped or eroded embankments. In Erftstadt, a major landslide occurred as floodwaters undercut soft ground, destroying homes and cutting off roads (Mohr et al., 2023; WWA, 2021).

River Overflow: The Erft River reached flow rates up to 300 m^3/s, roughly six times higher than typical peak levels. Hydrological gauges along the Ahr, Erft, and Rur rivers recorded return periods exceeding 500 years. Riverbank erosion and infrastructure failure caused catastrophic inundation in both rural areas and urban zones, including disruption of energy, transport, and water networks.

Comparative Insights: Emilia - Romagna (2023) vs. Rhine - Erft (2021) Flood Events

Event Structure:

- Emilia - Romagna: Experienced two major rainfall events (early and mid - May), with the second building on already saturated soils.
- Rhine - Erft: Impacted by a single, intense storm system ("Bernd") that remained stationary for several days.

Rainfall Amounts:

- Emilia - Romagna: Up to 600 mm of rainfall recorded in some areas by mid - May (Fondazione CIMA, 2023).
- Rhine - Erft: Peak rainfall of 207 mm in 24 hours; exceeded July monthly averages by 3–4 times (Lengfeld et al., 2023).

Meteorological Drivers:

- Emilia - Romagna: Inflow of moist Mediterranean and North African air, intensified by Apennine topography.
- Rhine - Erft: Driven by persistent thunderstorms and convective cells within a blocked low - pressure system.

Topographic Impact:

- Emilia - Romagna: Flooding affected broad river basins and agricultural plains.
- Rhine - Erft: Severe flash flooding in narrow valleys (e.g. Ahr, Erft), with landslides and erosion.

Soil Saturation:

Both regions had high antecedent soil moisture, which limited infiltration and increased surface runoff.

Forecasting Challenges:

- In both cases, forecast models underestimated intensity and impact, limiting early warning effectiveness.

Hydrological Extremes:

- Emilia - Romagna: Over 23 rivers breached, widespread basin overflow.
- Rhine - Erft: Return periods over 500 years, with river discharges up to 300 m^3/s.

3.2 Geomorphic Information

3.2.1 Emilia - Romagna Geomorphic Summary

Geographical Context

This region in northern Italy is known for its fertile agricultural lands and is bordered by the Apennine Mountains to the south. Rivers such as the Savio, Lamone, and Montone flow through the region, contributing to its agricultural productivity.

Cause of Flooding

The floods in Emilia - Romagna were driven by a combination of meteorological and hydrological factors. The region experienced a prolonged dry period before May 2023, which caused soil crusting and reduced infiltration capacity. When record - breaking rainfall occurred, the hardened ground contributed to rapid surface runoff. Cumulative precipitation of up to 300 mm in 36 hours, particularly in the Apennine foothills, overwhelmed natural and artificial drainage systems. The situation was exacerbated by prior soil saturation from the first May event (1–4 May), which had already compromised the ground's absorption capacity (Regione Emilia - Romagna, 2023a; ARPAE Emilia - Romagna, 2023).

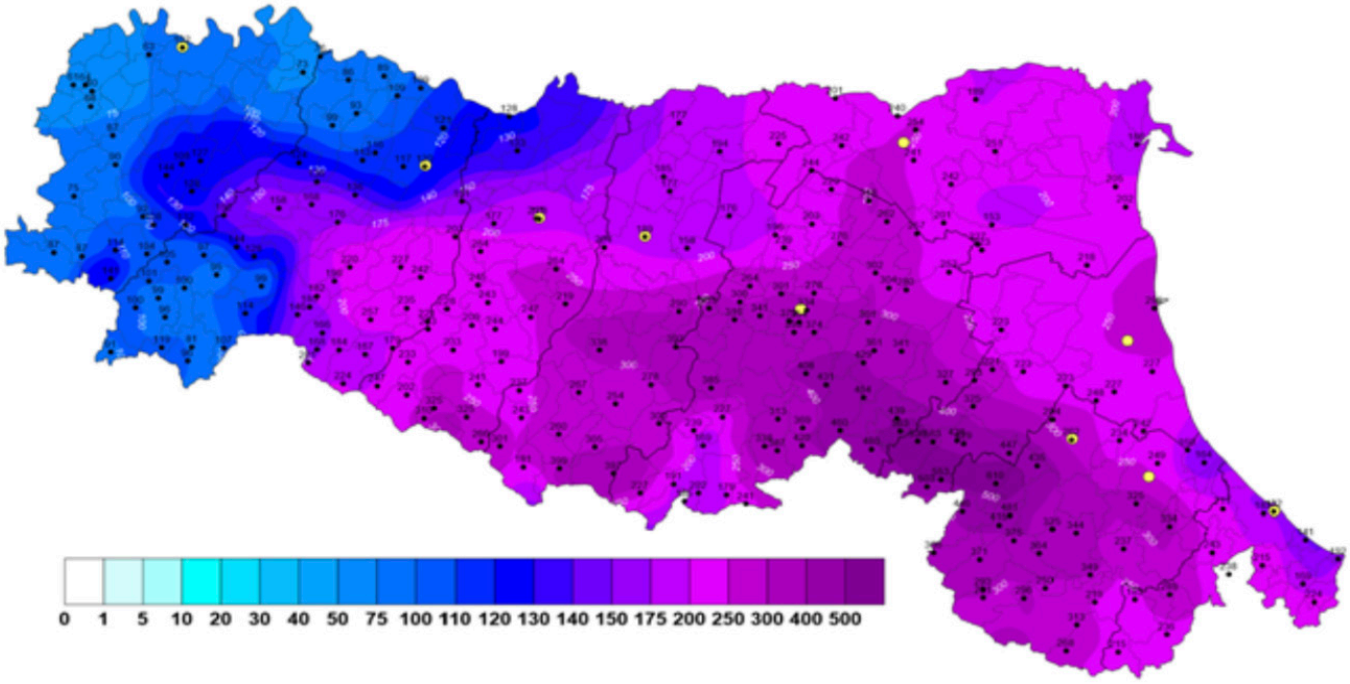

Figure 10: Cumulative observed precipitation for the entire period from May 1 - 17th, 2023, with indication of point values and municipal boundaries. (validated ERG5 dataset) (Source: ARPAE, Emilia Romagna, 2023)

Flooding Patterns

The floods were primarily caused by overflowing/breaching rivers, which submerged large areas of farmland, towns, and cities. Alongside the flooding, thousands of landslides occurred, blocking roads and isolating communities. Aerial and satellite mapping covered over 90% of the affected areas, identifying rapid debris slides, mudflows in clay - rich soils, and deep - seated landslides spanning over 72 km2s (Technical - Scientific Commission of the Emilia - Romagna Region, 2023). While landslides were clearly present, the flooding, in agricultural and residential areas, was a more prominent feature.

The floodwaters affected 42 municipalities, resulting in substantial damage to both urban and rural areas, with roughly €9 billion in estimated economic losses (Regione Emilia - Romagna, 2023a). This event highlights the vulnerability of the region's geomorphology to extreme weather events and underscores the importance of adaptive strategies to mitigate future flood risks.

Climate and Environmental Context

Post - flood agricultural recovery is highly dependent on sediment quality and soil management practices. The May 2023 floods in Emilia - Romagna left behind large quantities of silt and clay, requiring targeted soil rehabilitation strategies. Field studies have shown that sediment thickness above 20 cm significantly impacts soil fertility, necessitating deep tillage and remediation efforts.

An illustrative example, although not directly in the agricultural field, is provided by the Cervia salt pans, where flood - borne sediments and debris disrupted production for 2 years after the flood event. This case highlights how extreme events can compromise specialized land - use systems, reinforcing the broader evidence that flood impacts extend beyond conventional crop production to affect distinctive local economic and cultural assets (La Repubblica, 2025).

Figure 11: Cervia (Ravenna) salt pruciton site flodded. (Slowfood Italia, 2023)

Flooding Patterns

Additionally, flood - related waste management remains a major challenge. The sudden influx of debris, organic matter, and hazardous materials requires coordinated efforts for safe disposal and recycling. The response to flood waste in Emilia - Romagna was streamlined through emergency ordinances, allowing for faster cleanup and disposal .

The floods followed a period of drought, which exacerbated the flooding impact by reducing soil absorption. Experts also connected the extreme weather to climate change, citing the unpredictability of intense rainfall following long dry periods. The event highlighted the vulnerability of agricultural lands and infrastructure to changing climate patterns.

3.2.2 Rhine - Erft Geomorphic Summary

Geographical Context

Located in the state of North Rhine - Westphalia, Germany, this region lies along the Erft River and has smaller tributaries flowing towards the River Rhine. The area is characterized by both urban and rural landscapes, with significant human development near rivers.

Cause of Flooding

The floods were caused by a slow - moving low - pressure weather system in mid - July 2021, which dumped record - breaking rain over several days. Rivers and smaller streams rapidly overflowed due to the persistent rainfall, resulting in flash floods and a major landslide.

Flooding Patterns

The region saw rapid - onset flash flooding, particularly in small catchments. The Erft and its tributaries responded quickly, overwhelming both natural channels and engineered drainage systems. In Erftstadt, riverbank collapse near a gravel pit caused buildings to collapse into a sinkhole - like depression. The flood wave peaked within hours, providing little time for warnings or evacuations, especially in areas like Bad Münstereifel and Euskirchen (WWA, 2021).

Climate and Environmental Context

The July 2021 floods are widely linked to climate change, which is increasing the frequency and intensity of extreme precipitation events in Central Europe (Pinto et al., 2023). Warmer air holds more moisture, enhancing convective rainfall.

The event highlighted vulnerabilities in flood risk governance, early warning systems, and urban planning. Hydrological modelling has shown that return periods exceeded 500 years in some basins (Lengfeld et al., 2023), underscoring the need for systemic adaptation, particularly in densely populated and geomorphically sensitive areas.

3.2.3 Comparative Insights: Emilia - Romagna (2023) vs. Rhine - Erft (2021)

Flood Events

This section provides a structured comparison between the Emilia - Romagna (2023) and Rhine - Erft (2021) flood events. By aligning geographical context, causal factors, flooding patterns, and environmental consequences, it distills shared lessons and highlights region - specific dynamics relevant for disaster risk management and climate adaptation.

Geographical Context

Emilia - Romagna: Characterised by extensive agricultural plains bordered by the Apennine Mountains; includes sediment - rich floodplains with highly cultivated land and historically modified rivers (e.g. Savio, Lamone).

Rhine - Erft: Located in North Rhine - Westphalia, with a mix of urban and rural zones; includes steep catchments and areas altered by lignite mining (e.g. Erftstadt near gravel pits), which influence flood dynamics.

Cause of Flooding

Emilia - Romagna (2023):

- Two back - to - back rainfall events in May 2023, with the second event (16–18 May) delivering 200–300 mm in <48 hours.
- Prolonged antecedent drought followed by a soil - crusting effect reduced infiltration and caused high surface runoff.
- Over 23 rivers overtopped and breached, with rainfall return periods exceeding 100 years (Regione Emilia - Romagna, 2023a).

Rhine - Erft (2021):

brought >200 mm rainfall in 48 hours in July 2021.

- Soils were already near - saturated (90–100%) after a wet spring (WWA, 2021).
- Resulted in intense overland flow and severe flash flooding in narrow valleys.

Flooding Patterns

Emilia - Romagna:

- River overflows/breaching affected 42 municipalities and caused widespread flooding across agricultural and urban areas.
- Thousandsof landslides occurred, especially in clay - rich Apennine zones.
- Satellite imagery and field mapping identified debris slides and mudflows in areas > 72 km2 (Technical - Scientific Commission, 2023).

Rhine - Erft:

- Flash floods rapidly overwhelmed drainage systems.
- Catastrophic riverbank collapse in Erftstadt created sinkholes, destroying homes and roads.
- River levels and discharges reached levels associated with >500 - year return periods (Lengfeld et al., 2023).

Climate and Environmental Context

Emilia - Romagna:

- The preceding drought reduced soil permeability, then compounded runoff when extreme rains fell.
- Post - event, fields were buried under sediment >20 cm thick, affecting fertility and requiring deep tillage.
- Emergency waste management strategies were enacted to address flood debris and contamination.

Rhine - Erft:

- Event linked to climate change increasing convective precipitation in Central Europe.

- Raised questions about early warning systems and preparedness in highly developed areas.
- Urban sprawl and sealed surfaces increased vulnerability to rapid - onset floods.

Key Shared Insights

- Both floods were driven by persistent, extreme rainfall events with prior conditions (drought or saturation) amplifying impact.
- Each region experienced both flooding and geomorphological hazards (landslides or erosion).

The events underline the importance of:

- Integrating soil - moisture monitoring into forecasting,
- Strengthening land - use planning and floodplain management,
- Enhancing climate adaptation strategies to cope with compounding hydrometeorological risks.

3.2.4 Emilia - Romagna geomorphic and landslide impacts

Geomorphic Impacts

During the event of May 2023 huge sediment transport was observed, as well as significant landslide activity. According to official reports and to a subsequent landslide atlas published, the heavy and prolonged rainfall led to over 80,000 landslides, with particularly severe impacts in the Apennine foothills and mountainous areas (Regione Emilia - Romagna. Alluvione, 2023b). The geomorphic processes, including the mobilization of vast amounts of sediment, caused severe disruption to infrastructure, isolating communities, and blocking major transportation routes (Emilia - Romagna Region, 2023b). The landslides were concentrated in areas already prone to terrain instability due to the region's geological composition, particularly in the provinces of Forlì - Cesena, Ravenna, and Bologna (Regione Emilia - Romagna, 2023b). Some municipalities, such as Modigliana and Casola Valsenio, experienced extreme landslide activity, with over 75 significant landslides recorded in specific areas. The HuT (Hydro - geological Technical Unit) and qualified experts from research and academia have been involved in further analyzing these geomorphological impacts to better understand the dynamics of sediment transport and slope failure during the event.

In particular, the special issue published by ARPAE - Emilia - Romagna ,2023 highlighted the complexity of these landslide processes, noting that the saturation of the soil from previous rains in early May further weakened slopes, leading to catastrophic failures. The accumulation of debris and sediment exacerbated the flooding downstream, particularly along the Senio, Santerno, and Lamone rivers, where river courses were blocked by the material carried by landslides (Ferrario & Livio, 2023).

The reports stressed the need for updated landslide risk maps and stronger coordination between local authorities and emergency services to manage such large - scale geomorphic events in the future. As the HuT and other research bodies continue to analyze the data, new insights are expected to emerge regarding how these processes can be mitigated in future extreme weather events.

River Morphology Changes: The flooding events led to significant changes in river morphology, including erosion, sediment deposition, and alterations to riverbanks, channels, and floodplains.

Soil Erosion: Heavy rainfall accelerated soil erosion, particularly in areas with steep slopes or reduced vegetation cover, leading to loss of fertile topsoil and declining agricultural productivity.

Sediment Transport: Increased sediment transport due to surface runoff modified aquatic ecosystems and affected water quality. Additionally, sediment deposition within floodplains created new landforms, influencing future flood behaviour and land - use patterns.

Floodplain Dynamics: The flood events contributed to the dynamics of floodplains, where sediment deposition can create new landforms or alter existing ones. These changes can impact future flood behavior, land use and ecosystem stability in the region.

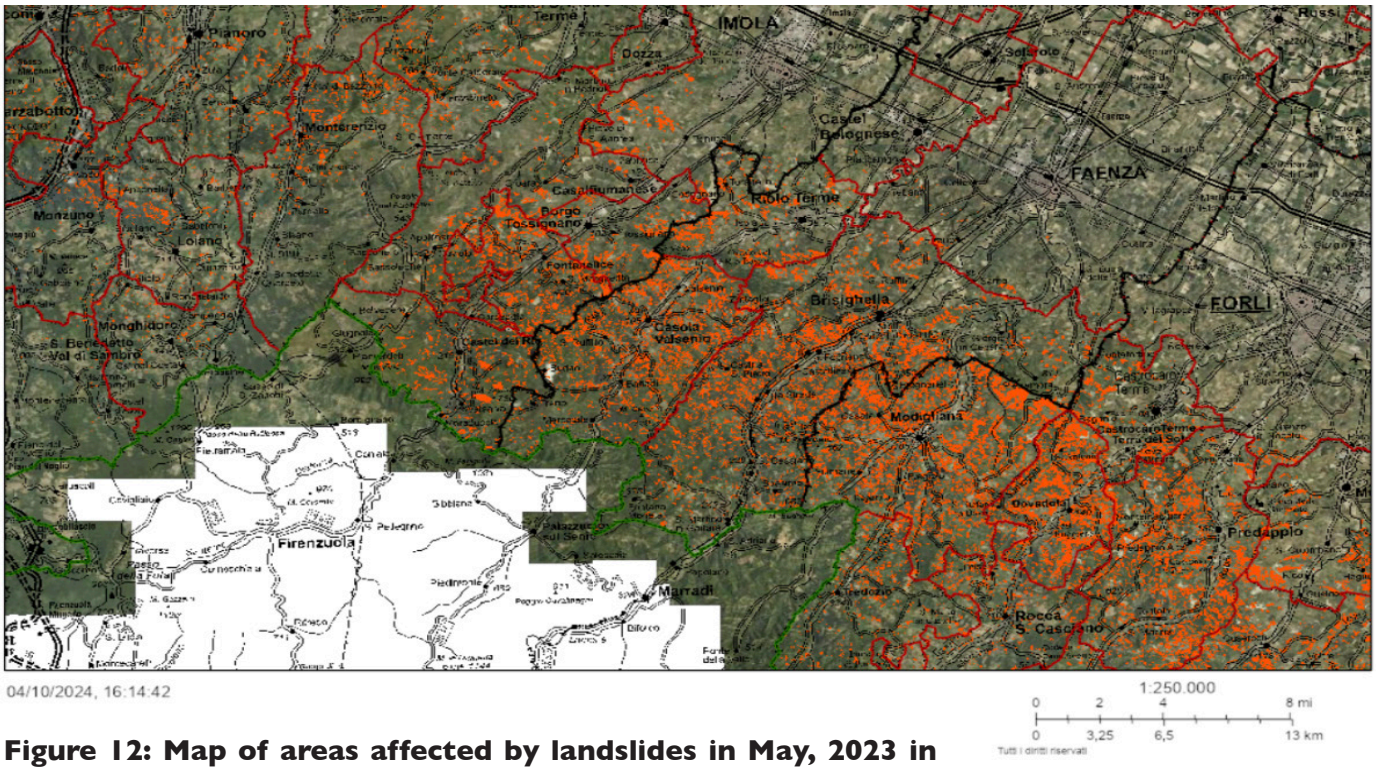

Figure 12: Map of areas affected by landslides in May, 2023 in Emilia - Romagna Region. (Source: Regione Emilia - Romagna, 2023)

Landslide Impacts

- Landslide Incidence: Persistent rainfall and saturated soils triggered thousands of landslides, impacting both urban and rural areas by blocking roads and isolating communities (Guzzetti et al., 2023).
- Types of Landslides: Different landslide types, including earth slides, debris flows, and rockfalls, were observed, particularly in steep terrains (Rosi et al., 2023).
- Infrastructure Damage: The resulting infrastructure damage was severe, affecting roads, railways, and buildings, complicating rescue and recovery efforts.
- Vegetation Loss: The landslides often resulted in the loss of vegetation, which can destabilize slopes further and increase the risk of future landslides. The removal of plant cover reduces soil cohesion, making slopes more vulnerable.
- Long - Term Geomorphic Changes: The combined impact of flooding and landslides led to long - term geomorphic changes, influencing drainage patterns, land use, and ecosystem stability in the region.

3.2.5 Rhine - Erft geomorphic and landslide impacts

Geomorphic Impacts

Erosion of Riverbanks: During the July 2021 flood in the Rhine - Erft region, exceptionally high rainfall combined with already saturated soils led to immediate surface runoff, triggering severe erosion. In many places, the force of the water undercut and destabilised riverbanks, leading to collapses and significant morphological changes. The LAWA (2022) report confirms that peak discharges in rivers such as the Erft far exceeded the 100 - year flood threshold (HQ100), overwhelming monitoring infrastructure and intensifying sediment transport. Washed - out materials were deposited downstream in slower - flowing areas, such as retention basins and floodplains. The destruction of gauging stations and the shifting of riverbeds complicated both immediate responses and long - term flood modelling (LAWA, 2022).

Channel Widening and Deepening: The 2021 floodwaters also caused marked changes in channel morphology. As water overtopped the banks and scoured through floodplains and steep valleys, many rivers and streams widened and deepened. The LAWA (2022) report highlights that this process was especially pronounced where hydraulic pressures combined with sediment - laden flows to excavate riverbeds. The reshaping of these channels has had lasting effects on local landscapes and floodplain connectivity, requiring significant re - evaluation of flood risk maps and infrastructure vulnerability in affected areas (LAWA, 2022).

Floodplain Modifications: Floodwaters in the Rhine - Erft region during July 2021 deposited large volumes of sediment across affected areas, particularly in flatter floodplain zones. This was especially visible in agricultural lands, where fertile topsoil was displaced or buried, and in urban environments where silt and debris clogged drainage infrastructure. The repeated inundation of floodplains under high sediment load led to morphological change, including the formation of levees, sediment bars, and altered flow paths. These effects were most pronounced where flow velocity slowed, such as in natural retention zones and meander bends (LAWA, 2022).

Landslide Impacts: The exceptional rainfall between 14 and 15 July 2021 led to extreme soil saturation in the steep headwaters of the Eifel mountains and the valleys around the Erft rivers. This triggered numerous landslides and debris flows, as waterlogged soils and weakened cohesion caused whole hillside sections to collapse - depositing soil, rock, and organic debris into the channels and valley floors (Ludwig et al., 2023).

Landslide - Triggered River Modifications: Many of these landslides had lasting impacts on river morphology. They created new scarps, altered river courses, dammed streams temporarily, and dumped substantial amounts of sediment downstream, reshaping channel cross - sections and floodplain topography (Ludwig et al., 2023).

Key shared insights

The following points synthesise the main key insights and priority lessons emerging from the two case studies:

- Different triggers, similar outcomes: While Emilia - Romagna faced prolonged rainfall following earlier storms, and Rhine - Erft was struck by an intense deluge over saturated ground, both events resulted in rapid - onset geomorphic disruption and widespread damage.

- Hazard overlap amplifies impact: The interaction between hydrological extremes and unstable terrain proved highly destructive - not just in terms of flooding, but through landslides, channel collapse, and floodplain transformation.

- Legacy effects: Neither event was confined to the disaster window; both reshaped river systems, altered drainage patterns, and affected long - term land use and ecosystem functioning.

- Systemic weaknesses exposed: Infrastructure failures (e.g. blocked roads, broken gauges, isolated towns) revealed critical dependencies that require rethinking resilience beyond just flood defences.

Forward - looking priorities:

- Consider embedding real - time soil saturation and geomorphological risk indicators into operational forecasting.

- Move from static to adaptive land - use planning in high - risk zones.

- Develop climate adaptation strategies that explicitly address multi - hazard and compound - event scenarios.

Case Study

4.0 Emila - Romagna Disaster Management

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Funded by the European Union

4.1 Emilia - Romagna emergency preparedness

Before the catastrophic floods of May 2023, Emilia - Romagna had developed a well - established disaster risk reduction (DRR) framework. Guided by its Civil Protection Agency, the region implemented measures such as hydrological monitoring systems, flood risk mapping, and structural defenses to mitigate the impact of extreme weather events. However, the scale of the May floods exposed significant gaps in the existing systems (3,1).

The region's hydrological monitoring systems, managed by ARPAE, provided real - time data on river levels and rainfall. This data enabled early warnings, including the red alert issued on May 15, which triggered preemptive actions such as school closures, roadblocks, and local emergency activation. Despite these successes, the response faced challenges in scaling up to meet the disaster's magnitude, particularly in densely populated areas (ARPAE, 2023).

Extensive flood risk mapping and urban planning initiatives had been implemented to identify vulnerable areas and inform zoning regulations. While these measures proved valuable in some cases, they struggled to address vulnerabilities in rural and agricultural zones, where infrastructure was insufficient to handle such large - scale inundation. Structural defenses, such as levees, were similarly overwhelmed, revealing the need for more robust engineering solutions and maintenance protocols (ARPAE, 2023).

Despite the investments in preparedness, the floods revealed some gaps in Emilia - Romagna's DRR framework including :

Interoperability of Systems: Data - sharing between regional and local authorities struggled, leading to delays in decision - making during critical phases of the disaster (ARPAE, 2023).

Community Engagement: While public awareness campaigns were conducted, there were disparities in how communities understood and acted on early warnings, particularly in rural areas.

Infrastructure Resilience - The failure of structural defenses and the widespread disruption to transportation networks underscored the need for more adaptive and resilient infrastructure (Bertolini, le Clercq & Kapoen, 2005.)

Preparedness efforts in Emilia - Romagna provide a valuable comparison point for understanding DRR practices. The region's use of real - time hydrological data, combined with coordinated early warning systems, successfully minimized casualties. However, the floods emphasized the importance of further integrating risk reduction strategies into local governance, ensuring that both rural and urban communities are equally prepared.

Potential improvements include enhancing community education on disaster risks, increasing investments in nature - based solutions, and strengthening the capacity of emergency response systems to handle simultaneous crises. These measures will be strategicas the region confronts the increasing frequency and intensity of extreme weather events linked to climate change(ARPAE 2023; ,(Fekete, 2020.)

4.2 Emilia - Romagna emergency response

As the management systems within Italy are more centrally and regionally managed, unlike the Federal system in Germany, we have been able to build a more detailed case study of the Emilia - Romagna 2023 flood management.

For the purpose of this case study we felt it important to understand the decision - making structures engaged during the Emilia Romagna floods as each authority has set responsibilities during a disaster. In this way, we are able to draw some understanding of the interoperability of information flows and its communication during the Emilia - Romagna floods.

The floods that struck Emilia - Romagna in Italy in May 2023 were a result of heavy rainfall that led to the overflowing/breaching of rivers, causing floods in the entire main hydrographic network of the central - eastern sector over a two - week period, affecting, among others, the rivers Enza, Tresinaro, Secchia, Tiepido and Panaro in the provinces of Modena and Reggio Emilia,

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the river Reno and all its tributaries (rivers Samoggia, Lavino, Idice, Savena, Quaderna, Sillaro, Santerno, Senio) in the provinces of Bologna and Ferrara, and also the rivers Lamone, Marzeno, Montone, Ronco, Bevano, Savio, Rubicone, Pisciatello and Marecchia, in the provinces of Ravenna, Forlì - Cesena and Rimini. During the entire event, the floods of the rivers exceeded the third level of the hydrometric thresholds (defined as the alarm or "red" level) several times, causing overflows, floods, hydraulic and hydrogeological criticalities, numerous breaches of the banks and extensive flooding, including all 240 municipalities belonging to the six provinces of Ferrara, Forlì - Cesena, Modena, Ravenna, Reggio Emilia, Rimini and the Metropolitan City of Bologna. Only the 2 westernmost provinces of Piacenza and Parma are excluded (ISPRA, 2023). The emergency response to these floods was a complex operation involving a wide range of government, regional, and local authorities, as well as civil protection agencies, humanitarian organisations, and volunteers (Regione Emilia - Romagna, 2023; European Commission, 2023). The following is an overview of the emergency response management during the Emilia - Romagna floods of 2023.

Immediate Emergency Response

- Civil Protection Department (Protezione Civile): The region's Civil Protection issued an early red alert on May 15, forecasting the potential for extreme weather and flooding. This early warning system was crucial in preparing local authorities and the population for the impending disaster. Specific measures included the closure of over 400 roads, recommendations to move to higher floors in homes, and advisories against traveling in and out of affected areas. Schools were also closed, and preventive evacuations were carried out in particularly vulnerable areas. These preventive actions helped mitigate the impact, although the extent of the flooding overwhelmed local defenses . Civil Protection teams were mobilized across the region, and local authorities were instructed to prepare for such emergency measures like possible evacuations and road closures.

During the event, continuous updates were provided to local authorities, and evacuation measures were enforced in high - risk areas.

Nearly 10,000 people were evacuated, and approximately 760 roads were closed or damaged due to flooding and landslides according to Emilia - Romagna Civil Protection evaluations. Operational challenges have been faced by the early warning and response systems, as well as logistical difficulties in handling the simultaneous closure of roads, railway lines, and other key infrastructures. The official reports emphasized the importance of improving real - time data transmission between emergency services and municipalities, highlighting issues in the sharing of hydrological data during the peak of the flood.

Territorial Safety and Civil Protection Regional Agency: At territorial level, the operations rooms of the following Territorial Offices were activated: Reggio Emilia, Modena, Bologna, Ferrara, Ravenna, Forlì - Cesena and Rimini. Seven Relief Coordination Centres and 160 Municipal Operations Centres were activated throughout the area affected by the event. The connection between the various operational rooms and the components and structures of the civil protection system was also guaranteed through periodic meetings with video conference connections. The operationality of the national system was ensured with the activation of the National Crisis Unit from 2 May. A constant connection was then guaranteed between the Regional Operations Room and the National Civil Protection Operations Committee, active from the evening of 16 May, with the participation of all the Operational Structures and Bodies and Administrations of the National Civil Protection Service (National Fire Brigade, Army, Navy and Air Force, Carabinieri, State Police, Penitentiary Police, Guardia di Finanza, Harbour Master's Offices - Coast Guard, Italian Red Cross, Civil Protection Volunteers, National Alpine and Speleological Rescue Corps - CNSAS, personnel of the scientific bodies of the National System for Environmental Protection, and personnel of the companies providing essential services - telephony, energy, gas and mobility).

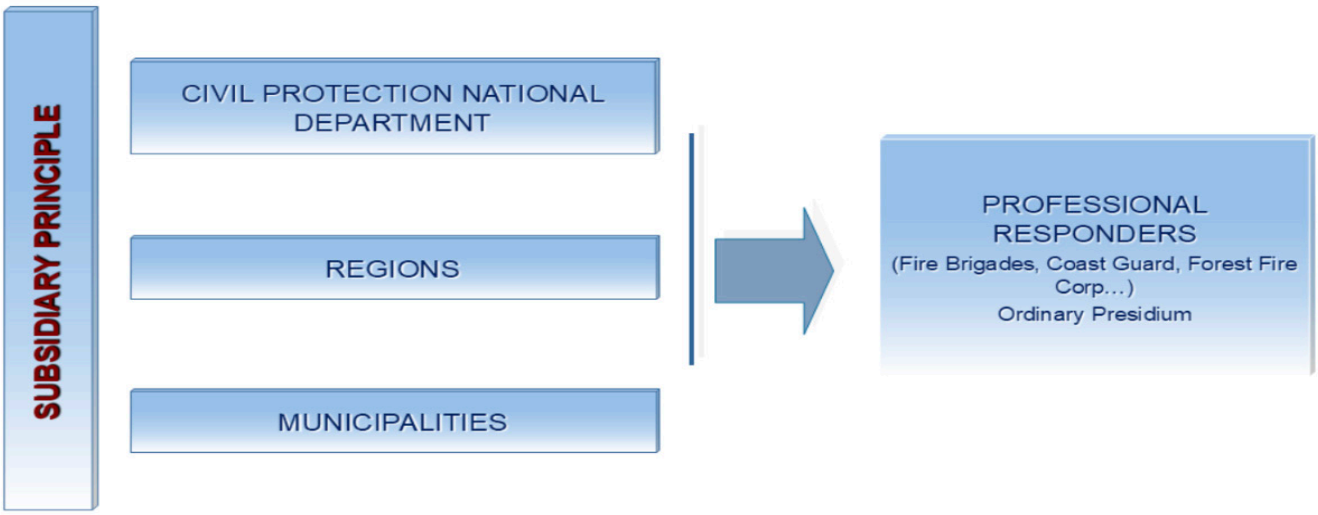

Figure 13: Simple schematic of informal decision points in Italy.

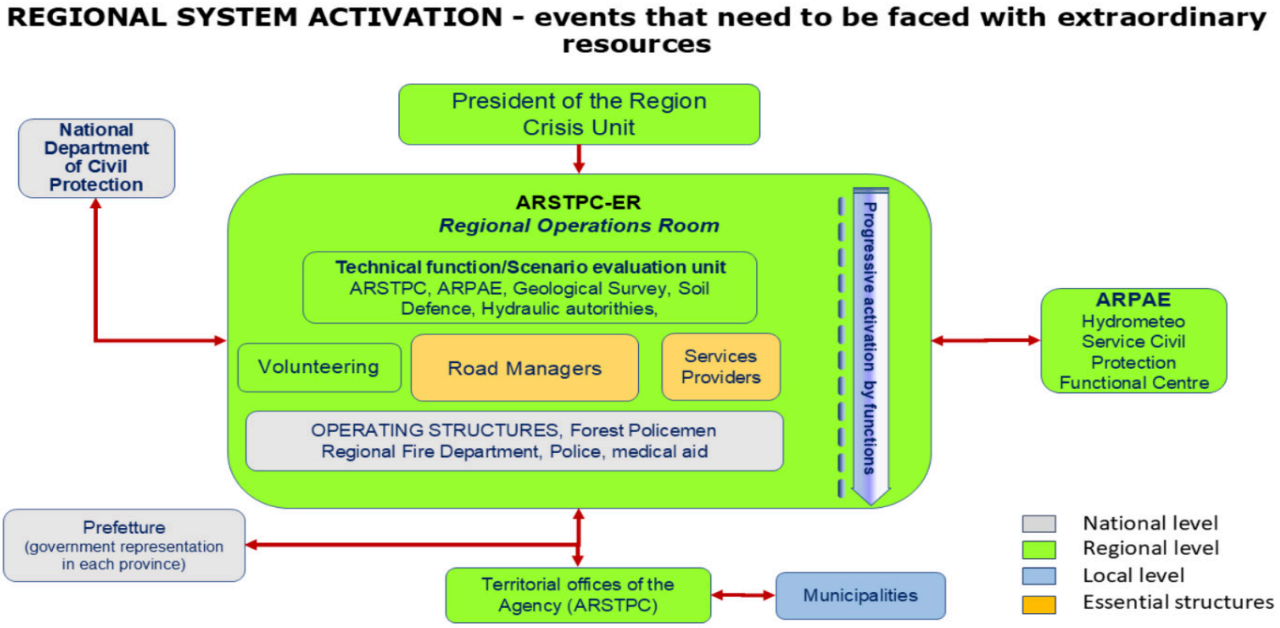

Figure 14: Regional disaster management structure for Emilia - Romagna.

Flood Alerts and Warnings: The authorities had advanced warning systems that issued flood alerts and evacuations to people living in high - risk areas (ISPRA, 2023).

The alert system had been agreed upon by ARPAE Hydrometeo Service with agencies such as AIPo, reclamation consortia, and regional civil protection in advance of the event and can be summarised as follows:

Threshold Levels:

Threshold 1 (Green–Yellow transition): Water fills the low - flow channel but remains well below ground level. Minor flood event; may require minor preventive action.

Threshold 2 (Yellow–Orange transition): Water reaches floodplains or natural expansion areas; may exceed ground level and affect levees. Indicates significant flooding with erosion and sediment transport.

Threshold 3 (Orange–Red transition): Water occupies the entire river section, near historical highs or levee tops. Indicates exceptional flooding with major erosion and transport.

Color Code Summary Table:

Color - Green
Scenario - No significant phenomena forecasted.
Effects and Damages: No major effects expected. Isolated minor damage cannot be excluded.
Green

Color - Yellow
Scenario - Localised rise above Threshold 1 in major rivers and drainage networks. Can occur even without rainfall.
Effects and Damages: Occasional danger to personal safety. Possible isolated deaths. Minor damage to hydraulic works, agriculture, construction sites, and buildings near rivers or drainage.

Color - Orange
Scenario - Widespread flooding above Threshold 2. Floodplain/levee involvement. Sediment transport and riverbed movement. Bridge blockage.
Effects and Damages: Danger to life in flooded or nearby areas. Damage to levees, water management works, infrastructure, buildings, and agriculture. Drainage system overload may worsen flooding.

Color - Red
Scenario - Extensive flooding beyond Threshold 3. Possible overflow into areas far from rivers. Levee failure, bridge overflow, and infrastructure collapse.
Effects and Damages: Severe danger to life. Major damage to levees, bridges, transport, essential services, homes, and agriculture. Drainage failure exacerbates flooding.

- In the period from 1 May to 13 June 2023, through the regional warning system (https://allertameteo.regione.emilia - romagna.it) 44 alerts were issued and distributed for the following phenomena: Hydraulic Criticality, Hydrogeological Criticality, Criticality for Storms, Wind, Sea State and Coastal Criticality:
- 17 with RED code (02 - 03 May; 10 - 11 May; 14 May; 16 - 27 May);
- 10 with ORANGE code;
- 17 with YELLOW code;

During the event the following were reported to the territory:

- 93 exceedances of the hydrometric threshold 3.
- 285 exceedances of the hydrometric threshold 2.
- 15 exceedances of the pluviometric threshold 30mm/h.

To monitor the progress of floods and peaks forecasted in the regional basins, 33 monitoring documents were prepared by the ARPAE Functional Center and distributed.

The alerts, exceedances of rainfall/water thresholds and monitoring documents were transmitted to the subjects of the civil protection system by sending e - mails and text messages.

In total, approximately 170,000 SMS were sent, distributed as follows:

- Alerts: 88,555;
- Exceedances of hydrometric/pluviometric thresholds: 51,397;
- Monitoring documents: 30,957.

In the above - mentioned period, the intense and persistent rainfall, which occurred in several bursts, led to the activation of the "dam risk" and "downstream hydraulic risk" phases for 6 large dams.

The communications sent by the dam managers were received and forwarded by the Agency to the system of territorial bodies, as required by the current civil protection documents (DPC) and by the dam emergency plans (PED) were already approved, providing the indication to keep the respective civil protection plans operational.

4.2.2 Evacuations and Shelters

- Evacuations: In the most affected areas, including parts of Bologna, Ravenna, Cesena, and Forlì, local authorities carried out large - scale evacuations of residents from flood - prone zones (Regione Emilia - Romagna, 2023). More than 36,600 people had to leave their homes due to the event, were relocated to temporary shelters as rivers breached their banks and floodwaters inundated homes, streets, and businesses (European Commission, 2023), placed in structures, sports halls, schools, hotels and other solutions.
- Temporary Shelters: The regional government, in coordination with the Italian Red Cross and other humanitarian organisations, opened numerous shelters to accommodate displaced people. These centres provided food, water, and medical care, as well as psychological support for those traumatised by the disaster (IFRC, 2023).

4.2.3 Search and Rescue Operations

- Rescue Teams: The Italian Fire Brigade and other specialised rescue teams were immediately deployed. Helicopters, boats, and all - terrain vehicles were used to reach stranded people in flooded areas.

Urban search and rescue teams were particularly important in areas where floodwaters rapidly rose and trapped residents.

- Volunteers: Thousands of regional volunteers employed, activation of the national system and the European mechanism, up to 8,000 men and women from the National Civil Protection Service operated daily, the Mobile Columns of 12 regions and national volunteer organizations were activated. The European modules of Slovakia, Slovenia, France and Belgium were also activated for a total of 109 personnel and 55 vehicles, supporting the rescue operations, delivering supplies, providing first aid, and assisting with evacuation efforts (Regione Emilia - Romagna, 2023). Local groups, such as the Italian Red Cross and Civil Protection volunteers, played a critical role in both immediate response and long - term recovery.

4.3 Coordination of Emergency Response

4.3.1 Regional and Local Coordination

- Regional Operations Centre: The Emilia - Romagna region set up its own operations centre for flood management, which worked in coordination with the national Civil Protection Department. Local mayors and municipal authorities, with the activation of 7 Rescue Coordination Centres and 160 Municipal Operations Centres, also coordinated with regional agencies to implement evacuation orders, direct traffic away from flooded zones, and distribute emergency supplies (Valente et al., 2023).
- Inter - Agency Coordination: The emergency response was a collaborative effort, with different agencies working together to manage the crisis. These included police forces, the army, the Red Cross, environmental protection agencies, and local fire brigades. The use of a shared digital platform () allowed for real - time information exchange between agencies, helping to streamline decision - making and avoid delays.

4.3.2 Municipality/Regional Response Management

In May 2023, the Emilia - Romagna, the major cities: Bologna and Ravenna, were hit by catastrophic flooding caused by intense rainfall. Rivers like the Reno, Montone, and Savio overflowed/breached affecting several municipalities. The response involved coordination between regional, municipal, and national authorities, as well as civil protection agencies, humanitarian organisations, and local volunteers (European Commission, 2023).

4.3.3 Activation of Regional and Municipal Emergency Plans

- Protezione Civile (Civil Protection): The regional Civil Protection Department activated emergency protocols as soon as flood warnings were issued. The Emilia - Romagna Regional Operations Room (SOR) became the hub for coordinating disaster response efforts across multiple municipalities, operating 7 days a week and in 24 - hour mode from 1 to 5 May 2023 and from 10 to 28 May 2023.
- Municipal Coordination: Local mayors and municipal authorities were responsible for implementing evacuation orders, securing vulnerable populations, and managing shelters. Seven Relief Coordination Centers and 160 Municipal Operations Centers were activated throughout the area affected by the event. These authorities worked closely with the regional government and civil protection to ensure swift and coordinated action (Valente et al., 2023)

4.3.4 Evacuations and Shelters

- Evacuations: Thousands of residents in high - risk flood zones, particularly in towns along the Reno and Savio rivers, were evacuated. Emergency shelters were set up in local schools and community centres to accommodate the displaced people (European Commission, 2023).

- Shelter Management: Municipalities, in collaboration with the Region, the National system and the Italian Red Cross and other humanitarian groups, ensured that the shelters provided food, medical supplies, and psychological support to affected individuals.

4.3.5 Rescue Operations and Immediate Relief Search and Rescue

- Deployment of Resources: Municipal and regional emergency teams, along with the Italian Fire Brigade (Vigili del Fuoco), were dispatched for search and rescue operations. Boats, helicopters, and all - terrain vehicles were used to reach stranded people and provide immediate medical care.
- Volunteer Engagement: Regional and local volunteers played a key role in assisting emergency services with evacuations and distributing supplies. The involvement of these volunteers ensured that the immediate needs of affected communities were met rapidly (Valente et al., 2023).

Provision of Aid

- Emergency Supplies: Municipalities coordinated the distribution of essential supplies (water, food, clothing, hygiene kits) to residents in shelters and affected areas. Local emergency teams also focused on providing temporary medical assistance to those injured.

Case Study

5.0 Rhine - Erft Disaster Management

Project 101073978 - DIRECTED - HORIZON - CL3 - 2021 - DRS - 01

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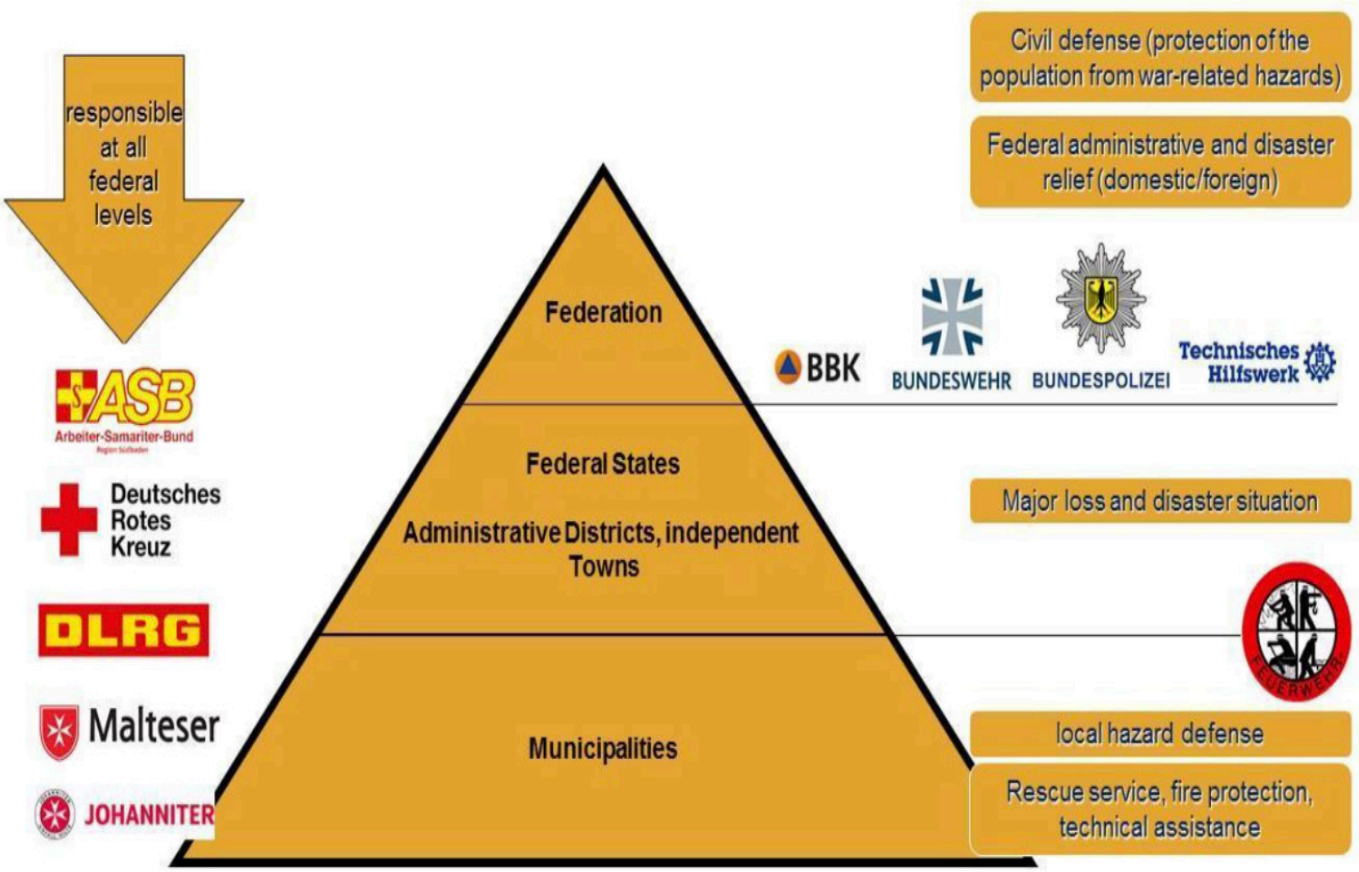

Figure 15: Integrated assistance system in Germany. Source: German Federal Office of Civil Protection.

5.1 Activation of Emergency Plans

The Rhine - Erft floods of July 2021 were part of a wider, devastating flooding event across Western Europe, triggered by extreme rainfall that caused rivers like the Erft to burst their banks. The floods impacted municipalities in the Rhine - Erft district in North Rhine - Westphalia, Germany, causing widespread damage. The response involved regional, municipal, and national coordination to manage evacuations, emergency relief, and recovery efforts as outlined in Figure 15 (German Federal Office of Civil Protection, 2022).

Regional Civil Protection

- NRW Civil Protection: The coordination of emergency responses in North Rhine - Westphalia during flood events involved close collaboration between regional operations centers, municipal governments, and local civil protection agencies to ensure effective disaster management and resource distribution (IDOS, 2022).
- Municipal Coordination: Local mayors in towns such as Erftstadt, Bad Münstereifel, and Leverkusen took charge of evacuation plans, shelter management, and providing updates to residents. Municipal teams worked alongside regional authorities to respond to the rapidly escalating flood situation (German Red Cross, 2021).

5.2 Rescue, Relief, and Recovery

- Fire Brigades and Emergency Services: Local fire departments, police, and volunteer organisations were mobilised for search and rescue operations. Helicopters, boats, and all - terrain vehicles were used to rescue stranded people, especially in towns like Erftstadt, where many residents were trapped by flash floods.
- Health and Medical Care: Temporary medical stations were set up in shelters and affected communities. Health teams provided first aid and psychological care to residents dealing with trauma and injuries (German Red Cross, 2021).

5.3 Post - Flood Reconstruction

- Reconstruction Funds: In response to the July 2021 floods, the German federal and state governments established the Aufbauhilfe 2021 fund - a €30 billion programme to repair and rebuild homes, roads, public buildings, and critical infrastructure in disaster - hit areas including the Rhine-Erft district. An immediate relief package of €400 million was disbursed to address urgent needs. Low-interest loans, combined with advisory services, were provided to homeowners and businesses through state development banks like NRW.BANK (BMI & BMF, 2022; NRW.BANK, 2022).

However, these efforts encountered several implementation challenges. Reports from municipalities revealed administrative delays, especially impacting private homeowners and small enterprises unfamiliar with complex grant processes. Overlapping responsibilities across federal, state, and local authorities further slowed fund disbursement, sometimes leading to frustration and deferred recovery (DKKV, 2022).

- Strengthening Flood Protection: Reconstruction included urgent repair and reinforcement of embankments, levees, retention basins, and drainage systems. Flood hazard maps were revised, and some regions imposed stricter planning permissions in high - risk zones (UBA, 2022).

Critics argue that many measures remained reactive rather than transformative. According to a German Federal Environment Agency review, while infrastructure repairs were initiated, broader adaptation strategies - such as ecosystem - based approaches, land - use adjustments, and floodplain restoration - were often secondary or delayed. Local disparities in administrative capacity exacerbated uneven implementation across municipalities (UBA, 2022).

Comparative Insights: Emilia - Romagna (2023) vs. Rhine - Erft (2021)

This section compares emergency preparedness, response, and recovery in the Emilia - Romagna (2023) and Rhine - Erft (2021) events, synthesising system design, warning and communication, operations (search and rescue), sheltering and health care, recovery, and resilience - building.

Emergency Preparedness, Response, and Recovery

System Design and Activation

- Emilia - Romagna activated structured civil protection protocols under a regionalised Italian system, enabling integrated early warning, evacuation, and shelter planning with clear institutional mandates.
- Rhine - Erft relied on a decentralised, multi - tiered German federal model. While formal structures like NRW Civil Protection and municipal leadership were mobilised, fragmentation slowed initial response and confused responsibility for key decisions.

Early Warning and Communication

- Emilia - Romagna issued 44 colour - coded alerts and over 170,000 SMS notifications. Red alerts prompted school closures, evacuations, and pre - emptive infrastructure checks.
- Rhine - Erft communities received alerts via apps and radio, but delays and inconsistent messaging led to underestimation of risk, particularly in Erftstadt.

Search and Rescue

- Emilia - Romagna mobilised national civil protection assets, army, and 8,000+ volunteers, plus international teams via the EU Civil Protection Mechanism.
- Rhine - Erft response was led by local fire brigades, THW, and Red Cross units, with significant reliance on volunteer first responders. In hard - hit areas like Erftstadt, rescues were hindered by infrastructure collapse and real - time coordination gaps.

Sheltering and Health Care

- Emilia - Romagna activated 160 municipal operation centres and provided coordinated shelters with psychological and medical support, particularly in Ravenna, Cesena, and Bologna.
- Rhine - Erft established medical stations and shelters through local Red Cross and municipal agencies. Mental health support was offered

but under - resourced, especially in rural zones.

Post - Flood Recovery and Reconstruction

- Emilia - Romagna recovery is still ongoing, but efforts include rapid assessments, inter - agency collaboration, and discussions around ecosystem - based solutions and adaptive rebuilding.
- Rhine - Erft received €30 billion through the Aufbauhilfe 2021 programme. However, delays in fund disbursement, administrative burden, and unequal local capacity led to uneven re-construction outcomes.

Resilience Building

- Emilia - Romagna initiated discussions on risk - sensitive land use and civil protection reform, aiming to strengthen nature - based approaches.
- Rhine - Erft updated flood maps and repaired defences, but critics note that many interventions were reactive, with long - term adaptation measures largely postponed or deprioritised.

Broader Lessons from Comparative Disaster Management

- Integrated Command and Local Autonomy Must Be Balanced: Emilia - Romagna's regional - led model enabled fast vertical coordination, while Rhine - Erft's decentralised system empowered local mayors but revealed major weaknesses in horizontal integration. Future frameworks must blend local responsiveness with coordinated decision - making platforms.
- Preparedness & Resilience: Both regions had technical preparedness systems (maps, plans, alerts), yet structural weaknesses, communication failures, and overwhelmed infrastructure demonstrated that resilience requires not just plans - but real - time coordination, redundancy, and adaptability.
- Recovery Should Be Transformative, Not Just Reconstructive: While Rhine - Erft committed substantial funds to rebuild, administrative complexity and lack of ecosystem - based planning hampered transformative change. Emilia - Romagna's early moves to embed climate adaptation into recovery plans suggest a more

operations (search and rescue), sheltering and health care, recovery, and resilience - building.

Emergency Preparedness, Response, and Recovery

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- Equity Matters in Disaster Response: Disparities in administrative and financial capacity - whether between urban and rural areas, or between households and institutions - shaped who recovered faster and who fell behind. Future disaster governance must address these equity gaps directly.
- The Role of Volunteers Is Critical, but They Need Support.: Both regions depended heavily on volunteer networks. These must be institutionalised with training, coordination platforms, and funding to ensure effectiveness without burnout or system overload.

6.0 Communications

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6.1 Communication and Public Information

Emilia - Romagna communications and public information

During the Emilia - Romagna floods of 2023, early warning systems played a crucial role in alerting residents and authorities, although the extreme nature of the event posed significant challenges (European Environment Agency, 2023; IFRC, 2023).

- Early Warning Systems: Throughout the event, the Italian Civil Protection Department utilised its national early warning system, "SISTEMA di Allerta," to keep residents informed. The public was regularly updated via social media, text alerts, and news channels. Local authorities also used sirens and door - to - door communication to warn people of immediate threats.
- Weather Forecasting and Alerts: The Italian Civil Protection, in collaboration with the European Centre for Medium - Range Weather Forecasts, issued early warnings based on meteorological forecasts predicting heavy rainfall and rising river levels. These alerts were shared through multiple channels, including SMS, social media, and local radio stations.
- Flood Alerts: The Centro Funzionale Decentrato (CFD) in Emilia - Romagna monitored river levels in real - time, issuing warnings as water levels rose dangerously in rivers such as the Reno and Savio.
- Public Communication: Emergency messages were delivered via sirens, mobile notifications, and municipal websites. The integration of AI - driven risk modelling improved early warning effectiveness, but disparities in digital literacy limited accessibility for some vulnerable populations.
- Challenges: Despite these efforts, the extreme weather exceeded predictions, leading to overwhelming floods that left little time for response in certain areas. The crisis underscored the need for enhanced climate adaptation policies and improved regional coordination.
- In the second flood event (May 15 - 17), all hydrometeorological alert zones in Emilia - Romagna exceeded moderate warning thresholds, with several - including those covering Bologna, Ravenna, Forlì - Cesena, and Rimini - reaching maximum criticality levels. The increasing runoff coefficients, reaching 77% in the Montone basin and 59% in the Senio basin, further intensified the floods, highlighting the challenges in forecasting extreme hydrological events (Technical - Scientific Commission of the Emilia - Romagna Region, 2023).

While early warning systems were effective in many cases, the unpredictability of extreme weather events calls for a reassessment of flood forecasting methodologies and crisis response strategies. In particular, targeting appropriate levels of information to relevant agencies and the general public.

Rhine - Erft communications and public information

The floods affecting the Rhine - Erft region in 2021 demonstrated both the strengths and limitations of Germany's early warning infrastructure. This underscored the need for enhanced risk communication strategies and cross - border cooperation to improve early warning effectiveness in future climate - related disasters.

Rhine - Erft

The 2021 floods in the Rhine - Erft district served as a demonstration of both the capabilities and limitations of Germany's early warning and response systems in the face of increasingly extreme weather events. Although meteorological and hydrological monitoring frameworks were in place, their translation into timely and effective action on the ground revealed critical weaknesses.

Meteorological Alerts:

The German Weather Service (Deutscher Wetterdienst, DWD) provided advance warnings of prolonged heavy rainfall in the days leading up to the event, based on ensemble predictive models supported by the European Flood Awareness System (EFAS). These forecasts identified elevated flood risk across western Germany, and alerts were issued through multiple channels, including mobile app notifications, SMS alerts, and public radio and television broadcasts (EFAS, 2021; Coper-

Despite this, many affected residents reported either not receiving warnings or failing to interpret them as requiring urgent action, pointing to a disconnect between forecast accuracy and public risk perception. As a result of a questionnaire conducted by Thieken et al (2023), only 35% of residents reported receiving the alerts, with a high proportion of those not receiving it being the elderly. Indeed, the Westdeutscher Rundfunk (WDR) Cologne, Programmdirektion NRW, Wissen und Kultur suggested that considerably more people would have been reached if the flood warnings were put out through TV and radio for several days in easily accessible storylines.

River Monitoring and Flood Onset:

Regional water authorities, including the Rheinisch - Westfälisches Wasserwirtschaftsamt (RW - WWA), continuously monitored river levels using automated sensor networks linked to hydrological data centres. However, the rainfall volumes - locally exceeding 100 mm in 24 hours - led to flash flooding in tributaries and low - lying urban zones not previously categorised as high risk. The speed and intensity of the flooding outpaced the response capacity in some municipalities, suggesting that historical hazard maps and design standards underestimated compound rainfall and runoff scenarios (Surminski, Roezer & Golnaraghi, 2020).

Governance and Communication Challenges:

The response effort exposed significant coordination gaps between federal, state, and municipal levels. Decision - making about evacuations and disaster declarations was delayed in several communities due to unclear communication protocols and fragmented responsibilities across jurisdictional tiers. A European Parliamentary Research Service review found that this fragmentation "reduced the speed and clarity of protective action" (EPRS, 2022). Additionally, socio - economic inequalities affected access to timely alerts, with some residents - especially the elderly, migrants, and those in digital poverty - unaware of or unable to act on the warnings issued (German Committee for Disaster Risk Reduction, 2024). It is evident that the local census information has little value in helping authorities in assessing vulnerability due to its coarseness and should be improved to understand vulnerability in the future.

Public Communication and Community Response:

Local authorities issued evacuation notices in the most severely impacted towns such as Erftstadt and Blessem, but these were often reactive rather than preventative. In the absence of unified public alerting infrastructure, community networks - such as local volunteer fire brigades and neighbourhood groups - played a critical role in spreading the word, particularly in areas with older populations or language barriers. These informal systems helped to reduce casualties in some cases, but their reliance also highlighted the absence of a national, rapid push - alert mechanism at the time.

Lessons and Outlook:

The floods underscored the urgent need for integrated risk communication strategies that combine forecast information with clear, action - oriented public messaging. They also reinforced calls for improved cross - sector and cross - border cooperation, particularly in shared river basins, where upstream rainfall can have rapid downstream impacts. As climate change increases the likelihood of similar or more extreme events, the Rhine - Erft case has become a reference point in debates about modernising Germany's disaster risk governance.

6.2 Communications between impacted municipalities

Emilia - Romagna

During the Emilia - Romagna floods of 2023, effective communication between municipalities was essential for coordinating emergency responses and ensuring timely information flow.

- Regional Coordination: The Emilia - Romagna Region facilitated communication between municipalities via the Regional Civil Protection Centre, which served as a central hub for real - time information sharing between local authorities and emergency services.
- Local Authorities: Municipalities used local emergency operation centres (EOCs) to share updates on flood levels, evacuations, and resource needs. These centres were integrated

with regional and national crisis management systems to ensure a coordinated response (CRED, 2024; IFRC, 2023).

- Communication Tools: Authorities employed SMS alerts, radio broadcasts, social media, and dedicated emergency apps to keep municipalities and the public informed. Teleconference systems facilitated direct coordination between municipalities and the regional crisis management team.
- Challenges: Communication networks suffered temporary disruptions in some areas due to infrastructure damage, which complicated coordination, particularly in remote/ agricultural locations. In these cases, backup systems such as satellite communication and emergency radio links were used (WMO, 2023).
- Post - Flood Analysis: Authorities conducted a post - flood assessment to identify communication gaps and enhance future coordination. Recommendations included upgrading digital communication infrastructure and improving early warning dissemination methods (European Environment Agency, 2023).

While communication between municipalities was largely effective, the event highlighted the need for more resilient communication systems and infrastructure to ensure rapid and reliable information exchange in future disasters.

Rhine - Erft

The floods affecting the Rhine - Erft region of 2021 revealed both the strengths and limitations of municipal communication during extreme flood events. Although communication systems were in place, the scale and speed of the flooding created challenges (German Committee for Disaster Risk Reduction, 2024).

- Central Coordination: The North Rhine - Westphalia (NRW) State Government coordinated the emergency response in collaboration with the Ministry of the Interior of NRW and the State Office for Nature, Environment and Consumer Protection (LANUV). The Regional Emergency Management Centre served as a coordination hub, linking federal and state agencies with municipal crisis teams to exchange real - time data on water levels, infrastructure damage, and evacuation planning.

complemented by predictive modelling from the European Flood Awareness System (EFAS), which had issued flood risk alerts several days in advance (Surminski, Roezer & Golnaraghi, 2020; EFAS, 2021).

- Communication Tools: Municipalities used a mix of channels - SMS alerts, local radio, television, social media, and municipal websites - to disseminate warnings. Two digital emergency apps, KATWARN and NINA, provided geolocated alerts to residents and authorities. These systems, while technically functional, suffered from inconsistent usage across municipalities and populations. In particular, elderly residents, non - German speakers, and people without smartphone access were disproportionately excluded from receiving digital warnings (EPRS, 2022; Fekete & Sandholz, 2021).
- Challenges: The sudden onset and intensity of the flooding caused widespread power outages and telecommunications failures. In hard - hit areas such as Erftstadt, digital systems became inoperable, and emergency responders had to fall back on satellite phones, analogue radio, and physical door - to - door notifications to issue evacuation orders (Fraunhofer Institute for Communication, Information Processing and Ergonomics, 2022; Helmholtz Centre for Environmental Research, 2022).

Fekete and Sandholz (2021) identified additional systemic issues:

- Unclear distribution of responsibilities between administrative levels caused delayed or inconsistent implementation of emergency measures.
- Low public trust in warnings, partly due to past false alarms and a lack of actionable messaging.
- Lack of redundancy in communication channels made the system highly vulnerable to outages.
- Communication inaccessibility for socially or digitally marginalised groups limited the effectiveness of alerts.
- Coordination hurdles: Despite the existence of early warning systems, information flow between federal, state, and municipal levels was often fragmented. Local authorities reported delayed receipt of warnings and poor interoperability across systems. In remote or flood - isolated areas, this contributed to slower emergency response times and disrupted logistics for evacuation and relief distribution (Fekete & Sandholz, 2021).

Post - Flood improvements: In the aftermath of the disaster, emergency agencies and policymakers called for urgent improvements in Germany's crisis communication infrastructure. Key recommendations included:

- The development of redundant communication systems that can function during power outages
- Greater integration between municipal and federal emergency communication platforms
- Improved multilingual communication strategies tailored to regional demographics

These priorities were also highlighted by the Rhine - Erft Real - World Lab under the EU - funded DIRECTED project, which gathered local stakeholder input to identify critical gaps in preparedness and coordination (DIRECTED Project, 2023).
Despite the challenges faced during the 2021 floods, municipal communication played a crucial role in coordinating emergency efforts. The event underscored the importance of strengthening communication networks to improve disaster preparedness and response in future extreme weather events.

6.3 Communications between Regional Emergency Services

Emilia - Romagna

During the Emilia - Romagna floods of 2023, communication between regional emergency services was essential for coordinating rescue efforts, evacuations, and managing the crisis across multiple municipalities.

- Centralised Coordination: The Emilia - Romagna Regional Civil Protection acted as the primary coordination hub, ensuring seamless communication between various emergency services, including firefighters, police, medical teams, and volunteers. These agencies collaborated to manage operations in flood - affected areas and shared real - time updates.
- Communication Tools: During the May 2023 floods, emergency responders in Emilia - Romagna faced significant disruptions to power and telecommunications infrastructure, particularly in the most affected areas such as Faenza, Lugo, and parts of Ravenna province. To maintain coordination, they relied on a combination of analogue and digital systems.

Analogue radio networks and satellite phones were used to sustain communications among emergency teams when mobile and broadband networks failed (Italian Red Cross, 2023). The regional Weather Alert Emilia - Romagna portal, operated by the Civil Protection Agency of Emilia - Romagna, provided real - time hydrological data, flood bulletins, and public safety messages via a mobile - accessible interface (Regione Emilia - Romagna, 2023a).

In early 2023, the region also took part in the pilot phase of Italy's IT - Alert system - a national cell broadcast platform designed to deliver geo - targeted emergency alerts directly to mobile phones. Although still under development at the time of the floods, initial deployments were tested in Emilia - Romagna and complemented existing SMS - based warnings (Dipartimento della Protezione Civile, 2023).

Where digital communication proved unreliable, municipal authorities and volunteers used loudspeaker vehicles and door - to - door notifications to reach residents, particularly in rural areas or where language or digital barriers limited access to official alerts (Caritas Italiana, 2023).

- Cross - Service Coordination: Local fire departments, ambulance services, and rescue teams worked closely with the regional coordination centre. Helicopters, boats, and specialised vehicles were deployed to inaccessible areas, with operations coordinated in real time through direct communication networks (CRED, 2024; IFRC, 2023).
- Challenges: The rapid escalation of the flooding and widespread infrastructure damage disrupted communication lines in some areas. Although satellite communication and radio systems provided backup, the sheer volume of data and the need for rapid coordination posed significant challenges (European Environment Agency, 2023).
- Post - Event Review: Following the floods, authorities conducted reviews of communication systems to identify gaps and enhance emergency coordination for future disasters. Recom-

infrastructure and investing in more resilient emergency communication technologies.

In summary, while communication between regional emergency services during the Emilia - Romagna floods was largely effective, the extreme nature of the event underscored the need for improved infrastructure and more resilient systems for handling large - scale, rapidly evolving disasters.

Rhine - Erft

During the floods affecting the Rhine - Erft Region in 2021, communication between regional emergency services played a vital role in disaster response yet faced significant challenges due to the scale and speed of the event (German Committee for Disaster Risk Reduction, 2024).

- Regional Emergency Services: Fire Department & Control Center Rhein - Erft - Kreis, The district's emergency control center was fully staffed during the flood events and coordinated over 3,000 emergency operations for fire brigades throughout the area. Local coordination centers were also set up in several municipalities to help manage the high volume of calls and ensure effective emergency response (Feuerwehr Kerpen, 2021). German Red Cross (DRK) Rhein - Erft, On the night of July 13 –14, volunteer DRK teams established an emergency shelter in Frechen for evacuees. They provided accommodation, food, and psychological support for displaced residents. DLRG (German Lifesaving Association), Bergheim Chapter, supplied rescue boat units as part of the Rhine - Erft district's disaster response plan and the water rescue task force of North Rhine - Westphalia. These teams were deployed to rescue people and animals trapped by floodwaters. (DLRG Ortsgruppe Bergheim, 2021). Over 17,000 THW personnel from across Germany were mobilized in the aftermath of the flooding in July 2021. They contributed more than 2.7 million work hours, assisting in debris removal, restoring infrastructure, and supporting logistical operations. (Technisches Hilfswerk, 2024).
- Communication Tools: Emergency services relied on radio communications, satellite phones, and emergency apps such as KATWARN to issue warnings and share updates.

These tools were vital for coordination, particularly as floodwaters cut off roads and disrupted conventional communication networks (EPRS, 2022; Helmholtz Centre for Environmental Research, 2022).

- Cross - Agency Collaboration: Fire brigades, THW (Technical Relief Organisation), the Red Cross, and local police worked together, exchanging information about flood zones, evacuations, and resource needs in real time. Helicopters and boats were deployed to reach isolated areas, with operations coordinated through emergency communications networks (Fraunhofer Institute, 2022).
- Challenges: The intensity of the July 2021 flooding in the Rhine - Erft region, particularly due to flash floods, caused extensive power outages and communication failures. At the peak of the disaster, over 200,000 people in North Rhine - Westphalia and Rhineland - Palatinate lost electricity, with restoration efforts taking several weeks in some areas (Bundesnetzagentur, 2021). The failure of critical infrastructure also disrupted flood monitoring - approximately 25% of hydrological gauging stations went offline due to power loss or physical damage (Fekete & Sandholz, 2021).

Although satellite phones and portable radio units were available to emergency responders, their limited coverage and technical capacity made continuous coordination difficult, particularly in flood - isolated municipalities such as Erftstadt (Civil Protection Knowledge Network, 2024). Loss of mobile and broadband networks also rendered digital emergency apps ineffective during key response windows (Helmholtz Centre for Environmental Research, 2022).

- Post - Event Review: Following the disaster, a series of institutional reviews and technical assessments identified urgent areas for improvement:

Interoperability between emergency services was cited as a priority, with calls to establish integrated, real - time communication systems that connect federal, state, municipal, and civil society actors (Fekete & Sandholz, 2021; DKKV, 2024).

Investment in redundant communication systems - such as satellite relay stations and battery - backed telecom infrastructure - was recommended to ensure continuity during outages (Fraunhofer Institute, 2022).

Authorities also highlighted the need for enhanced digital alert platforms, including wider rollout of cell broadcast systems, multilingual interfaces, and more user - friendly mobile apps (EPRS, 2022).

Resilience of monitoring systems was also discussed. Proposals included providing back - up power for river gauging stations and decentralised data access for crisis managers (UBA, 2022).

In summary, while communication between regional emergency services in the floods affecting the Rhine - Erft region was essential for coordinating the response, weaknesses in infrastructure resilience were exposed, highlighting the need for improved communication systems in future emergencies.

6.4 Cross Communications between Sectors

Emilia - Romagna

During the Emilia - Romagna floods of 2023, cross - sector communication was essential for a coordinated and effective response. Multiple sectors, including emergency services, local government, healthcare, infrastructure, and social services, collaborated to manage the crisis.

- Centralised Coordination: The Emilia - Romagna Regional Civil Protection served as the central coordination body, facilitating communication between local authorities, emergency services, healthcare providers, transport agencies, and volunteer organisations. This ensured rapid and accurate dissemination of information about flooding, evacuations, and resource needs.
- Emergency Services and Healthcare: Fire brigades, ambulance services, the Red Cross, and medical teams worked together, exchanging data on affected areas and casualties. Healthcare services coordinated with shelters and hospitals to manage patient surges and provide immediate care (CRED, 2023; IFRC, 2023).
- Transport and Infrastructure: Communication between transport agencies and infrastructure services was critical for ensuring road safety, organising evacuations, and repairing damaged infrastructure. Railway operators and local transport networks adjusted services, while utility companies addressed power outages, water supply disruptions, and emergency repairs (European Environment Agency, 2023).
- Social Services and Volunteers: Social services collaborated with NGOs and volunteer groups to provide shelter, food, and psychological support to displaced populations. Effective cross - sector communication facilitated the mobilisation of volunteers and equitable resource distribution.
- Challenges: Despite strong communication, infrastructure damage caused disruptions. Power and internet failures in certain areas necessitated the use of satellite communication and radio networks as backups (European Environment Agency, 2023; WMO, 2023).

Cross - sector communication during the Emilia - Romagna floods was generally effective, but the event highlighted the need for improved infrastructure resilience and emergency communication protocols for extreme conditions.

Rhine - Erft

The floods affecting the Rhine - Erft region in 2021 required effective cross - sector communication to coordinate emergency services, local government, healthcare, infrastructure, and social services.

- Centralised Coordination: Local crisis management teams facilitated communication between emergency services, local governments, utility providers, and healthcare facilities to manage evacuations and resource distribution (Surminski, Roezer, & Golnaraghi, 2020).
- Communication Tools: Emergency responders relied on radio networks, satellite phones, KATWARN alerts, and social media to share real - time data on flood levels, affected areas, and evacuation progress (EPRS, 2022; Helmholtz Centre for Environmental Research, 2022).

- Emergency Services and Healthcare: Fire departments, police, and rescue teams worked alongside hospitals and ambulance services to evacuate and treat injured individuals. Healthcare providers coordinated patient care and medical response efforts (Fraunhofer Institute, 2022).
- Transport and Infrastructure: Transport authorities, road maintenance teams, and railway operators coordinated to manage disruptions, reroute traffic, and repair damaged infrastructure. Utility companies provided updates on power outages and water supply restoration.
- Social Services and Volunteers: Social services, NGOs, and volunteer groups collaborated to provide essential aid, ensuring displaced populations received shelter, food, and mental health support.
- Challenges: The rapid and widespread nature of the floods overwhelmed communication infrastructure, causing network disruptions and power failures. Emergency responders depended on satellite communications and radio systems as contingency measures (WMO, 2022).

While cross - sector communication was crucial during the floods affecting the Rhine - Erft Region, the event underscored the need for more resilient communication infrastructure to withstand extreme weather conditions.

6.5 Public Risk Communications and (Mass) Media Publications

Emilia - Romagna

To deal with the exceptional media impact caused by the flood events in May 2023, the Regional Agency for Territorial Security and Civil Protection implemented a series of actions, agreed upon and organized with the Press Office of the National Department of Civil Protection, the Emilia - Romagna Region Press Agency, and the Staff of the President and Vice President of the Council.

The Objective was: to respond unambiguously to the information bodies, providing data on the management of the emergency and on the priorities to communicate to citizens; promptly and clearly.

First, a dedicated Communication and Information Function was structured with Agency staff. At the Agency's headquarters, a physical space was identified where officials from other bodies can also be accommodated, close to the offices reserved for other functions, which has become a fundamental logistical point for organising activities. A larger and better equipped press room was also set up at the Agency's headquarters in Bologna.

On average, starting from May, 2/3 official press releases per day were issued by the Region containing updates on the issuing of alerts, the damage situation, and the interventions of the National Civil Protection Service. Useful information for citizens on the reception areas open, who to contact in the area, the social, health, school, veterinary, waste collection assistance facilities activated and the measures adopted specifically to protect vulnerable people was also implemented.

The web and social pages of the Region's portal and the Agency were continuously updated.
https://allertameteo.regione.emilia - romagna.it/

The Communications Office supported the offices of the President of the Region to organize, especially from the second half of May, a daily press point for journalists which became the most important event from a media point of view. Furthermore, all the necessary support was provided, including logistical support, for the organization of visits to the places hit by the flood by representatives of the Government and the European Commission.

The numerous requests from journalists and communications professionals at regional, national and international levels – for statements, reports, interviews, updates – were shared among the officials on duty and managed according to shared criteria.

Importantly, due to the amount of work, was the direct information given to citizens. After the first days of the emergency, considering the exceptional nature of the event and its extension, an increasingly precise and effective procedure was agreed at regional level. From the list of FAQs to be provided to the secretariats to answer citizens' calls, the Agency moved on to the publication of more

Figure 16: Civilian Rescue - Emilia - Romagna Region - Source: Territorial Safety and Civil Protection Agency, 2023.

structured QUESTIONS and ANSWERS on the websites and a regional FREE NUMBER was activated with dedicated operators who, in the first emergency phase, provided assistance to over 8 thousand citizens.

The web pages of the regional institutional sites were reorganized to inform citizens of the first measures adopted to secure the territories and ensure the restoration of normal living conditions.

During the Emilia - Romagna floods of 2023, effective public risk communication and mass media played a key role in informing the public about the ongoing situation, evacuation orders, and safety measures.

- Early Warnings and Public Alerts: The Italian Civil Protection Department issued official flood warnings and emergency alerts through various channels, including SMS messages, social media, radio, and television broadcasts. In particular, in the period from 1 May to 13 June 2023, through the regional warning system (https://allertameteo.regione.emilia-romagna.it) 44 alerts were issued and distributed for the following phenomena: Hydraulic Criticality, Hydrogeological Criticality, Criticality for Storms, Wind, Sea State and Coastal Criticality. These types of warnings provided critical information about flood risks, evacuation orders, and safety precautions, particularly to at - risk populations.
- Social Media and Digital Platforms: Platforms like Twitter, Facebook, and Instagram were widely used by regional and local authorities to share real - time updates on the flood situation. Information on road closures, evacuation points, and emergency contacts was regularly posted, with residents encouraged to follow official channels for the latest news.
- Role of Mass Media: Traditional mass media outlets such as newspapers, TV, and radio stations were key in broadcasting updates and informing the public, particularly in rural areas where digital access was more limited. News outlets, like RAI and local broadcasters, provided round - the - clock coverage of the floods, helping raise awareness and direct people to safety.
- Visual Communication: Visuals, including drone footage, photos, and live videos, were used to show the scale of the disaster and highlight areas in immediate need of assistance. These visuals help to convey the severity of the

situation and prompted quicker responses from both local residents and external agencies (Palen & Anderson, 2016).

- Collaboration with NGOs and Volunteers: Non - governmental organisations (NGOs) and volunteer groups also played an active role in disseminating information about available relief services. They used both traditional and digital media to promote relief efforts, provide shelters, and encourage donations (IFRC, 2023). The Red Cross and other humanitarian groups leveraged both online and offline communication channels to coordinate disaster response efforts.
- Challenges: Although communication was largely effective, some challenges arose due to the overload of information, particularly on social media, where misinformation and rumours sometimes spread. Efforts were made to verify and counter false information, but in the chaos of the disaster, this proved difficult in certain areas.

In summary, public risk communications during the Emilia - Romagna floods relied heavily on a mix of traditional and digital media to reach a broad audience. While the system was generally effective, the rapid escalation of the floods and the spread of misinformation, such as the floods being caused by cloud - seeding and dam releases, presented challenges that highlighted the need for better information management and clearer communication strategies in future emergencies (EDMO, 2023).

Rhine - Erft

During the floods affecting the Rhine - Erft region in 2021, public risk communications and mass media played a pivotal role in informing the public and coordinating evacuations, but the speed and scale of the disaster created significant challenges (Thieken et al., 2022a).

- Early Warnings and Public Alerts: The German Weather Service (DWD) and the German Civil Protection Agency (BBK) issued flood warnings via SMS, social media, emergency apps (such as KATWARN and NINA), and official websites. These alerts informed residents of rising water levels, areas at risk, and recommended actions, such as evacuations.

Local authorities also used sirens to signal imminent danger, a method that remains crucial in areas with limited digital connectivity (Fekete & Sandholz, 2022).

- Role of Mass Media: Traditional mass media outlets, including TV, radio stations, and newspapers, were crucial in providing updates to the public. Public broadcasters like ARD and ZDF, as well as regional stations, provided continuous coverage, including live broadcasts and drone footage, showing the devastating impact of the floods and guiding people to safety. News reports played a key role in ensuring that affected populations had access to timely and reliable information during the crisis (Boin et al., 2021).
- Social media and Digital Platforms: Social media platforms like Twitter, Facebook, and Instagram were used extensively by both official channels and citizens to share real - time updates and warnings (Reuter et al., 2022). Municipalities and emergency services regularly posted evacuation instructions, safety measures, and shelter locations. However, social media also provides the risk of the spread of misinformation, such as anti - government rhetoric (Coda, 2021), political disinformation (News Guard, 2021, APNews, 2021) requiring authorities to quickly clarify and correct false reports.
- Visual Communication: Powerful visuals, including images and videos from affected areas, were broadcast widely. These images helped emphasise the urgency of the situation and prompted action from residents and authorities. The visuals also played a role in mobilising national and international support (Fiorucci et al., 2023).
- Challenges: One of the main challenges was the overload of information. With the disaster unfolding rapidly, authorities and media struggled to keep up with the scale of the flood, particularly in remote or less accessible areas. Communication infrastructure was also impacted, with power outages and mobile network congestion affecting the ability to send timely updates (Fekete et al., 2022).
- Collaboration with NGOs and Volunteers: Alongside government bodies, NGOs like the German Red Cross and local volunteer organisations used mass media and social media to inform people about available aid, shelters, and emergency services, and to encourage

donations and volunteer support (IFRC, 2022). NGOs played a critical role in coordinating local relief efforts and filling gaps where official responses were delayed.

In summary, public risk communications during the floods affecting the Rhine - Erft region involved a blend of traditional media, social media, and emergency alerts to provide crucial information. Despite challenges such as information overload and network disruptions, the overall communication effort played a critical role in guiding people through the crisis and coordinating the response (Thieken et al., 2022a).

6.6 Post Event Communications

Emilia - Romagna

On information for citizens, the Region has continued to issue press releases to update on all the safety, restoration, assistance and reconstruction interventions.

A dedicated portal has been created "Emilia – Romagna. Rebuilding after the flood" (www.regione.emilia - romagna.it/alluvione) and a service dedicated to the works that are being carried out in the affected areas has been created with georeferenced sheets on the hydraulic defence interventions (https://www.regione.emilia - romagna.it/alluvione/cantieri) queryable by external users with individual cards on location, type of work, amount financed.

The Region has organized numerous initiatives in the territory to remember the events and the commitment made in emergencies, including the event "A day to say thank you" in Faenza on June 15, 2024 organized together with institutions, state forces, and the world of volunteering and editorial initiatives (for example: "What matters") https://www.regione.emilia-romagna.it/alluvione/quel-che-conta

After the devastating Emilia - Romagna floods of 2023, post - event communications focused on recovery, relief efforts, and providing transparency about the ongoing situation.

- Damage Assessment and Public Updates: Regional and local authorities, including the Emilia - Romagna Civil Protection Agency, issued frequent updates to the public on the extent of the damage, including road closures, infrastructure damage, and recovery timelines. These updates helped residents and businesses stay informed about the evolving situation and how it might impact their daily lives.
- Government Statements: The Italian government and the regional president held press conferences to inform the public about the official response and the disbursement of aid. These briefings were carried by both television and social media, detailing relief measures, emergency funds, and plans for rebuilding efforts.
- Media Coverage: Traditional media outlets such as RAI, local broadcasters, and national newspapers continued to provide comprehensive coverage of the aftermath, including human interest stories, updates on affected communities, and recovery progress. These media outlets played a role in maintaining public awareness and encouraging national solidarity, with past research indicating that continued media attention can influence political and financial support for disaster - stricken regions (Houston et al., 2014).
- Social media and Digital Platforms: Local and regional authorities, along with NGOs and volunteer groups, used social media to update the public on donation drives, volunteer opportunities, and recovery efforts. Hashtags related to the floods helped consolidate information and raise awareness about ongoing needs in affected areas. While digital platforms were crucial for mobilising support, they also posed challenges in terms of controlling misinformation.
- Community Engagement: Authorities provided a platform for affected residents to share their experiences and receive feedback through online forums and community meetings. This was important in ensuring that voices from the ground were heard and that recovery efforts were aligned with community needs. Studies highlight that participatory communication approaches improve public trust and the effectiveness of disaster response efforts (Fothergill & Peek, 2019).
- Challenges: One of the main challenges in post - event communications was managing the vast

flow of information regarding relief efforts, donations, and recovery plans. There was also a need to combat misinformation or rumours circulating on social media, and authorities worked hard to correct false narratives that arose. The risk of "disaster fatigue" was also noted. This is where prolonged exposure to crisis - related content leads to declining public engagement over time (Pfefferbaum et al., 2019).

- Long - Term Communication: As the focus shifted to rebuilding, ongoing communications campaigns highlighted the long - term recovery process, encouraging support for sustainable rebuilding and flood prevention measures to reduce future risks. The Emilia - Romagna Region has dedicated a section, in the official website (Emilia - Romagna, ricostruire dopo l'alluvione del maggio 2023 - Emilia - Romagna, ricostruire dopo l'alluvione del maggio 2023 - Regione Emilia - Romagna), to the May 2023 event, in which are reported information about contributions and aid, shipyards, Acts - decrees - ordinances, donation Report. Research suggests that transparent and continuous communication about recovery progress is key to maintaining public trust and ensuring resilience against future disasters (Aitsi - Selmi et al., 2016).

In summary, post - event communications following the Emilia - Romagna floods of 2023 relied heavily on traditional media, social media, and government updates to inform the public about relief efforts, recovery timelines, and the progress of rebuilding initiatives. Despite challenges in managing information overload, the communication strategy helped maintain transparency and encouraged collective action during the recovery phase.

Rhine - Erft

In the aftermath of the floods affecting the Rhine - Erft region in 2021, post - event communications focused on providing updates, coordinating relief efforts, and ensuring transparency for affected residents and the broader public.

- Damage Assessment and Official Reports: After the flooding, regional authorities, including the North Rhine - Westphalia (NRW) state government and local municipalities, issued regular updates on the damage assessment. These reports covered infrastructure damage, evacuation centre locations, and road closures. They were shared via official websites, press releases, and social media channels to keep residents informed about the recovery process. Research suggests that transparent communication in disaster response is essential in mitigating uncertainty and improving public trust (Houston et al., 2014).
- Government and Local Authority Briefings: The NRW state government and local officials held press conferences to update the public on the ongoing relief efforts, funding allocations, and recovery plans. These briefings were widely broadcast by TV stations and online media, ensuring that crucial information reached a broad audience (Land Nordrhein - Westfalen, 2021).
- Media Coverage: National and regional media outlets such as ARD, ZDF, and local newspapers provided ongoing coverage of the aftermath, highlighting the personal stories of flood victims, the extent of the damage, and recovery progress. Continuous reporting also helped raise awareness about areas still in need of urgent assistance. Research shows that disaster media coverage plays a key role in shaping public perception and encouraging donations for relief efforts (Pantti, Wahl - Jorgensen & Cottle, 2012).
- Social Media and Digital Communication: Social media played a key role in post - event communications, with local authorities, NGOs, and volunteer groups using platforms like Twitter, Facebook, and Instagram to disseminate real - time updates. Social media also became a channel for fundraising campaigns, volunteer mobilisations, and public appeals for donations. However, scholars note that while digital platforms improve communication speed, they also present challenges in verifying information.
- Challenges: One of the main challenges in post - event communications was the overload of information and the disruption of communication infrastructure. Many areas experienced power outages and network congestion, making it difficult for residents to access timely information (Zhao & Shi, 2024). Additionally, misinformation circulated on social media, leading to confusion, which local authorities had to address. The need to counter false narratives is a well - documented issue in crisis

communication, as misinformation can undermine response efforts.

- Long - Term Recovery Messaging: As the focus shifted to long - term recovery, authorities continued to communicate about sustainable rebuilding efforts, flood protection measures, and future prevention plans to reduce the risk of similar disasters (Birkman et al, 2023). These messages were designed to build resilience in affected communities and encourage national and international support for long - term reconstruction. Research shows that continued public communication is crucial in maintaining trust and ensuring that disaster - affected communities remain engaged in the rebuilding process (Aitsi - Selmi et al., 2016).

In summary, post - event communications following the floods affecting the Rhine - Erft region were crucial in keeping the public informed about recovery efforts, providing vital information on relief services, and coordinating long - term rebuilding efforts. While challenges like misinformation and infrastructure disruptions were present, the overall communication strategy played an essential role in the aftermath.

6.7 Comparative Insights – Communication and Public Information

Emilia - Romagna (2023) vs. Rhine - Erft (2021)

This section compares public risk communication in Emilia - Romagna (2023) and Rhine - Erft (2021), covering early warning systems, inter - municipal and inter - service coordination, cross - sector interfaces, public - facing messaging, post - event outreach, and targeted recommendations.

Early Warnings and Forecasting Systems

Emilia - Romagna utilised a multi - layered, integrated early warning system (SISTEMA di Allerta), combining regional forecasts, real - time hydrological monitoring, and colour - coded alerts. The region coordinated across municipal, regional, and national levels and deployed a wide range of delivery tools including sirens, SMS, social media, and websites.

Rhine - Erft depended on DWD and EFAS forecasts distributed via mobile apps (KATWARN, NINA), media broadcasts, and local sirens. However, limited uptake of alerts, unclear messaging, and weak integration between agencies undermined response effectiveness. Only 35% of residents reported receiving warnings.

Key insight: Emilia - Romagna demonstrated more cohesive, centrally coordinated multi - channel delivery, while Rhine - Erft's fragmented and less accessible warning mechanisms reduced public responsiveness, especially among the elderly and digitally excluded.

Communication Between Municipalities

Emilia - Romagna ensured high levels of coordination between municipalities via local emergency operation centres (EOCs), teleconference systems, and regional support from Civil Protection. Despite infrastructure damage, satellite and radio backups sustained communication.

Rhine - Erft established regional coordination via the NRW Emergency Management Centre, but inconsistent usage of communication tools, lack of interoperability, and fragmented jurisdictional roles led to slower action and delayed information transfer in some areas.

Key insight: Emilia - Romagna achieved more seamless horizontal coordination by integrating municipal centres with regional structures and contingency tools; Rhine - Erft's more siloed system created information flow bottlenecks during critical periods.

Communication Between Emergency Services

Emilia - Romagna maintained real - time communication among fire brigades, police, health services, and volunteers via both digital and analogue systems. Pilot use of the new IT - Alert system provided geo - targeted warnings. Where digital services failed, door - to - door and loudspeaker methods filled the gap.

Rhine - Erft deployed radio, satellite phones, and emergency apps across emergency teams, but power outages and network collapse in places like Erftstadt disrupted operations. Limited redundancy

Key insight: Emilia - Romagna's preparedness with analogue and satellite backups sustained operations; Rhine - Erft suffered from inadequate resilience in digital infrastructure and system interoperability.

Cross - Sector Communication

Emilia - Romagna facilitated strong coordination between emergency services, healthcare, utilities, transport, and social services through Civil Protection - led interfaces. Volunteers and NGOs played active, integrated roles in information flow.

Rhine - Erft ensured basic inter - sector collaboration, but disruption to infrastructure and lack of unified platforms hampered consistency. Efforts varied across municipalities and were reactive rather than pre - emptive.

Key insight: Cross - sector integration in Emilia - Romagna was more robust and centralised; Rhine - Erft faced greater fragmentation and limited systemic planning for cross - sectoral communication under stress.

Public Risk Communication and Media

Emilia - Romagna implemented a centralised communications strategy involving daily press briefings, real - time digital updates, and a public - facing FAQ portal. Social media was used actively, and a free hotline fielded 8,000+ calls. Efforts to manage mis/disinformation were explicit.

Rhine - Erft used traditional media and emergency apps to share information, and volunteers also supported outreach. However, misinformation circulated widely, and reliance on app - based systems excluded vulnerable groups.

Key insight: Emilia - Romagna invested in a proactive and unified public - facing strategy. In contrast, Rhine - Erft's more reactive communication - without strong control of the narrative - allowed confusion and exclusion to persist.

Post - Event Communication

Emilia - Romagna launched a comprehensive digital recovery portal with interactive maps, policy

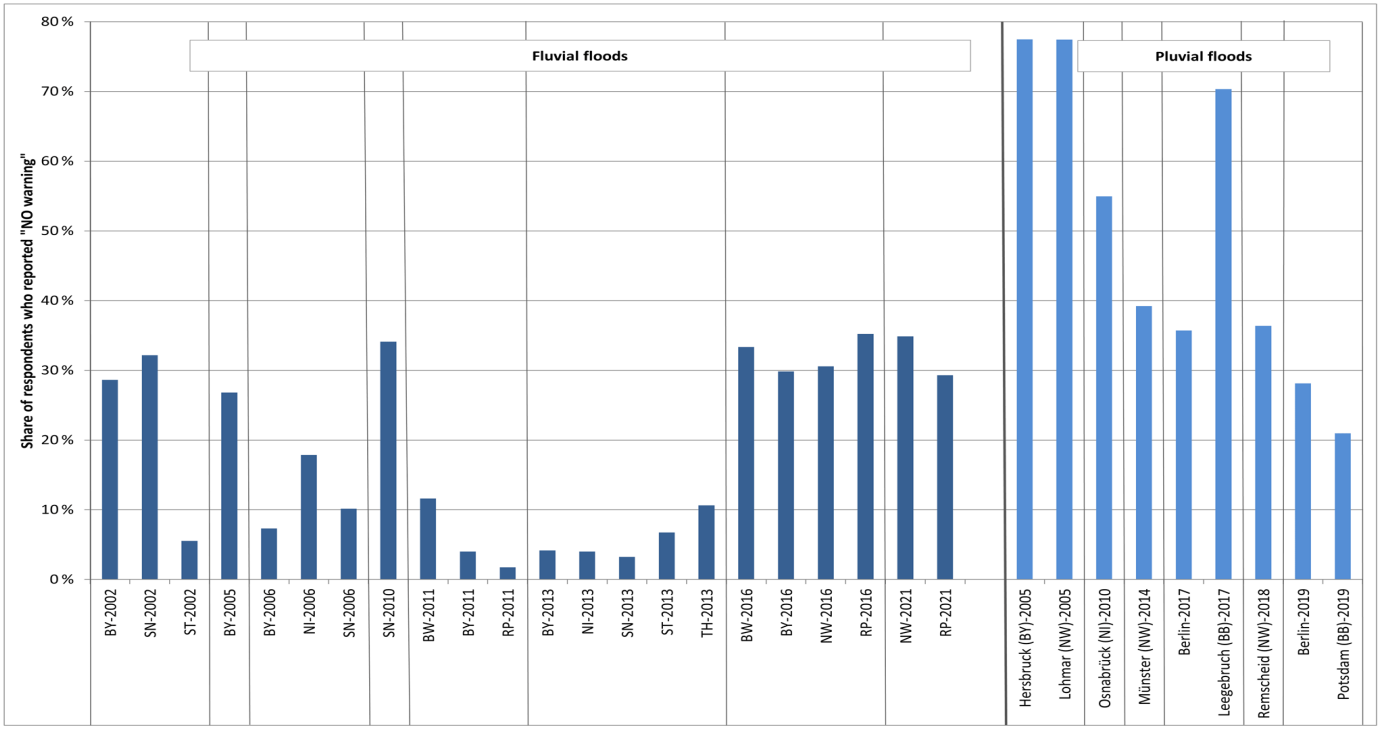

Figure 17: Share of German respondents who reported that they had not been warned before the flood danger became imminent (from Thieken et al. 2023: Fig. 2)

policy updates, and funding pathways. Public ceremonies and press initiatives maintained visibility and solidarity.

Rhine - Erft issued damage assessments and media updates, but recovery communication relied more on individual municipalities. Limited community participation and digital infrastructure weakened consistency.

Key insight: Emilia - Romagna used long - term, transparent communications to maintain momentum and rebuild trust. Rhine - Erft's post - crisis outreach was less centralised and lacked participatory platforms.

Local - Level Recommendations

Emilia - Romagna

- Expand IT - Alert coverage: Accelerate full deployment of the national cell broadcast system with geo - targeted alerts, integrating it more deeply into regional emergency protocols.
- Increase digital literacy outreach: Launch community - based training to support vulnerable populations - especially the elderly and migrants - in accessing digital alert systems and understanding emergency messaging.
- Strengthen local backup systems: Invest in more widespread satellite and radio redundancy at the municipal level, particularly in rural/agricultural areas prone to network disruption.
- Improve citizen engagement platforms: Develop more interactive channels (e.g. regional apps, participatory forums) for residents to both receive and provide information before, during, and after crises.
- Enhance misinformation resilience: Establish rapid verification teams within Civil Protection's press units to detect, counter, and clarify false information on social media during emergencies.

Rhine - Erft

- Adopt a unified, multi - hazard warning platform: Transition from fragmented systems (KATWARN/NINA) to an integrated, cell broadcast - based alert mechanism accessible without app installation. This was since implemented in 2023. (BBK, 2025)
- Develop inclusive communication strategies: Create multilingual and low - tech communication materials (e.g. flyers, radio PSAs) targeting digitally excluded groups including seniors and migrants.
- Clarify cross - level responsibilities: Define clear communication protocols between federal, state, and municipal governments, including who triggers evacuations and when.
- Improve system interoperability: Standardise communication protocols between emergency services (e.g. THW, fire brigades, Red Cross) using shared platforms and cross - training.
- Conduct regular disaster drills involving media: Simulate full - spectrum disaster communication scenarios (digital + analogue) involving press, public broadcasters, and volunteers to test readiness.

EU - Level Recommendations

- Mandate interoperable alert standards: Establish EU - wide minimum standards for early warning system compatibility (e.g. CAP protocol adherence, multilingual formats, accessibility requirements).
- Support regional communication infrastructure upgrades: Expand funding instruments under the EU Civil Protection Mechanism and Horizon Europe for analogue/digital system redundancy in disaster - prone regions.
- Invest in cross - border coordination protocols: Create shared platforms for transnational early warning dissemination - especially important for river basins like the Rhine - building on EFAS and Copernicus services.
- Develop a European media resilience framework: Promote guidance for media agencies on disaster coverage ethics, misinformation response, and equitable access to crisis information.
- Embed communication audits in EU disaster planning: Require member states to regularly assess the inclusivity, redundancy, and clarity of their disaster communication frameworks as part of EU risk assessments and Sendai Framework reporting.

Case Study

7.0 Volunteers, Emergency Housing and Vulnerable People Managment

Project 101073978 - DIRECTED - HORIZON - CL3 - 2021 - DRS - 01

Funded by the European Union

7.1 Volunteer Management

Emilia - Romagna:

Volunteers played an indispensable role in the response to the catastrophic floods that struck Emilia - Romagna in May 2023. Their contributions spanned all phases of emergency management, from immediate rescue to long - term recovery (Valente et al., 2023; European Commission, 2023).

Volunteer Coordination

Volunteer mobilisation was rapid and highly structured. The Emilia - Romagna Regional Civil Protection Department coordinated the deployment of thousands of volunteers from regional units, national organisations such as the Italian Red Cross and ANPAS, and local civil society groups (Valente et al., 2023). Modules from the European Union Civil Protection Mechanism (UCPM) were also activated, including specialised pumping units from Slovakia, Slovenia, France, Belgium, Austria, Germany, and Poland (European Commission, 2023). Spontaneous volunteers, particularly youth groups, also mobilised organically in highly affected areas such as Cesena and Forlì (Futuresilience, 2024).

Roles and Responsibilities

- Volunteers supported a wide range of critical response and recovery tasks:
- Assisting in search and rescue operations,
- Supporting the evacuation of vulnerable residents,
- Providing first aid and basic health support,
- Distributing food, clean water, and essential supplies,
- Setting up and operating emergency shelters,
- Participating in extensive debris and mud clearance operations once waters receded (EFAS, 2023; IFRC, 2023).

In remote or isolated municipalities, where professional responders were delayed or overwhelmed, volunteers often served as the first point of assistance.

Training and Wellbeing Support

Volunteer safety and psychological wellbeing were prioritised throughout the response. Just - in - time training was provided on personal protective equipment (PPE), safe rescue equipment (SRE), safe rescue techniques, and risk mitigation strategies (Valente et al., 2023). In addition, Psychological First Aid (PFA) was made available by trained specialists from the Italian Red Cross, Società Italiana di Psicologia dell'Emergenza (SIPE), and other national mental health networks (European Environment Agency, 2023a). This support was essential in mitigating the emotional toll on volunteers operating in high - stress and traumatic conditions.

Integration with Emergency Services

Volunteers were fully integrated into the wider emergency coordination framework and worked alongside firefighters, healthcare personnel, army units, and municipal authorities (Valente et al., 2023; IFRC, 2023). Their efforts were coordinated through Municipal and Regional Emergency Operations Centres (Centri Operativi Comunali and Regionali), ensuring alignment of actions and resource prioritisation. This integration extended the reach and responsiveness of official services and helped to restore essential functions in overburdened districts.

Impact and Legacy

The swift, structured, and widespread involvement of volunteers alleviated pressure on institutional response mechanisms and accelerated both rescue and recovery phases. Their actions not only enhanced operational capacity but also fostered social solidarity, reinforcing the region's resilience in the face of disaster (European Commission, 2023).

Identified Issues in Volunteer Management

Coordination of Spontaneous Volunteers

While institutional volunteer deployment (e.g. Italian Red Cross, Protezione Civile) was well managed, spontaneous or unaffiliated volunteers - those who showed up independently - were often difficult to coordinate, track, or integrate effectively. This sometimes led to duplication of effort, unsafe actions, or congestion at emergency sites (Futuresilience, 2024; Valente et al., 2023).
"The presence of a large number of spontaneous volunteers, while valuable, created logistical

challenges for local coordinators and occasionally overwhelmed official emergency operations."
- (Valente et al., 2023)

Uneven Training and Preparedness

Although many volunteers received just - in - time training, not all were adequately equipped to handle high - risk tasks. Reports noted inconsistent use of PPE and limited understanding of local hazards, particularly among new or spontaneous volunteers (Valente et al., 2023; IFRC, 2023).

Volunteer Fatigue and Psychological Strain

Some volunteers worked in difficult conditions for extended periods without sufficient rest or mental health support. Although Psychological First Aid was offered, coverage was uneven, especially in smaller municipalities (EEA, 2023). This contributed to emotional burnout, especially among younger and first - time volunteers.

Data Gaps in Volunteer Tracking

There was no unified digital system in place to track hours, deployment, or tasks across all levels of the volunteer force. This limited the region's ability to evaluate performance, assign responsibilities effectively, or reward contributions fairly (Futuresilience, 2024).

Limited Local Capacity for Surge Management

Smaller municipalities lacked pre - established protocols for absorbing large numbers of volunteers. This led to bottlenecks in housing, food provision, and task allocation, especially in the first days of the emergency (Valente et al., 20235).
The swift and organised involvement of volunteers helped ease the burden on professional services and was vital to the overall recovery effort (European Commission, 2023).

Volunteer Management – Rhine-Erft Region Floods (July 2021)

Volunteers were vital in response and recovery operations during the catastrophic flooding in the Rhine-Erft region (including Erftstadt) in July 2021, when extreme rainfall triggered widespread flooding along the Erft and Rhine tributaries (Kron et al., 2022; Bier et al., 2023).

Volunteer Coordination

Key organisations such as the German Red Cross (DRK), Technisches Hilfswerk (THW), and local volunteer fire brigades led official response efforts. The THW, with over 80,000 volunteers, deployed more than 2,100 personnel from nearly 165 regional units, supported by an additional 4,000 federal volunteers over the following weeks (DRK, 2021). Coordination was managed through Landkreis (district - level) civil protection offices, ensuring volunteer deployment was aligned with evolving community needs.

Roles and Tasks

Volunteers played many essential roles:

- Conducted search and rescue and evacuations, especially in Erftstadt/Blessem (Surmann et al., 2022; Bier et al., 2023).
- Operated flood pumps, cleared debris, and supported engineers in reinforcing breached embankments (THW annual report, 2021).
- Distributed food, clean water and managerial support at shelters, working alongside local fire brigades and police forces (DRK, 2021).

Support and Training

Volunteers received rapid operational briefings and safety training, with THW and civil protection agencies providing PPE orientation and technical guidelines. Psychological support services - including Psychological First Aid - were made available through the German Red Cross to address trauma experienced in high - risk deployments (DRK, 2021; WHO, 2021).

Collaboration with Authorities

Volunteers operated seamlessly alongside official services - fire departments, police, technical teams, and local administration - particularly in rural and residential zones where professional capacity was quickly overstretched (Surmann et al., 2022). Multi - agency coordination facilitated integrated operations at regional control centres.

Challenges Identified

Despite the overall success, evaluations noted several areas for improvement:

Integration of Spontaneous Volunteers
Numerous spontaneous volunteers self - deployed, especially in Erftstadt - Blessem. Though well - intentioned, their integration was not systematically managed, creating coordination difficulties and safety risks.

Communication Breakdown
Post - event surveys revealed significant communication issues between volunteers and authorities, with many volunteers expressing confusion over roles, reporting lines, and safety protocols.

Resource Strain and Logistics
Removing debris from homes and infrastructure placed heavy demands on volunteer teams, with equipment shortages (e.g. for pumping) and limited logistical support noted during peak hours (DRK, 2021).

7.2 Emergency Housing

Emilia - Romagna

During the Emilia - Romagna floods of 2023, emergency housing was a critical part of the response as thousands were displaced (European Commission, 2023; BBC News, 2023).

- Shelter Setup: Temporary shelters were established in community centres, schools, and sports halls across the affected municipalities. These shelters provided displaced residents with food, water, and basic medical care.
- Accommodation Support: For those whose homes were severely damaged, local authorities, in collaboration with the Italian Red Cross and other organisations, worked to arrange temporary housing in hotels, guesthouses, and other available accommodation.
- Long - Term Housing Solutions: In the aftermath, efforts were made to find longer - term housing solutions for those whose homes were uninhabitable, including government grants for repairs and relocation assistance (IFRC, 2023).
- Coordinated Efforts: The regional government and local municipalities coordinated housing efforts, ensuring that displaced residents were housed as quickly as possible and supported during the recovery phase.

Rhine - Erft

During the floods affecting the Rhine - Erft Region in 2021, emergency housing was urgently needed as many homes were damaged or destroyed.

- Temporary Shelters: Municipalities set up emergency shelters in community centres, sports halls, and schools to accommodate displaced residents. These shelters provided essential services such as food, medical care, and psychological support (German Red Cross, 2021).
- Alternative Accommodation: For those whose homes were severely damaged, local authorities coordinated with hotels, guesthouses, and other private accommodations to provide temporary housing (THW, 2021; Financial Times, 2021).
- Rehousing Support: Longer - term housing solutions included government assistance for home repairs, rental support, and financial aid for those whose homes were rendered uninhabitable. Efforts were made to expedite the recovery process for affected residents (IFRC, 2023).
- Collaboration: The German Red Cross and local volunteer organisations helped manage shelters and provided logistical support to ensure displaced people had safe and comfortable accommodation during the crisis.

7.3 Support of Vulnerable Groups

Emilia - Romagna

During the Emilia - Romagna floods of 2023, vulnerable groups, such as the elderly, people with disabilities, and low - income families, received targeted support (European Commission, 2023; BBC News, 2023).

- Evacuation Assistance: Vulnerable individuals were prioritised during evacuations. Civil protection teams, along with volunteers, ensured that people with mobility challenges, elderly

Figure 18: Aftermath clean - up - Emilia - Romagna Region - Source: Territorial Safety and Civil Protection Agency, 2023

residents, and those with special needs were safely evacuated from high - risk areas. safely evacuated from high - risk areas.

- Emergency Shelters: Special provisions were made in temporary shelters for vulnerable groups, including accessible facilities for people with disabilities, and designated areas for elderly individuals who required medical care or assistance (IFRC, 2023).
- Healthcare and Psychological Support: Dedicated healthcare teams, including those from the Italian Red Cross, provided medical care to vulnerable individuals, ensuring access to necessary medications and support. Psychological assistance was also offered to help those traumatised by the floods.
- Targeted Aid: Local authorities worked with social services to ensure that low - income families and other disadvantaged groups received timely aid, including food, clothing, and financial support for temporary housing (Reuters, 2023; The Guardian, 2023).

This coordinated approach helped ensure that vulnerable populations were given the care and protection they needed during and after the floods.

Rhine - Erft

During the floods affecting the Rhine - Erft region in 2021, vulnerable groups, including the elderly, disabled, and low - income families, were given focused support.

- Evacuation and Transport: Priority was given to vulnerable individuals during evacuations. Emergency services worked to ensure that the elderly, people with disabilities, and those with medical needs were safely evacuated, often using special transport or helping at shelters (German Red Cross, 2021).
- Emergency Shelters: Vulnerable groups were provided with accessible spaces in temporary shelters, with additional care provided for those needing medical attention or extra assistance, such as in hospitals or care facilities (THW, 2021; Financial Times, 2021).
- Healthcare Support: Mobile healthcare teams, including those from the German Red Cross, ensured that elderly individuals and those with chronic conditions received necessary care. Psychological support was also provided to those traumatised by the floods (IFRC, 2023).
- Targeted Aid: Social services coordinated the

distribution of food, clothing, and financial assistance to low - income families and individuals, ensuring they had the resources to cope with the immediate aftermath of the disaster.

These efforts were crucial in ensuring that vulnerable populations received the necessary care, protection, and support during and after the flood crisis.

7.4 Comparative Insights: Volunteers, Emergency Housing and Vulnerable People Management

This section compares how Emilia - Romagna (2023) and Rhine - Erft (2021) managed volunteers, emergency housing, and vulnerable groups, summarising coordination arrangements, operational gaps, and targeted recommendations at local and EU levels.

Volunteer Management

- Role and Scale of Volunteers: In both Emilia - Romagna (2023) and the Rhine - Erft region (2021), volunteers were indispensable across all stages of the emergency - rescue, relief, and recovery. Each region saw thousands of trained and spontaneous volunteers engage in debris removal, evacuations, food distribution, and shelter operations.
- Coordination Mechanisms: Emilia - Romagna's volunteer response was centrally coordinated by the Regional Civil Protection Agency and integrated into the national Civil Protection system. It included regional units, national actors (e.g., Italian Red Cross), and international support through the EU Civil Protection Mechanism. In contrast, the Rhine - Erft region relied heavily on the structured volunteer corps of THW (Technisches Hilfswerk), local fire brigades, and the German Red Cross, with coordination managed through Landkreis - level civil protection offices.
- Integration with Emergency Services: Both systems achieved strong integration between volunteers and official emergency services. Volunteers worked closely with fire brigades, health workers, police, and military forces in affected areas, expanding the capacity of formal institutions.
- Challenges with Spontaneous Volunteers: A shared issue was the difficulty in integrating unaffiliated volunteers. In both regions, spontaneous individuals - especially local youth and residents - mobilised organically but were often hard to track, manage, or equip, leading to occasional confusion or safety concerns.
- Wellbeing and Support: Psychological First Aid was available in both regions, supported by the Red Cross and other mental health organisations. However, coverage was uneven, particularly in rural municipalities. Volunteer fatigue, emotional burnout, and inconsistent PPE usage were noted in both cases.
- Data and Logistics Gaps: Emilia - Romagna faced digital coordination and tracking issues, limiting accurate assessments of volunteer contributions. Rhine - Erft, meanwhile, encountered equipment shortages and unclear communication channels at peak response times.

Emergency Housing

- Temporary Shelter Provision: Both regions rapidly established emergency shelters in schools, sports halls, and community centres. These shelters offered essential services: food, clean water, medical care, and psychological support.
- Alternative Accommodation Arrangements: In both Italy and Germany, partnerships with hotels, guesthouses, and other private facilities were formed to house displaced populations whose homes were uninhabitable.
- Coordination of Shelter Management: Emilia - Romagna's shelter strategy was driven by regional and municipal governments in coordination with the Italian Red Cross. In Rhine - Erft, municipalities worked closely with the German Red Cross and civil protection volunteers. In both cases, NGOs played a critical role in managing logistics and basic service provision.
- Transition to Long - Term Housing: Both areas initiated longer - term solutions post - disaster. Emilia - Romagna focused on grants and relocation assistance, while Rhine - Erft relied on rental support and government - funded home repair initiatives. Housing remained a key concern into the recovery phase in both contexts.

Vulnerable Groups

- Prioritised Evacuations: Evacuation of elderly individuals, people with disabilities, and those with medical needs was prioritised in both regions. Special transport arrangements and door - to - door assistance ensured safe removal from high - risk zones.
- Shelter Accessibility and Care: Emergency shelters in both cases incorporated accessible infrastructure for people with disabilities and separate care zones for those requiring medical or psychological support.
- Medical and Psychological Care: Targeted healthcare was delivered through mobile health teams, especially in Rhine - Erft, and through integrated Red Cross units in Emilia - Romagna. Psychological services were available but varied in consistency, particularly in rural or resource - limited settings.
- Support for Low - Income and Disadvantaged Groups: Social services in both regions ensured that low - income families and marginalised individuals received food, clothing, and financial support. Coordinated aid provision was central to ensuring equity in disaster recovery.

Local - Level Recommendations

Emilia - Romagna

1. Develop a unified digital volunteer management system: Introduce an integrated platform to register, track, and coordinate volunteers - including spontaneous responders - with role assignments, safety briefings, and feedback mechanisms.
2. Establish municipal surge protocols: Enable smaller municipalities to pre - plan logistics (housing, food, supervision) for sudden surges in spontaneous volunteers, drawing on templates from larger regional centres.
3. Expand psychological support coverage: Ensure Psychological First Aid (PFA) is equitably available across urban and rural shelters, including structured debriefing for youth and first - time volunteers.
4. Create volunteer fatigue monitoring systems: Use shift rotations, digital check - ins, and peer support teams to identify burnout early and sustain long - term response capacity.
5. Institutionalise vulnerable people registries: Strengthen local databases (in compliance with GDPR) of individuals needing priority support during disasters, ensuring timely evacuation and shelter planning.
6. Scale inclusive shelter design: Ensure all shelters meet accessibility standards and provide dedicated spaces for elderly residents, people with disabilities, and those needing medical or psychological support.

Rhine - Erft

1. Formalise spontaneous volunteer integration: Introduce structured protocols for spontaneous volunteer registration, task assignment, and supervision at emergency sites, building on THW and DRK models.
2. Enhance inter - agency communication: Improve clarity of roles, reporting lines, and command structures for volunteers through coordinated briefings and signage at shelters and operations centres.
3. Expand mobile medical and mental health units: Deploy rapid - response teams to support vulnerable populations during evacuations and in temporary housing, especially in low - resource municipalities.
4. Pre - designate accessible evacuation sites: Identify and adapt facilities with accessible infrastructure and proximity to medical support for rapid conversion into shelters.
5. Streamline post - disaster financial aid: Ensure vulnerable groups (e.g., low - income families, renters) receive expedited assistance for emergency housing, avoiding bureaucratic delays through simplified application processes.

EU - Level Recommendations

- Support cross - border volunteer coordination platforms: Fund interoperable systems that allow registration, credential verification, and mobilisation of volunteers across EU member states during transnational emergencies.
- Create EU guidelines for spontaneous volunteer management: Develop best practices and templates for local governments to integrate unaffiliated volunteers quickly and safely.
- Standardise emergency shelter accessibility requirements:

Mandate EU - wide minimum accessibility and care standards in emergency shelters, including medical support and psychological care for vulnerable groups.

- Launch an EU - wide registry of deployable mental health and medical teams: Build rapid - deployment rosters of trained responders (e.g., from ECHO partners) to assist in shelters and disaster zones across Europe.
- Include vulnerable group mapping in risk assessments: Require member states to identify and update the spatial distribution of at - risk populations (e.g. elderly, disabled, socioeconomically disadvantaged) as part of EU Civil Protection and Sendai reporting.

Case Study

8.0 Damage Assessment

Project 101073978 - DIRECTE HORIZON - CL3 - 2021 - DRS - 01

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8.1 Emilia - Romagna damage assessment

The Emilia - Romagna floods of May 2023 caused an overwhelming initial estimation of €8.8 billion in damages across multiple sectors. This figure includes substantial damage to infrastructure, agriculture, and commercial assets (ESA, 2023). Approximately 4.3 billion euros were allocated to public infrastructure repairs, which included roads, bridges, and water systems that were severely impacted by both the flooding and subsequent landslides.

The agricultural sector suffered heavily, particularly in areas like the Fruit Valley, where long - term damage to crops such as tomatoes, soybeans, and sugar beets was recorded due to waterlogged fields. Orchards, vineyards, and other fields experienced severe crop losses, amounting to an estimated 1.1 billion euros. Additionally, commercial losses amounted to 1.2 billion euros, with more than 14,200 businesses affected by the floods.

On top of these direct damages, the floods led to widespread contamination of water systems, with untreated wastewater being released into rivers, coastal wetlands, and urban areas, further complicating the recovery process.

8.1.1 Human Impact

- Casualties: At least 17 people were confirmed dead, with many others injured. The rapid onset of the flooding and the strength of the torrents contributed to the fatalities (BBC News, 2023).
- Displacement: Over 36,000 people were forced to evacuate their homes due to rising floodwaters and the threat of landslides. Temporary shelters were set up across the region to accommodate displaced families (The Guardian, 2023a).

8.1.2 Infrastructure Damage

The May 2023 floods in Emilia - Romagna caused catastrophic damage to the region's infrastructure, severely affecting roads, railways, bridges, public buildings, and utilities. According to the Commissario Straordinario alla Ricostruzione, over €2.7 billion was allocated specifically for the reconstruction of public infrastructure, with critical allocations including €761.7 million for road repairs, €270.3 million for hydraulic protection works, and €38.6 million for restoring water and sewage systems (Commissari Straordinari, 2024).

Figure 19: Estimated economic losses for residential buildings for the City of Faenza. Source: ESA, 2023.

The regional civil protection authority reported that hundreds of bridges and roads were rendered impassable, severely disrupting both local transit and national logistics (Regione Emilia - Romagna, 2023). In addition to physical damage, key utilities including gas, electricity, and digital networks also sustained failures across multiple municipalities, exacerbating the challenges of emergency response and recovery (ARPAE, 2023). The flooding also led to the collapse or closure of schools, hospitals, and cultural infrastructure in some of the hardest - hit urban and rural areas (Fusco et al., 2023). This widespread destruction highlights the vulnerability of regional infrastructure to compound climate - driven hazards and emphasizes the urgent need for adaptation investment across Italy's built environment.

8.1.3 Agricultural Damage

Crops and Livestock

The 2023 floods in Emilia - Romagna caused devastating impacts on the region's agriculture. Known for its production of fruits such as peaches, nectarines, and apricots, as well as wheat, vineyards, and livestock, the region saw over 5,000 farms submerged. Warehouse grains also were affected. Losses to both crops and livestock were substantial. According to Guy Carpenter (2023) Confagricoltura and Cia - Agricoltori Italiani estimated over EUR 1.5 billion in damages from Forli and Cesena alone. This did not include damages to machines and future lost revenue.
An estimated 400,000 tonnes of wheat were lost, and thousands of animals died due to floodwaters. Orchards and vineyards suffered both immediate yield losses and long - term damage to perennial crops, significantly affecting farmers' livelihoods (Reuters, 2023a; Guy Carpenter, 2023).

Soil Erosion and Debris Deposition

In addition to crop and livestock losses, the floods caused widespread soil erosion and deposited large amounts of sediment and debris across farmland. These processes disrupted the soil structure and fertility, making land unsuitable for immediate replanting and further delaying agricultural recovery. Satellite imagery confirmed extensive sediment run - off into coastal waters, highlighting the scale of erosion across the landscape (NASA Earth Observatory, 2023).

8.1.4 Economic Impact

Small businesses and local industries were particularly vulnerable, with many forced to shut down temporarily or permanently due to flood damage. The tourism industry also suffered, as many popular areas were closed for recovery.

8.1.5 Environmental Damage

Rivers and Wetlands: The intense rainfall caused rivers like the Santerno and Bidente to burst their banks, inundating large swathes of wetlands and protected areas. The floodwaters carried with them large amounts of debris and pollutants, further damaging ecosystems.

Landslides: The heavy rainfall triggered landslides in mountainous areas, particularly in the Apennines. These landslides not only destroyed habitats but also blocked roads, making rescue operations more difficult.

8.1.6 Housing and Residential Damage

Property Damage: During the May 2023 floods, over 15,000 buildings in Emilia-Romagna - primarily residential homes - were inundated by floodwaters from rivers like the Santerno, Lamone, and Ronco, particularly in towns such as Faenza, Cesena, Ravenna, and Forlì. In some areas, groundwater and flood levels reached up to 7 meters, causing complete waterlogging of ground and basement levels. This resulted in widespread loss of personal belongings, extensive damage to internal infrastructure (plumbing, electrical systems), and structural weakening of foundations and load - bearing walls due to prolonged saturation, subsidence, and sediment deposition.

Insurance Claims: The recovery process was financially challenging for many homeowners and businesses due to insufficient or entirely absent flood insurance coverage. Despite the widespread destruction, only a small proportion of affected properties were insured, particularly in high - risk areas where flood policies are not mandatory. This protection gap left the majority of residents

reliant on state aid or personal savings, significantly delaying recovery and increasing long - term vulnerability. Guy Carpenter (2023) estimated that only 5.5% of homeowners had flood insurance, with only 3% of micro - enterprises having insurance.

8.1.7 Summary of Key Damages

- 17 fatalities, and over 36,000 evacuations (BBC News, 2023).
- Extensive infrastructure damage, including roads, railways, and bridges (Reuters, 2023).
- Agricultural losses exceeding €1 billion, with destroyed crops and damaged farmland (FAO, 2023).
- Regional Authorities reported to the European Union €8.5 billion of damages (Emilia - Romagna Region ,2024)
- Severe environmental damage, including soil erosion and pollution.
- Thousands of homes affected, with many rendered uninhabitable due to flooding

The Emilia - Romagna floods of 2023 were one of the most devastating floods in recent history for the region, and the long - term recovery efforts are expected to take years, with a focus on rebuilding infrastructure and improving flood resilience.

8.2 Rhine - Erft Damage Assessment

The floods of 2021, which struck parts of Germany, including the Rhine - Erft and Euskirchen districts in North Rhine - Westphalia, were among the most severe floods in the country's history. Heavy rainfall in mid - July 2021 caused rivers to overflow, leading to widespread destruction. The damage was significant, spanning human casualties, infrastructure, agriculture, and the economy (German Weather Service, 2021).

8.2.1 Human Impact

- Casualties: In July 2021, catastrophic floods struck Germany, resulting in significant loss of life. According to a study published in 2023, the floods claimed the lives of 189 individuals across the country. The fatalities were distributed as follows: 135 in Rhineland - Palatinate, 49 in North Rhine - Westphalia, 2 in Bavaria, 2 in Saxony, and 1 in Baden - Württemberg. This event stands as one of Germany's deadliest natural disasters in recent history. (Thieken et al., 2023).
- Injuries: Hundreds of people were injured, with some seriously, due to the rapid onset of flash floods and the force of the water.
- Displacement: Thousands of residents were forced to evacuate their homes. In the most affected areas, including Bad Münstereifel and Erftstadt, entire communities were displaced. Many residents were unable to return home for weeks due to the ongoing dangers posed by unstable structures and flooding (Civil Protection Knowledge Network, 2024).

8.2.2 Infrastructure Damage

- Roads and Bridges: Roads in the Rhine - Erft district were severely damaged or completely washed away. Many bridges were destroyed, including key transport routes connecting towns like Erftstadt, Grevenbroich, and Bedburg. The loss of key bridges severely disrupted mobility and rescue efforts.
- Repair delays: Damage to roads and railways impeded access to submerged infrastructure. Utility companies required weeks to mobilise and needed federal and EU assistance to restore full functionality due to the unprecedented scale of destruction (Koks et al., 2022)
- Railways: Severe flooding in July 2021 caused extensive damage to railway infrastructure across the Rhine–Erft region in North Rhine - Westphalia. Entire sections of track were submerged or washed away, especially near river - adjacent lines. Deutsche Bahn reported that across the affected regions, over 600 km of track and more than 80 stations were impacted, with bridges, embankments, and signalling systems severely damaged (DW, 2021).

In the Rhine–Erft corridor specifically, embankments collapsed and track beds were eroded, necessitating full reconstruction in many areas. The destruction of subgrades, catenary systems, and signal boxes rendered sections of the network completely inoperable for weeks and, in some cases, months (Koks et al., 2022).

Rail services across the region were suspended immediately following the floods. While some

operations resumed by late 2021, many lines - including those in the Erft and Eifel areas - remained partially or fully closed into 2022, with full restoration timelines extending as far as 2025 in some locations (Deutsche Bahn AG, 2021).

Financially, Deutsche Bahn estimated €1.3 billion in rail - specific damages, making this one of the costliest infrastructure repair efforts in German rail history (The Guardian, 2021). Over 2,000 personnel were mobilised for emergency restoration works across the hardest - hit areas, including the Rhine–Erft district (Koks et al., 2022).

- Power and Water Supply: The mid - July floods severely disrupted utility infrastructure in the Rhine–Erft area, causing widespread outages and contamination:
- Electricity outages: Over 200,000 properties in North Rhine - Westphalia and Rhineland - Palatinate lost power as floodwaters damaged substations, power lines, and transformers, with many households remaining without power for days due to impassable roads and extensive equipment damage (World Weather Attribution, 2021).
- Water supply failures: Flooding overwhelmed water treatment plants and sewer systems, leading to contamination of drinking water. Emergency services reported widespread disruption across both basic water distribution and sewage networks (Thiebes, 2022).
- Telecommunications: Mobile phone networks were impacted, and many areas experienced communication blackouts due to infrastructure damage, which hindered rescue operations and emergency response efforts (The Guardian, 2021).

8.2.3 Residential and Property Damage

- Homes: Tens of thousands of homes were impacted by the July 2021 floods, particularly in severely affected towns such as Erftstadt - Blessem and Bad Münstereifel. In Erftstadt, multiple houses collapsed after their foundations were undercut by fast - moving floodwaters, while in Bad Münstereifel, historic residential areas were submerged. Entire neighbourhoods became uninhabitable due to widespread structural damage, with ground floors and and basements completely inundated and streets left impassable for days (Frankfurter Allgemeine Zeitung, 2021).
- Commercial Properties: Local businesses across the Rhine–Erft region were similarly devastated. Shops, restaurants, and warehouses - many located in low - lying town centres - were either severely damaged or completely destroyed by the floodwaters. The economic impact on small and medium - sized enterprises (SMEs) was particularly acute, with many forced to close for extended periods or shut down permanently due to physical damage and loss of stock (Handelsblatt, 2021).

8.2.4 Agricultural Damage

- Crop Losses: The July 2021 floods caused devastating agricultural losses across the Rhine–Erft region, particularly in low - lying farmland areas. Crops such as vegetables, rapeseed, grapes, and orchard fruit were destroyed as fields were inundated for several days. According to Copa - Cogeca and the EU's Crop Monitoring Unit, more than 162 km² of agricultural land was flooded, with over 34% classified as arable land (He et al., 2022). In many areas, the flooding completely wiped out the harvest, with water erosion, root rot, and sediment deposits rendering fields unusable for the remainder of the season.

Reports from the Natural Hazards and Earth System Sciences journal noted that the timing of the floods, coming just before harvesting, had a particularly destructive effect on grain, rapeseed, and vegetable crops, eliminating any realistic yield expectations for the 2021 season (He et al., 2022).

- Livestock: Livestock farms also suffered substantial losses. The rapid onset of flooding in areas such as Erftstadt and Ahrweiler resulted in displacement and death of animals, the destruction of feed stores, and damage to barns, fencing, and milking systems. According to the HELP Global Report on Water and Disasters, the agricultural sector was one of the hardest hit, with estimated damages of several hundred million euros attributed specifically to livestock and on - farm infrastructure (Kron et al., 2022).

Additionally, a detailed economic study by Prognos (2022) indicated that total agricultural and food sector losses (including livestock, crop destruction, machinery damage, and supply chain interruption) reached €6.5 billion, making it one of the most heavily impacted sectors during the disaster.

8.2.5 Economic Impact

- Direct Financial Losses: The estimated economic damage from the floods in the Rhine - Erft region alone was billions of euros, with total nationwide damage surpassing €30 billion. The floods led to disruptions in manufacturing, agriculture, transport, and services (Bundesbank, 2022). The German Insurance Association (GDV) estimated €7 billion in insured property damage from the July 2021 floods - making it the largest natural disaster for German insurers in the past five decades. Of this, approximately €6.5 billion came from damage to homes, household contents, and commercial properties, while €450 million was related to motor vehicle losses. GDV also classified roughly €1.3 billion across more than 400 major losses (each exceeding €1 million), particularly affecting industrial and hospitality assets (GDV, 2021, Reinsurance News, 2021).
- Insurance Claims: The damage to properties, infrastructure, and businesses triggered a surge in insurance claims. However, many affected individuals and businesses found that their policies did not fully cover flood damages, especially in high - risk areas.

At the time of the floods, only 46% of German households held insurance that covered flood or heavy rain events. GDV executives emphasised that despite damage of this magnitude, over half of affected properties lacked adequate protection, highlighting a significant protection gap (FloodList, 2021)

8.2.6 Environmental Damage:

Soil and Water Pollution: The floodwaters carried debris, chemicals, and pollutants, causing contamination of waterways. Extensive soil erosion also occurred, further degrading agricultural land (Federal Environment Agency, 2021).

- Ecosystem Disruption: Local ecosystems were disrupted due to habitat destruction and industrial runoff contamination, raising concerns about long - term biodiversity effects.

8.2.7 Summary of Key Damages

- Casualties: Over 190 fatalities and hundreds of injuries in the region (49 in Rhine - Erft)
- Infrastructure: Widespread damage to roads, railways, bridges, and telecommunication.
- Property: Thousands of homes and businesses destroyed or severely damaged (Frankfurter Allgemeine Zeitung, 2021).
- Agricultural Losses: Hundreds of millions of euros in lost crops and livestock (AGCO Agriculture Foundation and Fendt, 2021)
- Economic Impact: Total damage in Germany exceeded €30 billion, with significant losses in transport, business, and agriculture (Bundesbank, 2022).
- Environmental Damage: Soil erosion, habitat destruction, and water pollution in affected areas (Federal Environment Agency, 2021).

The floods affecting the Rhine - Erft region in 2021 were a catastrophic event, and recovery efforts are ongoing. Beyond rebuilding physical infrastructure, authorities are focusing on improving flood resilience to mitigate future disasters (European Commission, 2021).

8.3 Waste management, recovery and restoration

8.3.1 Emilia - Romagna waste manage, recovery and restoration:

The Emilia - Romagna floods of May 2023 caused widespread devastation, necessitating extensive waste management, recovery, and restoration efforts. The floods not only caused significant damage to infrastructure and properties but also introduced large volumes of debris and waste, which had to be carefully managed to ensure public safety and prevent further environmental damage (Regione Emilia - Romagna, 2023). The recovery process involved restoring essential services, rebuilding damaged infrastructure, and implementing environmental rehabilitation measures (European Environment Agency, 2023).

8.3.2 Waste Management During the Recovery Phase

Initial Clean - Up and Waste Collection

Once the floodwaters receded, one of the most immediate challenges was managing the vast amount of waste generated. This included mud, debris, and damaged materials from buildings, vehicles, and infrastructure. Waste management efforts focused on:

Debris Removal:

- Local municipalities, supported by emergency services and volunteers, initiated large - scale debris removal operations, clearing streets, homes, and public spaces of damaged furniture, appliances, building materials, and vehicles (ISPRA, 2023).
- The floodwaters carried organic materials (e.g., trees, soil, and plants) as well as construction debris and household waste, which needed to be sorted for safe disposal.
- Specialized teams managed hazardous materials, including chemicals, petroleum products, and industrial waste, to prevent contamination risks (European Commission, 2023).

Temporary Waste Disposal Sites

- Local authorities established temporary waste collection sites, where flood debris was sorted, processed for recycling, or safely disposed of (Regione Emilia - Romagna, 2023).
- Recyclable waste (e.g., electronics, plastics, and metals) was sent to recycling plants or waste - to - energy facilities, reducing environmental impact (ISPRA, 2023).

Handling of Hazardous Waste

- Managing hazardous waste was a critical issue, as floodwaters spread pesticides, fuel oils, and chemical residues from industrial sites and agricultural land (European Environment Agency, 2025).
- Teams equipped with personal protective equipment (PPE) ensured proper handling and disposal of hazardous materials at certified waste treatment facilities (ISPRA, 2023).

8.3.3 Recovery and Restoration of Infrastructure

- The recovery of essential infrastructure was a top priority. This involved both immediate repairs and long - term restoration of flood - damaged roads, bridges, utilities, and communication systems.

Roads and Bridges

- Severe road and bridge damage disrupted access to affected areas, delaying aid distribution and emergency response efforts (European Commission, 2023).
- Temporary infrastructure, including emergency bridges and bypass roads, was established while long - term reconstruction projects were planned (Regione Emilia - Romagna, 2023).

Water and Sanitation Systems

- Flooding disrupted water supply and wastewater systems, leading to contaminated drinking water and public health concerns (ISPRA, 2023).
- Emergency teams worked to restore potable water supplies and repair wastewater treatment facilities to prevent the spread of waterborne diseases.

Electricity and Communication Networks

- Power outages and telecommunication failures were widespread.
- Restoration efforts included repairing downed power lines and deploying mobile generators to support hospitals, shelters, and emergency centers.

8.3.4 Environmental Restoration and Management

The floods had severe environmental consequences, particularly for agriculture, forests, and waterways (Arrighi, C. & Domeneghetti, A., 2024). Restoration efforts focused on mitigating long - term damage and ensuring ecosystem recovery.

Figure 20: Flood debris, Emilia - Romagna Region - Source: Territorial Safety and Civil Protection Agency, 2023.

Soil and Agricultural Land Recovery

- Agricultural lands suffered severe damage, with floodwaters contaminating soil with chemicals, sewage, and debris (Regione Emilia - Romagna, 2023a).
- Efforts included soil decontamination, fertilization, and replanting to restore farmland productivity.
- Financial support and technical assistance were provided to affected farmers (European Commission, 2024).

Floodplain Restoration

- Riverside erosion and habitat destruction required extensive revegetation efforts and erosion control measures (ISPRA, 2023).
- Restoration of wetlands and riparian zones was prioritized to enhance natural flood resilience (European Environment Agency, 2023).

Wastewater and Contamination Control

- Many wastewater treatment facilities were overwhelmed, leading to untreated sewage entering rivers and groundwater (ARPAE Emilia-Romagna, 2023). Immediate actions focused on repairing sewage systems and monitoring water quality to ensure safe drinking water.

8.3.5 Long - Term Restoration and Preparedness

While immediate recovery was prioritized, long - term efforts aimed at strengthening flood resilience and improving disaster preparedness across Emilia - Romagna (European Environment Agency, 2023).

Flood Defence Infrastructure

Authorities upgraded flood barriers, levees, and drainage systems in high - risk areas such as

Faenza and Forlì (Regione Emilia - Romagna, 2023).

- Flood forecasting and early warning systems were improved, ensuring better risk communication (ISPRA, 2023).

Environmental Restoration Projects

- Large - scale reforestation and wetland rehabilitation projects were launched to enhance natural flood mitigation (European Commission, 2023).

8.3.6 Key Challenges in Waste Management, Recovery, and Restoration

Despite major recovery efforts, several challenges complicated the process.

Logistical Issues

- Debris removal and waste collection were delayed due to damaged infrastructure and limited access to remote areas (ISPRA, 2023).

Environmental Contamination

- Chemical leaks and wastewater overflow made waste management more complex and resource - intensive (Italian Ministry of Ecological Transition, 2023).

Coordination Between Agencies

Effective collaboration among local authorities, national agencies, and NGOs was critical but sometimes hindered by communication gaps (Regione Emilia - Romagna, 2023).

8.4 Rhine - Erft - Waste Management and Recovery

The floods affecting the Rhine - Erft region in 2021 caused extensive damage across North Rhine - Westphalia, particularly in the Ahr, Erft, and Rhein valleys. The disaster required a coordinated effort to manage waste, restore essential services, rebuild infrastructure, and mitigate environmental and public health risks (Bundesministerium des Innern und für Heimat, 2022).

8.4.1 Waste Management During the Recovery Phase

Debris Collection

One of the most urgent tasks was the large - scale removal of debris, including mud, damaged furniture, appliances, construction materials, and vehicles. Local municipalities coordinated with waste management companies to clear streets, homes, and public spaces. Heavy machinery was used for efficient debris removal, ensuring that roads were accessible for emergency response (REMONDIS Aktuell (2021).

Hazardous Waste Handling

Floodwaters transported hazardous materials such as industrial chemicals, fuel residues, and sewage. The damage to industrial plants, fuel stations, and agricultural sites released dangerous substances into the environment. Hazardous waste management teams conducted decontamination procedures using personal protective equipment (PPE) to safely remove toxic waste (REMONDIS Aktuell, 2021).

Temporary Waste Disposal Sites

To facilitate waste processing, authorities set up temporary disposal sites where flood debris was sorted and disposed of according to material type. Recyclable materials, such as plastics and electronics, were sent to specialized recycling plants, while non - recyclables were either incinerated or transported to landfills (Landesumweltamt Nordrhein - Westfalen, 2022). It was reported that approximately 170,000 tonnes of rubble and bulky waste were generated by the floods (one 5th of the usual annual volume), and that a special coordination unit was established to organize collection, sorting at temporary sites, and routing of recyclables to treatment facilities (Baublatt, 2021).

8.4.2 Infrastructure Recovery and Restoration

Roads and Bridges

The floods severely damaged roads, bridges, and railways, hindering access to affected areas.

Emergency measures included clearing debris, temporary bridge construction, and traffic management solutions. Structural engineering assessments were necessary for the reconstruction of permanent infrastructure (Technisches Hilfswerk, 2022).

Water and Sanitation Systems

Floodwaters contaminated drinking water supplies with sewage, chemicals, and industrial waste, creating a public health crisis. Emergency water distribution points were established, and bottled water was provided to residents until water treatment facilities were restored. The restoration of wastewater treatment plants was crucial to preventing disease outbreaks (Robert Koch Institut, 2022).

Electricity and Communication Networks

Floodwaters submerged power stations and electrical grids, leading to widespread power outages. Technicians prioritized restoring electricity to hospitals, emergency shelters, and public infrastructure. Mobile generators provided temporary power until full restoration was achieved. Telecommunication networks were also repaired to restore communication in affected areas (REMONDIS Aktuell, 2021, Technisches Hilfswerk, 2021).

8.4.3 Environmental Restoration and Mitigation

Soil and Agricultural Recovery

Farmland was submerged, leaving behind contaminants such as fuel, sewage, and chemical residues. Farmers received government assistance for soil restoration and replanting efforts. Soil treatment, such as applying fertilizers and bio - remediation techniques, were used to recover agricultural land for future use. Damage from the floods for agriculture was calculated as 380 million euros. In answer to this in August 2021 a 'Reconstruction Aid 2021' fund was set - up by the federal government for 30 billion euros to support agricultural reconstruction (Bundesministerium für Ernährung und Landwirtschaft, 2022).

After the July 2021 floods, the German Federal Ministry of Food and Agriculture (BMEL) implemented this comprehensive aid package for farmers and foresters. Support measures included compensation for crop and property damage, emergency funds and loans through Rentenbank to ensure liquidity, and grants covering up to 80 % of restoration costs for soil remediation, safety measures, and replanting. BMEL also coordinated with states to streamline administrative procedures, accelerate disbursement of aid, and expand guidance on preventive climate-adaptation strategies to better prepare agricultural sectors for future extreme weather events (Bundesministerium für Ernährung und Landwirtschaft, 2022).

Floodplain Restoration and Erosion Control

In July 2021, unprecedented flooding in the Rhine - Erft region caused severe geomorphological impacts along the Erft River, particularly in areas adjacent to the Tagebau Hambach open - pit lignite mine. The high water levels led to rapid erosion of riverbanks, the failure of embankments, and the redirection of watercourses, posing a serious risk to both infrastructure and the environment. One of the most critical incidents occurred near Erftstadt - Blessem, where riverbank failure led to the collapse of buildings and roads, and floodwaters nearly breached the lignite mine's perimeter, threatening widespread environmental contamination.

To address these hazards, immediate ecological restoration measures were initiated by the Erftverband, the regional water authority. These efforts focused on re - establishing the natural river course, reinforcing weakened banks, and controlling sediment movement. Restoration strategies included stabilizing soil with vegetation, rerouting water flow to prevent further erosion, and improving floodplain connectivity. The interventions were designed not only to repair the damage but to build long - term resilience against future extreme weather events (Geotechnical Extreme Events Reconnaissance Association (GEER), 2021) .

Water Quality Monitoring

Floodwaters contaminated rivers and lakes with industrial waste, sewage, and debris. Authorities conducted water quality assessments and clean - up efforts to minimize the risk of waterborne diseases. Monitoring programs ensured that drinking water sources met safety standards before being

restored for public consumption (Koks et al., 2022).

8.4.4 Long - Term Restoration and Preparedness

Flood Defence Systems

Following the catastrophic July 2021 floods, the NRW government launched an extensive flood protection initiative. Major investments - totaling approximately €76.7 million in 2022 - were allocated toward raising, reconstructing, and relocating levees along the Rhine and its tributaries (Landesregierung Nordrhein - Westfalen, 2025). Key projects include:

- Deichsanierungen along 4.6 km segments of the Lower Rhine between Wallach and Wesel-Büderich.
- Construction of retention basins in Cologne-Worringen to help manage peak flow surges.
- Establishment of mobile flood barriers and the restoration of levee defence paths (e.g., Ruhr) to support emergency response vehicles.
- Simultaneously, NRW authorities have been implementing floodplain zoning reforms, reinforcing bridge infrastructure with scour - resistant foundations, and creating new landscape - scale flood buffers by setting back levees - such as the "HaLiMa" project near Haltern–Lippramsdorf/Marl, which established ~60 ha of additional floodplain.

These measures combine traditional hydraulic engineering with nature - based solutions to ensure long - term resilience and prevent future disasters.

Flood Risk Assessment and Early Warning Systems

Authorities worked to improve early warning systems to better predict and communicate future flood risks. New weather forecasting models and flood monitoring networks were introduced to provide accurate and timely information to at - risk communities. Public awareness campaigns educated residents on evacuation procedures and emergency preparedness.

Cell broadcast has since been introduced in 2023. Cell Broadcast has proven effective in delivering over 200 warning messages since its introduction (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe, 2024).

Key Challenges in Waste Management, Recovery, and Restoration

- Logistical Bottlenecks: The scale of destruction made it difficult to transport relief supplies and waste management equipment. Road and bridge damage hindered response times (Technisches Hilfswerk, 2022).
- Environmental Contamination: Managing toxic waste and floodwater contamination was resource - intensive and complex, particularly in industrial and agricultural areas.
- Psychosocial Impacts: Many survivors suffered emotional trauma. While psychosocial support was provided, long - term mental health recovery required ongoing attention and funding.

8.5 Comparative Insights: Emilia - Romagna and Rhine - Erft Damage and Recovery

The extreme flood events that struck Emilia - Romagna in 2023 and the Rhine - Erft region in 2021, while separated by time and geography, reveal common patterns of vulnerability, disruption, and recovery across Europe's flood - prone areas. Despite differing hydrological dynamics and governance structures, the scale and complexity of damage in both cases point to shared systemic challenges and valuable cross - regional insights.

Human Impact In both regions, human lives were lost and entire communities displaced. Emilia - Romagna reported 15 fatalities and over 36,000 evacuations, primarily due to rapid - onset flooding and cascading landslides. In the Rhine - Erft district, 49 people lost their lives, and widespread displacement occurred, especially in hard - hit areas like Erftstadt and Bad Münstereifel. In both events, evacuation logistics were strained by rapidly changing conditions, inadequate early warning, and damaged transport routes, exposing the limits of preparedness for high - intensity, short - notice flood scenarios.

Infrastructure Disruption Both regions experienced catastrophic infrastructure damage. Emilia - Romagna saw major losses to roads, bridges, water networks, and public buildings, with over €2.7 billion allocated to infrastructure repair. In Rhine - Erft, roads and railways were extensively damaged, with Deutsche Bahn estimating €1.3 billion in rail - specific losses. Power outages and digital network failures exacerbated response challenges in both regions. Notably, in Rhine - Erft, the collapse of riverbanks near the Erft lignite mine posed secondary environmental hazards, illustrating the risk of critical infrastructure cascading failures.

Housing and Property Losses Tens of thousands of residential properties were damaged in each region. In Emilia - Romagna, more than 15,000 homes were inundated, with structural instability and deep waterlogging requiring long - term reconstruction. In Rhine - Erft, whole houses collapsed as floodwaters undermined foundations, especially in Erftstadt - Blessem. Insurance coverage was alarmingly low in both cases, with Emilia - Romagna reporting only 5.5% of homeowners and 3% of small businesses covered. Although Germany had a higher national insurance rate (46%), many policies did not include flood provisions, reinforcing the systemic protection gap across both regions.

Agricultural and Economic Impact Agriculture suffered significant losses. Emilia - Romagna's Fruit Valley and grain - producing areas were devastated, with an estimated €1.5 billion in agricultural damage. Similarly, the Rhine - Erft region lost an entire season's harvest across 162 km² of farmland, with livestock and infrastructure damage contributing to total food and farming sector losses of over €6.5 billion. Small businesses in both areas - especially tourism, retail, and agri - food sectors - faced closures, with many unable to reopen. National economic damage exceeded €8.5 billion in Emilia - Romagna and €30 billion in Germany, underscoring the cascading economic effects of environmental shocks.

Environmental Degradation Floodwaters in both regions carried significant pollutants - industrial chemicals, sewage, and sediment - causing water contamination, soil degradation, and damage to protected ecosystems. Emilia - Romagna faced significant wetland and riverbank erosion, while in Rhine - Erft, floodwaters triggered geomorphofloodplain reactivation, erosion control, and monitoring of long - term contamination. These events underscore the importance of nature - based solutions alongside engineered defences.

Waste Management and Recovery Operations Each region faced enormous challenges in post - flood debris and waste management. In Emilia - Romagna, mixed household, agricultural, and industrial waste required coordinated response from civil protection, municipalities, and national agencies. Hazardous materials posed long - term risks to human and environmental health. In Rhine - Erft, over 170,000 tonnes of rubble were collected, with temporary waste facilities established to triage material. Both regions experienced logistical bottlenecks due to damaged infrastructure, and both ultimately implemented significant recovery efforts including temporary housing, infrastructure rebuilding, and environmental remediation.

Long - Term Restoration and Preparedness Both Italy and Germany launched multi - billion - euro recovery programmes - Aufbauhilfe 2021 in Germany and an EU - coordinated package in Emilia - Romagna. Yet both faced delays due to administrative complexity, overlapping responsibilities, and gaps in local capacity. In both regions, rebuilding efforts included physical repairs and policy reforms. Notably, Rhine - Erft adopted major floodplain restoration and cell - broadcast warning systems, while Emilia - Romagna accelerated investments in natural flood defences and improved soil and water monitoring.

8.6 Recommendations

The extreme flood events in Emilia - Romagna and Rhine - Erft reveal shared systemic vulnerabilities that demand urgent, coordinated responses at both the local and EU levels. While the two regions differ in geography and governance, their experiences point to converging needs for improved resilience, governance reform, and investment in adaptation. The following recommendations are structured at two scales: local - level actions tailored to the distinct needs of each region, and EU - level policy interventions to support systemic transformation across member states.

Local - Level Recommendations: Emilia - Romagna

1. Strengthen Protection of Agricultural and Natural Landscapes Given the scale of agricultural and environmental losses, land - use planning should prioritise the conservation and restoration of floodplains, wetlands, and riparian buffers. Incentives for farmers to adopt soil - conserving and climate - resilient practices can reduce future exposure.
2. Invest in Hazard - Resilient Infrastructure The widespread damage to roads, bridges, and public utilities exposed critical weaknesses in the region's built environment. Public investment should prioritise resilient reconstruction, particularly in rural areas where infrastructure often lacked redundancy.
3. Expand Insurance Coverage and Risk Awareness The very low penetration of flood insurance - particularly among households and small enterprises - demands new financial instruments, awareness campaigns, and potentially public - private insurance schemes to close the protection gap in high - risk areas.
4. Improve Multi - Level Coordination for Recovery Bureaucratic delays and fragmented responsibility across agencies slowed fund disbursement and recovery. A streamlined, pre - approved framework for emergency procurement and inter - agency coordination should be institutionalised at the regional level.
5. Scale Up Community - Based Early Warning Systems The region should build on recent advances in risk communication and monitoring (e.g. soil moisture and river - level sensors) to develop real - time, community - level warning systems with multilingual communication strategies to reach vulnerable populations.

Local - Level Recommendations: Rhine - Erft

1. Modernise Flood Defence Infrastructure with Nature - Based Solutions Reconstruction efforts in Rhine - Erft should integrate grey and green infrastructure - combining raised levees, embankments, and mobile barriers with river renaturation, buffer zones, and floodplain reconnection.
2. Address Long - Term Mental Health Impacts of Flooding The psychological toll of the disaster remains profound, especially among survivors in towns like Erftstadt. Investments in long - term psychosocial care, including trauma counselling and community rebuilding programmes, are essential to holistic recovery.
3. Expand Cell Broadcast and Local Alert Systems While Germany has introduced cell broadcast alerts, these should be integrated with local sirens, radio, and accessible formats for people with disabilities. Community training on how to respond to alerts should also be expanded.
4. Improve Agricultural Risk Governance and Recovery Schemes Despite large federal reconstruction packages, many farmers reported slow access to recovery funds. Local governments should develop rapid - response protocols for agricultural disaster assistance, supported by climate - adaptive farm insurance schemes.
5. Secure Critical Infrastructure near High - Risk Sites The 2021 floods nearly caused a disaster at the Hambach lignite mine. Future land - use and risk planning must ensure that industrial sites, energy infrastructure, and extractive industries are not co - located with flood - prone zones.

EU - Level Recommendations

1. Establish a European Framework for Flood Resilience Indicators To support cross - country benchmarking and mutual learning, the EU should introduce a harmonised set of flood resilience indicators, covering infrastructure, insurance coverage, ecosystem capacity, and social preparedness.
2. Mainstream Ecosystem - Based Adaptation in EU Recovery and Resilience Facility (RRF) Funding Ecosystem restoration projects - such as floodplain recovery, river daylighting, and soil carbon restoration - should be prioritised within the RRF, with streamlined access for municipalities.
3. 3. Create a Rapid EU Disaster Insurance Guarantee Scheme In regions with low insurance uptake, the EU could co - develop a reinsurance or guarantee mechanism to support national schemes, reduce risk premiums, and promote uptake among vulnerable sectors such as SMEs and agriculture.
4. Mandate Inclusive Early Warning Systems Across Member States All EU member

states should be required to implement early warning systems that are multilingual, disability - inclusive, and capable of reaching mobile and offline populations. The EU Civil Protection Mechanism should monitor compliance and support implementation.

5. 5. Enhance Regional Capacity - Building Through Twinning and Knowledge Exchange
   The EU should fund twinning programmes between municipalities that have experienced recent floods to share best practices, from risk mapping and urban design to post - disaster recovery governance. These exchanges could be coordinated via the EU Disaster Risk Management Knowledge Centre.

9.0 Disaster Financial Management

Project 101073978 - DIRECTED - HORIZON - CL3 - 2021 - DRS - 01

Funded by the European Union

9.1 Emilia - Romagna Floods (2023)

The Emilia - Romagna floods of May 2023 caused severe destruction across northern Italy, inundating urban and rural areas with heavy rainfall and overflowing rivers. The financial response to the disaster included immediate emergency funding, compensation schemes, insurance claims, and long - term recovery investments. Managing the economic impact of such a catastrophe required coordinated efforts from national and regional governments, insurance providers, and international organisations such as the European Union (EU) (European Commission, 2024). Through the EU Solidarity Fund the EU provided €446.6 million to Italy, including €378.8 million for Emilia-Romagna (of which €94.7 million was paid as an advance) to support urgent emergency and recovery measures such as infrastructure repairs, debris removal, compensation programs, and long - term recovery initiatives (European Commission, 2024).

9.1.2 Immediate Emergency Financial Support

Governmental Aid

The Italian government and regional authorities quickly mobilised financial resources for emergency relief operations, which included:

Regional and Local Contributions

Following the devastating floods that struck Emilia - Romagna in May 2023, the Italian government issued Decree - Law No. 61 of 1 June 2023 to initiate urgent response and recovery measures . The decree declared a formal state of emergency for the affected areas and established a legal and financial framework to support immediate relief, infrastructure restoration, and long - term recovery.

The Decreto-legge 1 June 2023, No. 61 mobilised an initial €4.7 billion for Emilia-Romagna flood recovery: €2.7 billion was earmarked for restoring damaged infrastructure, such as roads, bridges, and utilities, while €1.9 billion was set aside for direct financial aid to households and businesses. Of the latter, €105 million was distributed to around 24,000 families via the Immediate Support Contri-

A further €700 million was made available through tax credit measures to facilitate reconstruction and support residents (Dipartimento della Protezione Civile, 2023).

The measures responded to the immediate support for community restoration efforts.

9.2 Insurance and Compensation

Limited Insurance Coverage

One of the most significant financial challenges following the Emilia - Romagna floods was the lack of widespread flood insurance coverage. In Italy, insurance against natural disasters such as floods is not mandatory, and uptake remains low. According to the Italian National Association of Insurers (ANIA), only around 5–6% of households and small businesses had flood - related coverage at the time of the disaster. This coverage gap was particularly pronounced in areas not previously classified as high - risk flood zones (ANIA, 2023; Guy Carpenter, 2024).

Estimated Insured Losses

The flood event of May 2023 resulted in insured losses estimated at approximately €495 million, according to PERILS AG, a catastrophe insurance data provider. However, this figure represented only a small fraction of the total economic damage, which PERILS estimated to exceed €9 billion across multiple sectors. The discrepancy highlighted the vulnerability of the Italian property market due to underinsurance and limited availability of natural catastrophe coverage (PERILS, 2024; Guy Carpenter, 2024).

Implications for Risk Financing

The limited role of the private insurance market in covering flood losses led to calls for the development of a public - private insurance scheme for natural catastrophes in Italy. Industry stakeholders and the government are now exploring models that would make basic disaster insurance compulsory or automatically bundled with property policies, improving the country's resilience to future climate - related disasters (ANIA, 2023; Guy Carpenter, 2024).

Government Compensation Schemes

To support those without insurance, the Italian government established several emergency assistance mechanisms:

- The national Decree - Law No. 61/2023 authorized funding for rescue operations, medical support, temporary housing, and compensation for affected households and businesses (Dipartimento della Protezione Civile, 2023).
- The Ministry of Economy and Finance introduced tax relief for flood - affected individuals and companies
- The Italian Revenue Agency implemented deferred tax deadlines and property tax exemptions for residents in disaster zones
- The European Investment Bank committed €900 million in financing for post - flood infrastructure recovery and resilience efforts in Italy (EIB, 2024).

Role of the European Union

The EU Solidarity Fund (EUSF) was activated to provide financial assistance for rebuilding infrastructure and environmental restoration (European Commission, 2023). Italy also applied for EU co - financed recovery funds to strengthen natural flood defences and improve transport networks.

9.2.5 Reinvestment in Climate Resilience

The flood prompted a re - evaluation of climate adaptation measures, leading to increased funding for:

- Strengthening flood defences (e.g., levees, reservoirs, and drainage systems) (ISPRA, 2023).
- Urban planning improvements including flood - proof buildings and green infrastructure (Legambiente, 2023).
- Advanced flood forecasting models to improve preparedness for future disasters

9.3 Rhine - Erft – Financial management

The floods affecting the Rhine - Erft Region in July 2021 were part of a catastrophic flooding event that devastated parts of North Rhine - Westphalia (NRW) and Rhineland - Palatinate, Germany. Extreme rainfall led to the overflowing of rivers such as the Ahr, Erft, and Rhine, causing severe damage to infrastructure, homes, and businesses. The financial response to this disaster involved government aid, insurance claims, compensation schemes, and international assistance.

9.3.1 Immediate Financial Response and Emergency Support

Federal Government Support

In response to the catastrophic floods that struck the Rhine - Erft region and wider parts of western Germany in July 2021, the German federal government mobilised substantial financial resources to support both emergency response and recovery. The flooding, triggered by extreme rainfall events, caused extensive damage to homes, infrastructure, and public utilities, particularly in the states of North Rhine - Westphalia and Rhineland - Palatinate.

To address the immediate humanitarian and infrastructural crisis, the federal government, in collaboration with the affected federal states, announced a financial aid package totalling €600 million. This included €400 million in direct emergency relief for affected individuals and households - allocated to cover urgent needs such as temporary accommodation, food, and essential household repairs. The federal government covered half of this amount, with the other half provided by the individual states.

Additionally, €200 million was allocated for infrastructure repairs, including the restoration of destroyed or damaged roads, bridges, energy grids, and water systems (Bundesregierung, 2021). This immediate support was later supplemented by a €30 billion national reconstruction fund designed to finance long - term rebuilding efforts in the most severely affected areas (BMVBS, 2021).

State - Level Contributions

North Rhine - Westphalia (NRW) and Rhineland - Palatinate contributed an additional €100 million in emergency relief (Landesregierung NRW, 2021).

This funding supported local municipalities in providing temporary housing, emergency medical services, and basic utilities (Landesregierung Rhein-

Figure 21: Flood damage to building - Deployment of aerial robots during the flood disaster in Erftstadt / Blessem, Germany (Figure 8 in Surmann et al. 2022).

services, and basic utilities (Landesregierung Rheinland - Pfalz, 2021).

9.3.4 Insurance Coverage and Claims

Insurance Penetration

In Germany, flood insurance is not mandatory, and protection against natural hazards - known as Elementarschadenversicherung (elemental damage insurance) - must be purchased separately from standard property policies. As of 2021, only around 46% of buildings nationwide had such coverage, and in flood - prone areas like parts of Rhine - Erft, uptake was also limited (GDV, 2023).

Several factors contributed to this:

- Perceived low risk: Many homeowners in the Rhine - Erft district had not experienced major flooding for decades and therefore underestimated their exposure.
- Cost and accessibility: In areas classified as high flood risk under the ZÜRS risk zone system, premiums can be high, or coverage may be denied altogether.
- Public awareness gaps: Residents often assumed their standard home insurance covered floods, only to discover exclusions after disaster struck.

The lack of coverage significantly affected recovery in towns like Erftstadt - Blessem, where flooding and landslides caused catastrophic property losses.

Estimated Insured and Uninsured Losses

The July 2021 floods across regions caused total economic damage of approximately €10–15 billion, making it one of the most costly natural disasters in German history (Munich Re, 2022).

- Insured losses were estimated at €4.5 billion, mostly from homes, vehicles, and business assets (GDV, 2022).
- Uninsured losses - including widespread destruction of public infrastructure and privately owned buildings - accounted for €6–10 billion.

In the Rhine - Erft district, many properties had no flood insurance, especially in areas not previously considered at high risk. The dramatic collapse of ground in Erftstadt - Blessem, for example, left dozens of homes destroyed or uninhabitable. Most affected residents had to rely entirely on state

Municipal infrastructure - roads, sewage, and public buildings - also suffered extensive damage that was not covered by insurance and required intervention through the Aufbauhilfe 2021 fund.

Challenges in Insurance Claims

The flood event overwhelmed the insurance sector, particularly in regions like Rhine - Erft, where destruction was concentrated but unexpected:

- Delays in claims processing occurred due to the sheer volume of cases and a limited number of adjusters (Gutachter).
- Access challenges further slowed assessments - roads were damaged, and some affected villages were temporarily inaccessible.
- Many residents only realised after the flood that their policies excluded elemental damage, such as flooding, landslides, or groundwater ingress.

As a result, large numbers of households in Rhine - Erft received no insurance payout, prolonging displacement and creating deep financial distress.

This event renewed national discussion about introducing mandatory flood insurance in Germany. Policy options - including a public - private reinsurance model - were debated, though no consensus had been reached as of mid - 2025.

9.3.5 Government Compensation and Financial Aid Programs

Direct Financial Assistance

- The NRW provided up to €3,500 per household for those without flood insurance (Landesregierung Nordrhein-Westfalen, 2021).
- Small businesses received additional grants of up to €5,000 and low - interest loans to support recovery (Landesregierung Nordrhein-Westfalen, 2021).

Reconstruction Funds

- Zero - interest loans and grants were provided to rebuild homes and businesses (Bundesregierung, 2021).
- Subsidies were available for property restoration and climate adaptation measures.

Special Tax Relief Measures

- Postponed tax payments and tax exemptions for affected individuals and businesses were allowed.

European Union (EU) Support

In response to the devastating floods in July 2021, the European Union provided substantial support to Germany through the EU Solidarity Fund (EUSF) and financing from the European Investment Bank (EIB).

The EU Solidarity Fund was activated to co - finance recovery measures, including the restoration of damaged infrastructure, environmental remediation, and emergency operations. A total of €612.6 million was allocated to Germany to assist with the aftermath of the floods, which caused an estimated €40.5 billion in total economic losses (Council of the European Union, 2022). This made the German allocation one of the largest ever disbursements under the EUSF.

In addition, the European Investment Bank (EIB) provided targeted support. On 28 July 2021, the EIB Institute donated €500,000 to organisations in Germany, Belgium, Luxembourg, and the Netherlands involved in emergency response and disaster recovery (EIB Institute, 2021).

Together, the EUSF and EIB contributions reflected the EU's multilevel approach to supporting member states in times of climate - related disaster, combining direct disaster aid with strategic investment in resilience and adaptation.

9.3.6 Financial Management Challenges and Data Gaps

The management of financial aid following the July 2021 floods in Germany exposed critical weaknesses in intergovernmental coordination, transparency, and accountability. Despite the rapid political approval of reconstruction funding - particularly the €30 billion Aufbauhilfe 2021 package - several structural inefficiencies delayed the delivery of vital support to affected communities.

Coordination of Funds

The Federal Court of Auditors (Bundesrechnungshof) found that the multi - level governance system - spanning federal, state (Länder), and municipal levels - resulted in overlapping responsibilities, fragmented workflows, and inconsistent implementation practices (Bundesrechnungshof, 2023). Each state adopted its own administrative procedures, digital platforms, and documentation requirements, with no unified federal guidance to ensure harmonisation. This led to lengthy application processes and unpredictable delays for individuals and municipalities seeking aid.

In many cases, local authorities received no funds until late 2021 or early 2022, even though the flood occurred in July 2021. Bureaucratic burdens such as redundant documentation, unclear eligibility requirements, and a lack of human resources within municipal administrations contributed to these bottlenecks (Bundesrechnungshof, 2022).

Transparency and Oversight Gaps

The Bundesrechnungshof highlighted the absence of a central data collection or monitoring system for tracking how funds were allocated and spent. Several Länder were unable to provide the federal government with reliable information on fund disbursement or project progress. This hindered both transparency and evidence - based decision - making for future disaster response.

Furthermore, financial reporting mechanisms were inconsistent or incomplete, and the eligibility of certain expenditures was not always clearly defined. As a result, the audit raised concerns about inefficient use of public resources and the risk of funding misallocations.

Recommendations for Reform

To address these challenges, the Bundesrechnungshof proposed a series of reforms aimed at improving financial governance in future disasters:

- Establish a centralised digital application and fund management platform to streamline coordination across states and federal agencies.
- Develop standardised eligibility criteria, documentation requirements, and reporting frameworks applicable nationwide.
- Implement real - time monitoring and data transparency tools to improve accountability and allow for evidence - based fund tracking.
- Clarify institutional responsibilities to reduce duplication and speed up fund approval and disbursement processes.
- Strengthen local administrative capacity with technical and staffing support, particularly in rural and flood - affected areas.

These findings underscore the urgent need for institutional reform to ensure that public funds are delivered rapidly and equitably in future climate - related disasters.

9.3.7 Data Gaps in Damage Assessment

- Difficulties in estimating economic damage due to incomplete flood risk data (German Meteorological Service, 2022).
- Initial insurance estimates underestimated the full extent of the damage.

9.3.8 Need for Improved Risk Models

- Experts recommended better flood forecasting and disaster risk financing mechanisms to strengthen future responses.
- Calls for mandatory flood insurance to increase financial preparedness.

10.0 Risk Perception of Local Populations before and after The Events

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10.1 Risk Perception and Communication: Comparative Insights from Rhine - Erft and Emilia - Romagna

Flood events in both the Rhine-Erft district (July 2021) and Emilia-Romagna (May 2023) offer valuable lessons about how the public perceives flood risks - and how institutions communicate those risks in moments of crisis. While both regions are technologically advanced and benefit from strong meteorological systems, each case revealed how critical factors such as trust, message clarity, and social context can influence public understanding and behaviour.

Rhine-Erft Public Perception of Flood Risk

The catastrophic floods that hit western Germany in July 2021 prompted serious reflection on how well early warning systems actually translate into action at the household level. In a survey conducted across North Rhine-Westphalia and Rhineland-Palatinate, 35% and 29% of respondents respectively reported not receiving an official warning, despite the presence of operational forecasting systems. Even more striking, among those who were warned, 85% underestimated the severity of the event, and nearly half (46%) were unsure how to respond (Thieken et al., 2023).

These figures point to important communication gaps. It suggests issuing a warning is not enough; how that warning is framed, who delivers it, and whether it resonates with prior experience and understanding all matter.

Complementing these findings, a study of social media activity during the floods revealed further insight into public response. Zander et al. (2023) analysed real - time Twitter (X) content and found that while many users actively shared information, much of the content expressed confusion, emotional distress, or disbelief - suggesting that the warnings did not feel personally relevant or credible to many residents. Moreover, warnings often lacked actionable detail and were dispersed across uncoordinated channels, contributing to a fragmented risk narrative. This indicates the need for not just broader dissemination, but more structured, empathetic, and localised communication strategies.

Emilia-Romagna Public Perception of Flood Risk

In Emilia-Romagna, the May 2023 floods triggered an intense wave of public reflection and media attention. Although no large - scale public survey has yet been published, qualitative research conducted in the months following the disaster provides useful insights. A study by IRIS-UPO et al. (2024), based on interviews with civil protection personnel, healthcare workers, and local volunteers, found that while institutional response was swift, communicating with the public in real time proved challenging. Local authorities struggled to reach diverse audiences quickly, especially in rural or lower - resourced areas, and respondents emphasised the need for real - time, clearly contextualised updates via trusted channels.

Emilia-Romagna has seen a shift towards human - centred communication following the floods. Regional agency ARPAE and media outlets worked to amplify personal stories of loss and resilience, with projects such as sharing first - hand experiences from affected communities (Regione Emilia-Romagna, 2024). These narratives brought visibility to climate risk in emotionally compelling ways, helping to spark conversations around preparedness, vulnerability, and collective responsibility.

At the same time, structural gaps persist. Despite the event's severity, only 6% of households and 5% of businesses had flood insurance at the time (The Guardian, 2024). This suggests that even as risk awareness grows, it does not necessarily translate into long - term behavioural change, especially where protective options are perceived as inaccessible, unaffordable, or insufficiently promoted.

Reflections and Policy Implications

Together, these cases highlight that risk perception is shaped as much by emotion, trust, and narrative as by data and alerts. In Germany, the challenge lay in translating warnings into belief and action. In Emilia-Romagna, the response featured emotionally resonant storytelling - but gaps remain in coverage,

preparedness, and pre - disaster education.

For policy and practice, four key lessons emerge:

1. Warnings must be timely and credible, but also humanised - linked to familiar places, faces, and po
2. Social media is both an opportunity and a risk - offering rapid dissemination but also potential for confusion unless guided by trusted voices.
3. Post - crisis storytelling can build collective memory and motivation, but must be supported by structural changes: public education, insurance reform, and accessible preparedness tools.
4. Raising awareness of flood risk at local level in at risk communities, including preparatory training is likely to be beneficial in developing community acceptance and ability to prepare and act in extreme flood events.

Going forward, investing in multi - channel communication, pre - event community engagement, and trust - building mechanisms will be essential to support more flood - literate and resilient societies.

11.0 Policy and Practice Recommendations/ Lessons Learned

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The increasing frequency and severity of extreme flooding events due to climate change necessitate stronger flood risk management strategies (IPCC, 2022). Effective flood mitigation requires a combination of early warning systems, resilient infrastructure, and sustainable land - use planning (Fekete et al., 2020). The integration of real - time hazard mapping, community - based preparedness, and cross - border cooperation is essential for reducing future flood impacts (Duo & Armaroli, 2018).

Investment in green infrastructure, such as wetland restoration and sustainable drainage systems, enhances flood resilience while reducing long - term recovery costs (Bertolini et al., 2005; European Environment Agency, 2023). Additionally, strengthening emergency response frameworks through improved data sharing and risk communication will ensure better preparedness for extreme weather events (Thieken et al., 2023).

The Emilia - Romagna floods of 2023 and the floods affecting the Rhine - Erft Region in 2021 provided critical insights into how flood risks are managed, communicated, and mitigated. The lessons learned from both disasters offer several policy and practice recommendations to improve preparedness, response, recovery, and long - term resilience.

11.1 Improved Early Warning Systems

- Recommendation: Enhance early warning systems to provide more accurate, timely, and actionable alerts to at - risk communities. In addition, ensure that the messaging enables people to take appropriate actions at citizen level e.g. safety procedures and evacuation locations and procedures.
- Lesson: Both floods demonstrated that early warnings were insufficient in preventing widespread damage, particularly in rural and small - town areas. In Germany, delays in issuing flood warnings meant many residents were caught off guard.
- Action: Implement advanced technology, such as AI - based flood prediction models and satellite monitoring, to improve the accuracy and lead time of flood warnings (Copernicus Emergency Management Service, 2023).

11.2 Strengthening Flood Resilience and Infrastructure

- Recommendation: Prioritise investment in flood - resistant infrastructure and natural flood defences.
- Lesson: Both floods exposed the vulnerability of existing infrastructure, including roads, bridges, and drainage systems. In Emilia - Romagna, agricultural infrastructure (e.g., irrigation systems) suffered extensive damage (, 2023). In the Rhine - Erft region, urban infrastructure, including transportation networks, was severely affected (Civil Protection Knowledge Network, 2024).
- Action: Governments should increase funding for climate - resilient infrastructure, including reinforced levees, upgraded drainage systems, and nature - based solutions such as restoring wetlands and floodplains.

11.3 Enhancing Public Awareness and Risk Communication

- Recommendation: Increase public education on flood risks and preparedness.
- Lesson: Both floods revealed that many local populations were not fully prepared for the scale of flooding. Many residents underestimated the risk and lacked knowledge about protective measures (Thieken et al., 2023).
- Action: Develop and distribute clear flood risk information, especially in high - risk zones. Governments should promote flood preparedness campaigns and conduct community - level drills to increase awareness (European Commission, 2023).

11.4 Expanding Flood Insurance Coverage

- Recommendation: Make flood insurance more accessible and mandatory in flood - prone areas.
- Lesson: The insurance gap was a major issue after both floods. In Emilia - Romagna, many agricultural losses were uninsured (Italian Association of Insurers, 2023). In the Rhine - Erft region, only 45% of affected homes had flood insurance (GDV, 2021).
- Action: Introduce government - backed flood insurance

schemes for at risk communities, provide subsidies for private insurance, and explore mandatory flood insurance in high - risk areas.

11.5 Strengthening Disaster Risk Financing and Financial Support

- Recommendation: Establish comprehensive disaster risk financing mechanisms to enable quicker and more equitable recovery.
- Lesson: Both regions faced challenges in securing adequate funding for immediate recovery. Bureaucratic delays slowed financial assistance in Germany, while Italy's compensation process struggled to reach all affected individuals efficiently (European Solidarity Fund, 2023).
- Action: Establish emergency funding mechanisms at national and regional levels and collaborate with private insurers to mobilise rapid financial resources. Develop more flexible aid systems to support individuals and businesses in post - disaster recovery (World Bank, 2023).

11.6 Improved Coordination Among Local, Regional, and National Authorities

- Recommendation: Enhance coordination between government levels and emergency response agencies.
- Lesson: During both floods, coordination gaps between local and national authorities caused delays in relief efforts. In Emilia - Romagna, damage assessment took longer than expected, while in Germany, overwhelmed local agencies struggled to handle the scale of the disaster (Federal Ministry of the Interior, 2021).
- Action: Clearly define roles and responsibilities across governmental levels, improve inter - agency collaboration, and develop joint flood response protocols to ensure efficient disaster management (Fekete et al., 2020).

11.7 Focus on Vulnerable Groups

- Recommendation: Ensure flood risk planning prioritises vulnerable groups, including the elderly, disabled, and low - income populations.
- Lesson:Vulnerable communities were disproportionately affected during both disasters, with limited access to evacuation resources and post - disaster assistance (German Red Cross, 2021).
- Action: Implement inclusive evacuation plans, specialised shelters, and ensure targeted flood - risk communication for at - risk populations.

11.8 Long - Term Climate Adaptation and Risk Management

- Recommendation: Integrate climate change adaptation strategies into urban planning and flood risk management.
- Lesson: Both floods were intensified by climate change, highlighting the need for proactive risk reduction strategies (IPCC, 2022). Urban expansion in flood - prone areas has exacerbated risks, particularly in Emilia - Romagna's agricultural zones and the densely populated Rhine - Erft region
- Action: Incorporate climate models into urban planning, promote green infrastructure, and introduce stricter zoning wregulations to limit construction in flood - prone areas.

11.9 Conclusion

The Emilia - Romagna floods (2023) and the floods affecting the Rhine - Erft Region (2021) highlight the urgent need for improved flood preparedness, climate adaptation, and disaster risk financing. While both regions provided rapid emergency relief, these disasters underscore the necessity of long - term resilience - building.

Key lessons learned include:

1. Strengthening early warning systems, communication and citizen training to improve disaster preparedness.
2. Expanding flood insurance coverage to ensure financial protection for all affected individuals.
3. Enhancing infrastructure resilience through investment in climate - adaptive solutions.
4. Improving coordination among governmental agencies to streamline disaster response.
5. Prioritising vulnerable communities in disaster planning and risk communication.
6. Integrating climate adaptation strategies into national and local flood policies.

Moving forward, policymakers must ensure that flood resilience and climate adaptation remain at the forefront of disaster risk management efforts, particularly as climate change increases the likelihood of extreme weather events in Europe and beyond.

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