

Deliverable D1.2

Report on virtual participatory workshops in all learning and Application Case Study sites, including Impact Chains diagram

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Contributors	Silvia Cocuccioni, Liz Jessica Olaya Calderon, Federica Romagnoli, Massimiliano Pittore (EURAC); Salsabila Ramadhani Prasetya (EURAC, UT), Betül Ergün Konukçu (IMM); Seda Kundak, Çağlar Göksu, Ahmet A. Aşıcı, Kerem Y. Arslanlı, Duygu Kalkanlı, Ece Özden Pak (ITU); Memory Kumbikano, Corina Markodimitraki (NRC); Iuliana Armas, Dragos Toma Danila, Gabriela Osaci, Cosmina Albulescu (UB); Till Wenzel, Philipp Marr (UNIVIE); Nuria Pantaleoni (UPC), Funda Atun, Cees van Westen, Marija Bockarjova, Ben Witvliet (UT)
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Abstract

This Deliverable D1.2 focusses on the PARATUS methodology for analysing past events and understanding current risks, which leverages and combines two different methods: the Forensic Analysis and the Impact Chains. The Forensic Analysis framework was co-developed and implemented by the project consortium through a series of virtual meetings to accommodate the high heterogeneity of the different Learning Case Studies as well as to achieve a shared understanding across the interdisciplinary team. The framework provides a structure for documenting and analysing past disaster events. The output of the Forensic Analysis feeds the Impact Chains, a conceptual model for risk assessment, illustrating the relationships between hazards, exposure, vulnerability, and their cascading impacts. The Forensic Analysis provides Impact Chains with evidence, based on past disaster events and supports the identification of missing elements and connections. For this deliverable a selection of Learning Case Studies has been conducted through a participatory prioritisation process, based on a specific criterion, while the additional Learning Cases will be available for consultation on the Disaster Risks Stakeholder Hub. The overall work has been reviewed through a meta-analysis (available in this deliverable) providing an overview on similarities across the different case studies.



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Disclosure Statement:

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About PARATUS:

The PARATUS project aims to increase the preparedness of first and second responders in the face of multi-hazard events and to reduce the risks related impacts on various sectors resulting from complex disasters. The outcome is to develop an open-source cloud-based Online Service Platform that offers support in reducing dynamic risk scenarios and systemic vulnerability caused by multi-hazard disasters. To achieve these objectives, the project will perform in-depth assessments of complex interactions between hazards and their resulting impacts on various sectors, analyse the current risk situation and study how alternative future scenarios could change multi-hazard Impact Chains. Based on these analysis, scenarios of multi-hazard impacts will be co-designed and developed with stakeholders in four case study areas (including the Caribbean, Romania, Istanbul, and Alpine regions).

List of Acronyms

Acronym	Definition
AFAD	Disaster and Emergency Management Authority
AKOM	Disaster Coordination Center Directorate
BRAGSA	Buildings, Roads and General Services Authorities
CS	Case Study
CWSA	Central Water and Sewage Authority
D	Deliverable
DLR	German Aerospace Center
DOI	Digital Object Identifier
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DSU	Department for Emergency Situations
ENGAGE	Geomorphological Systems and Risk Research
EOC	Emergency Operations Center
ESF	Emergency Support Functions
EURAC	Eurac Research
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
IC	Impact Chain
ICIMOD	International Centre for Integrated Mountain Development
ICU	Intensive Care Unit
IGSU	Romanian General Inspectorate for Emergency Situations
IIASA	International Institute for Applied systems Analysis
IMF	International Monetary Found
IMM	Istanbul Metropolitan Municipality
IPCC	International Panel For Climate Change



ISO	International Organization for Standardization
ISU	Coordination and Implementation of Resilience Requirements Unit
ITU	Istanbul Technical University
JEU	Joint Environment Unit
LOLA	Landslide Observatory Lower Austria
LU-LC	Land Use and Land Cover
MapN	Operative Centre for Emergency Situations
Mio	Million
mm	Millimetre
Mw	Moment magnitude
NEMO	National Emergency Management Office
NGO	Non-Governmental Organisation
NLRC	Netherland Red Cross
PAHO	Pan American Health Organization
PARATUS	Increasing Preparedness and Resilience of European Communities by Co-Developing Services Using Dynamic Systemic Risk Assessment
PDNA	Post-Disaster Needs Assessment
PGA	Peak Ground Acceleration
RC	Reinforced concrete
RCCC	Red Cross Red Crescent Climate Centre
SME	Small and Medium-sized Enterprises
SVG	St Vincent and the Grenadines
TEM	Trans European Motorway
UB	Universitatea din Bucuresti
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
UNICEF	United Nations International Children's Emergency Fund
UNIVIE	Universität Wien
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNU-EHS	United Nations University- Institute for Environment and Human Security
UNU-GLOMOS	United Nations University- Global Mountain Safeguard Research
UT	University of Twente
UWI-SRC	University of West Indies, Seismic Research Centre
VHF	Very High Frequency
VISES	Vienna International School of Earth and Space Sciences
WP	Work Package
WWF	World Wildlife Fund

Executive summary

Work Package 1 “*Learning from the past: understanding the dynamic and interactive conditions of risk*” focuses on utilizing information from historical disaster events (so-called Learning Case Studies) and combining this information with disaster history in Application Case Studies. This includes analysing how the hazardous events directly and indirectly impacted and would impact different sectors, such as health, cultural heritage, environment and biodiversity, public finance, and key economic sectors. Learning from past events allows us to advance risk science and achieve improved multi-hazard impact forecasting.

This Deliverable D1.2 focusses on the PARATUS methodology for analysing past events and understanding current risks, which leverages and combines two different methods: the Forensic Analysis and the Impact Chains.

The Forensic Analysis framework was co-developed and implemented by the project consortium through a series of virtual meetings to accommodate the high heterogeneity of the different Learning Case Studies as well as to achieve a shared understanding across the interdisciplinary team. The Framework provides a structure for documenting and analysing past disaster events. In particular, it includes four key components that can be allocated into the event's timeline: (i) Pre-disaster conditions, (ii) Hazards and Impact analysis, (iii) Recovery and (iv) Building resilience for future events. The output of the Forensic Analysis feeds into and supports the development of Impact Chains, a conceptual model for risk assessment, illustrating the relationships between hazards, exposure, vulnerability, and their cascading impacts.

In particular, the Forensic Analysis contributed to the development of the Impact Chains by providing evidence, references and more detailed descriptions for the Impact Chain elements and connections as well as identifying additional elements and connections (e.g. vulnerability elements, often overlooked given the different backgrounds of consortium members). Thus, the Impact Chains represent the dependencies and interconnections among risk elements identified in the Forensic Analysis. This combination helps identify the root causes and processes that shape vulnerability, analyse the measures taken to recover from the event's impacts, identify the measures implemented to build resilience for future events and point out the unaddressed vulnerabilities. The approach uses the synergies to overcome each method's bottlenecks and limitations, providing a clear picture of risk pathways and the role of underlying risk drivers and human-nature interactions in disaster risk materialisation.

In the context of this deliverable, the approach has been applied in a selection of Learning Case Studies: the (i) Kahramanmaraş and (ii) Vrancea earthquakes, (iii) Irma and Maria hurricanes in Sint Maarten (iv) Gloria and (v) Vaia storms, respectively in Cataluña and the Alps, (vi) the St. Vincent and the Grenadines volcanic Eruption and finally the (vii) Lower Austria Landslide Observatory. Within PARTAUS, Learning Case Studies constitute a collection of previous disaster events and are aimed at extracting valuable insights. The prioritisation process which led to the selection of the seven Learning Cases for this deliverable was based on specific criteria, including data availability, hazard and Application Case Studies coverages as well as previous developments of Impact Chains. The additional Learning Cases of the PARATUS project will be available for consultation on the Disaster Riks Stakeholder Hub.

The overall work has been reviewed through a meta-analysis, available in this deliverable. This analysis provides a comprehensive overview of the similarities across the different case studies, including the impacts addressed, the vulnerabilities identified as well as the management of the different events; moreover, it identifies the progress made and the gaps in building resilience.

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1 Introduction to WP1 and D1.2

Work Package 1 (WP1) “*Learning from the past: understanding the dynamic and interactive conditions of risk*” focuses on utilizing information from historical disaster events (so-called Learning Case Studies) and combining this information with disaster history in Application Case Studies. This includes analysing how the hazardous events directly and indirectly impacted and would impact different sectors, such as health, cultural heritage, environment and biodiversity, public finance, and key economic sectors. Learning from past events allows us to advance risk science and achieve improved multi-hazard impact forecasting. Moreover, WP1 activities include the exploitation of satellite remote sensing data for providing risk components for systemic risk assessment.

Hence, PARATUS methodologies (and therefore WP1-related work) incorporate two distinct types of case study approaches: Application Case Studies and Learning Case Studies. Learning Case Studies (see Table 1.1) encompass a collection of previous disaster events aimed at extracting valuable insights. By analysing historical data, these case studies provide a means to comprehend the effects of past disasters on various sectors. On the other hand, Application Case Studies (see Table 1.2) serve the purpose of testing the methods in real test cases, working with local practitioners, and simultaneously enhancing and transferring the impact of the research.

Table 1.1. Learning Case Studies of the PARATUS project

Learning Case Studies (European)	
2021 European floods	Extreme rainfall event leading to severe flooding and heavy damage in different sectors in Germany, Belgium and Netherlands: relevant cross-border disaster example.
2021 Southern European heatwave and wildfires	Severe impact on Greece, Italy and Turkey - interesting because of the multi-sectoral impacts (also touches on cultural heritage sites, vulnerable groups being more affected by heat).
2020 Gloria storm	Catastrophic winter storm that affected NE Spain and S France by winds and heavy rainfall. Severe impacts to coast, hillslopes and floodplains due to different cascading and compounding events.
2020-2021 COVID-19 pandemic	We will look specifically how during the COVID-19 crisis other compounding events caused larger impact due to COVID-19 restrictions and large pressure on health system in various locations, i.e. Romania (floods), Sint Maarten etc.
Landslides observatory, Lower Austria	In 2014 the long-term landslide observatory “NoeSLIDE – Monitoring of different landslide types in Lower Austria”, a multi-parameter measuring network for landslide monitoring was initiated.
2018 VAIA storm	Impact to forests, buildings, roads, due to cascaded hazards (landslides, fluvial floods)
2017 Irma and Maria	Severe Hurricane impact on St. Maarten and other Caribbean islands.
2017 Space weather event	September 2017's geoeffective space weather and impacts to Caribbean radio communications during hurricane response.
2010 Eyafjallajökull Volcanic Eruption	Volcanic eruption and ash cloud causing severe disruption of air space. The event sets an example to the global impact of a local disaster.
2005 Flood Disaster in Tyrol/Austria	The 2005 European floods hit mainly Romania, Switzerland, Austria and Germany during August 2005. Based on this event, a regional study was carried out in Tyrol, which also considered the road and rail infrastructure.
Earthquake	After the Izmit Earthquake, the national disaster risk management system has been improved by the means of new legal tools and organizations. Since 1999 several

August 17 th 1999 Kocaeli and February 6 th 2023 Kahramanmaraş Earthquakes in Turkey	earthquakes occurred but they were not as devastating as Kahramanmaraş Earthquakes on 6 th of February 2023. These two earthquakes are important to see the differences between planned actions and the reality due to cascading events.
Vrancea earthquakes, Romania	Historical earthquakes. Cross-border impact by several earthquakes in the Vrancea region, Romania in the 20th and 21st century affecting Bucharest, the most earthquake-prone capital in Europe.
Learning Case Studies (Global)	
August 2021 Haiti	Tropical storm hits after the earthquake in a region with political unrest.
Montserrat & St. Vincent and the Grenadines (SVG), Barbados in April 2021	Strong explosions generated ash plumes, which are not only impacting the entire island of Saint Vincent but also transporting massive amounts of ash to the neighbouring island country of Barbados in the Lesser Antilles of the West Indies. A team of UNU-GLOMOS led a Remote Environmental Assessment & Analysis Cell to support the UN mission teams.
India: Chamoli District on 7 February 2021	The flood swept away the unfinished Tapovan Vishnugad Hydropower Project and inflicted substantial damage on the Rishi Ganga Hydropower Project. Even as rescue and relief efforts were underway, a glacial lake outburst flood (GLOF) was suggested as the reason for the flood, possibly triggered by glacier collapse (Info source: ICIMOD: UNU-EHS has MoU).
India: Kerala Floods and Landslides in 2018	This historic flood led to the conduct of India's first PDNA exercise and one of India's most expensive reconstruction projects.
2011 Tohoku Earthquake and Tsunami and 1995 Great Hanshin Earthquake	The 2011 event provides data on complex reactions and dynamic situations during a disaster. On the other hand, the 1995 Great Hanshin Earthquake was the first earthquake in a metropolitan city. Legacies are still valid. We will investigate the improvements in DRR and DRM from 1995 until 2011 in Japan. UT is in contact with the Disaster Prevention Centre at Kyoto University. UNU-EHS has an agreement with Tohoku University.
2005 Hurricane Katrina	Heavy rainfall and storm surge caused extensive flooding of a major part of New Orleans. Major social and economic disruption, massive outmigration of population. Recovery dynamics.

Table 1.2. Application Case Studies of the PARATUS project

Application Case Studies
Istanbul, Turkey
Romania: Bucharest
Caribbean: Sint Maarten & Saint Vincent
Alps: Brenner corridor

Both Learning and Application Case Studies have been selected due to their unique characteristics concerning stakeholders, hazard interactions, impacts on different combinations of sectors, their diverse vulnerabilities, scale, and planning decisions. The coordination of Application Case Studies is part of Work Package 6; this includes the application and integration of activities belonging to different WPs, encompassing the involvement of the stakeholders. Therefore, more details on the different case studies can be found in the deliverables of WP6. Specifically, deliverable D6.1 “Strategy and Case Study Protocols” describes the strategies and case study protocols to be applied in four main Application Case Study areas. Deliverable D6.2 “Report 1 of Workshops in Application Case Studies” and Deliverable D6.3 “Report 2 of Workshops in

Application Case Studies” provide an overview of the workshops that have been organized in the period from January 2023 to March 2024 in the four Application Case Studies and present the main findings.

In WP1, the elected events are studied by developing Impact Chains with the help of Forensic Analysis, remote sensing, and disaster databases. The final objective of this work is to achieve a qualitative and quantitative conceptualization of systemic risk related to complex disaster events. PARATUS Impact Chains are developed following a two-fold approach. On the one hand, they can be built through a participatory approach with contributions from specific stakeholders. This includes interviews, testimonies, virtual workshops for learning cases and presence meetings for application cases organized in WP6. On the other hand, they can be developed through a desk-based analysis and be validated by stakeholders at a later stage. Therefore, there is a strong link between the development of ICs and participatory activities such as the workshops.

In total WP1 includes 6 deliverables (see Table 1.3).

Table 1.3: The list of deliverables in WP1

#	Name	Due date (month)	Description
D1.1	Report on participatory workshops in the four Application Case Study sites, including Impact Chains diagram for each analysed event.	10	Lead Beneficiary: EURAC
D1.2	Report on virtual participatory workshops in all learning and Application Case Study sites, including Impact Chains diagram	20	Lead Beneficiary: EURAC
D1.3	Impact, damage and loss data related to the considered events in the four core cases. Wiki-type structured Database.	20	Lead Beneficiary: EURAC
D1.4	Guidelines on the actionable assessment of hazards interactions in compound / cascading events	24	Lead Beneficiary: UNIVIE
D1.5	Methodology to project LU-LC in a given area based on the analysis of existing remote sensing data and AI	24	Lead Beneficiary: DLR
D1.6	Report on the exemplification of the use of remote sensing services analysis solutions	36	Lead Beneficiary: DLR

While Deliverable 1.1. presented an overview of preliminary Impact Chains developed in Application Case Studies through participatory workshops with stakeholders, Deliverable 1.2 focusses on analysing Learning Case Studies through an interdisciplinary process, to support the work of Application Case Studies. In particular, the aim of this deliverable is presenting the PARATUS Forensic Analysis framework, co-developed to improve the Impact Chains, and its application to a selected number of Learning Case Studies, prioritised through a participatory process (see Figure 1.1).

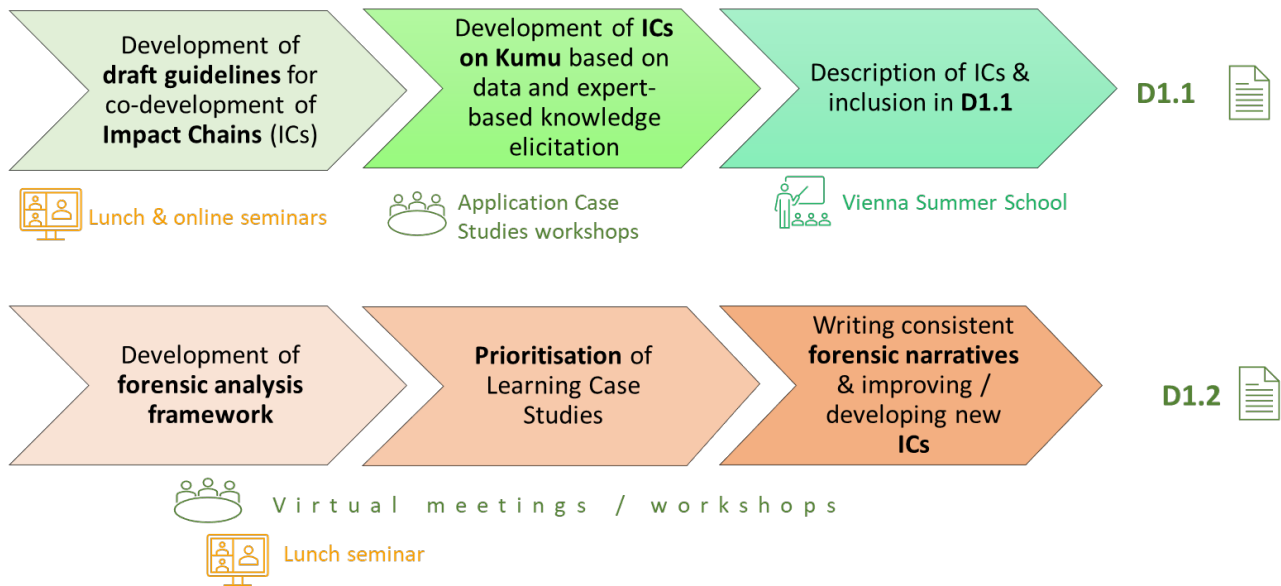


Figure 1.1. Workflow of the first two deliverables of WP1 (D1.1 and D1.2), encompassing mainly the Impact Chains and the Forensic Analysis approaches, strongly connected with co-development and participatory activities.

After this introduction which summarises the main links to the PARATUS project, this deliverable provides an overview on the methodology adopted within PARATUS to analyse selected past event (Chapter 2) followed by its application in a selection of Learning Case Studies (Chapters 3-9). Moreover, Chapter 10 provides a meta-analysis of the similarities and gaps resulting from the Forensic Analysis of the different Learning Cases, while Chapter 11 presents the related next steps.

2 PARATUS methodology for analysing past events and understanding current risks

Climate and disaster risks emerge from compounding and cascading hazards, resulting in complex and interconnected adverse effects on both ecological and human systems. Additionally, underlying risk factors such as poverty, demographic changes, land degradation, and conflicts exacerbate exposure and vulnerability to climate-related hazards (UNDRR, 2022). Moreover, modern societies are strongly characterised by interconnected systems driven by urbanization and technological trends; these complex interactions amplify the impact of local events (Pescaroli & Alexander, 2016). Identifying these interdependencies is paramount to understanding how the impacts of natural hazards propagate across different sectors and society. Consequently, risk assessment and management demand a comprehensive, systemic approach to understand and address the intricate and partly systemic nature of these risks (UNDRR, 2022).

In this context, Impact Chains offer a conceptual representation of risk, illustrating the relationships between hazards, exposure, vulnerability, and their cascading impacts (Zebisch et al., 2022). Climate-related hazards can directly impact the environment (e.g. water availability), which can indirectly affect society or sectors (e.g. agricultural sector). The development of a conceptual model summarising these cascades allows to

identify past weaknesses and deficiencies and to pinpoint entry points for improved disaster risk management and climate change adaptation. In particular, this approach is helpful for understanding and addressing compound hazards (Zebisch et al., 2023).

Studying past disasters is crucial for deepening our understanding of how various risk factors interact and lead to widespread impacts. By examining both direct and indirect impacts of past events and understanding their causes, we can better predict and prepare for future disaster events while implementing effective risk mitigation strategies. However, due to rapidly evolving economic, social, and environmental conditions we cannot solely rely on the view that "the past is the key to the future". In this context, Forensic Analysis of historical disasters helps to understand how system components might react, uncovering root causes, risk drivers and trends.

Within PARATUS we developed a methodology for the conceptualisation of risk, learning from past disaster events and mapping the interconnections between the different risk components. This approach is leveraging **Forensic Analysis** to develop a narrative of the event and to pinpoint and explore the different key elements composing the **Impact Chains**. In particular, the Forensic Analysis developed within PARATUS tries to overcome the weaknesses which arose arisen in the development of the preliminary Impact Chains, by better describing the existing elements, and by including those which were overlooked.

The aim is to systematically analyse and conceptualise historical disaster events in order to gain a better understanding of current and future risk in Application Case Studies (see Figure 2.1). More details on the Impact Chains methodology are available in Deliverable 1.1, while the Forensic Analysis and its integration with the Impact Chains are presented in the following sections.

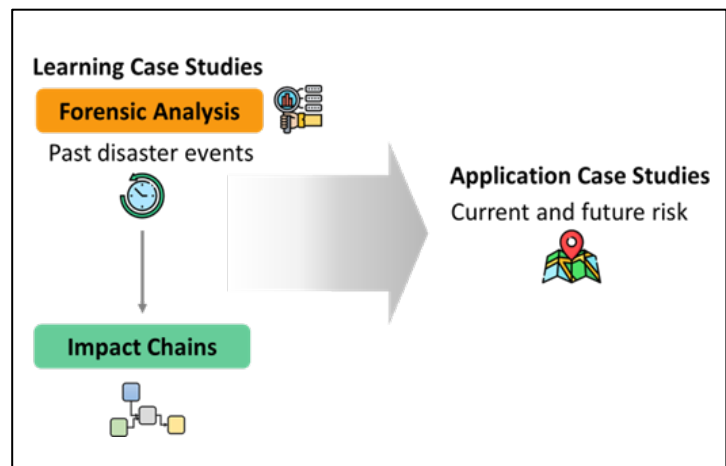


Figure 2.1 The integration of the Forensic Analysis approach with the Impact Chains to improve the understanding and conceptualisation of risk in Application Case Studies

2.1 Forensic Analysis framework

The PARATUS project's Forensic Analysis framework is a comprehensive approach to systematically address and analyse disaster events. This framework provides a structure for documenting and analysing past disaster events, which involves four key components that can be allocated into the event's timeline (see Figure 2.2). This approach aims to answer the following questions in order to write a descriptive narrative of each event: Why could the event happen? (Pre-disaster conditions), What happened during the event? (Hazard and impact analysis), What actions were taken to restore service and address impacts during the recovery phase? (Recovery), and What measures were taken to reduce future event risks and increase resilience? (Building back better). Each component of the framework has specific characteristics and subdivisions that address key points necessary to understand the disaster event (see Excel Table 12.1 in Annex I for details). These components are described below. We would like to clarify that for visualization purposes we visualize those

questions chronological order. Nonetheless for analytical purposes, we firstly describe the hazards and its impacts, secondly the vulnerabilities that influenced the overall impacts of the hazards (pre-disaster conditions), and finally we analyse the recovery actions and lessons capitalized to increase future resilience.

The **Pre-disaster conditions** element focuses on the characteristics of the socio-ecological system that explain why it was at risk and why the disaster could happen. This component is divided into Vulnerability, Underlying Risk Drivers, and Root Causes, and it is based on the progression of vulnerability proposed in the Pressure and Release framework (Wisner et al., 2004). Vulnerability is addressed in a multidimensional approach, covering the physical, environmental, economic, social, and institutional aspects that influence the given disaster impacts at the time of the event's occurrence. This involves addressing the intrinsic factors of a given context (susceptibility) and the capacity for coping, adapting, and recovering from these impacts. The underlying risk drivers are those short and long-term processes that shape vulnerability and exposure and directly affect risk management and reduction capacities, such as demographic patterns, failures in governance, environmental degradation, etc. Lastly, the root causes are structural dynamics deeply ingrained into society that lead to severe social and government dysfunctions and have led to the underlying risk drivers shaping the vulnerability (e.g. Pre-disaster conditions such as colonisation, internal conflicts, etc).

The **Hazards and Impact analysis** encompasses what happened during or (shortly) after the event. This section provides detailed information on the hazards, such as the epicentre, time, scale, intensity, and return period. This section further aims to collect all the necessary data to explain the performance of the early warning systems and the first response, as well as a description of the short-term impacts in terms of damage and loss of physical capital (e.g. critical infrastructure), loss of life and human health, environmental degradation and deploy of the ecosystem services, functional or systemic disruptions to services, and finally, the economic assessment.

The **Recovery section** deals with the steps taken to address the impacts of a disaster and restore the disrupted services. This crucial phase focuses on analysing the implementation performance of the necessary actions taken to recover, including their duration. Finally, the section on **building resilience for future events** aims to understand the measures and actions taken after the event to reduce future risk and increase resilience. It involves capitalising experience and knowledge, i.e., lessons learned for improvement, reflecting on the actions that eventually led to negative consequences and considering the points that still need improvement, such as the unaddressed vulnerabilities.

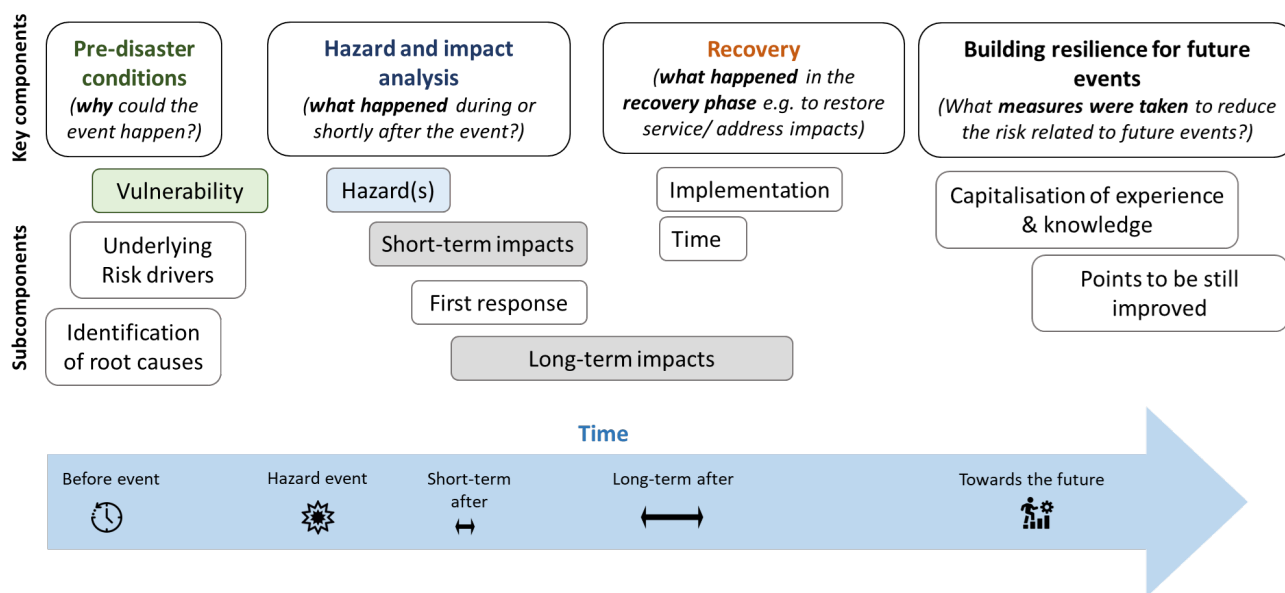


Figure 2.2 The PARATUS Forensic Analysis Framework, co-developed within the project to improve the development of Impact Chains. The different components of the framework are ordered chronologically in time with respect to the occurrence of the hazard event. On the top, the four main components are displayed; these are divided into sub-components, listed below. The coloured subcomponents are those which feed directly into the Impact Chains.

Despite the Forensic Analysis's focus on a specific disaster event, the components and concepts overlap partially with those of the IC risk analysis (Section 2.2). Therefore, the resulting text from applying Forensic Analysis can complement the different fields on the Impact Chains in KUMU, e.g., the description, the source, or the references fields.

While providing common guidance to allow comparability of results, the selected methodological approach maximises flexibility to accommodate the high heterogeneity of the various Learning Case Studies. This is because the framework addresses the temporal evolution of the disaster event and its management, making it broadly reproducible in any context.

The final output of the Forensic Analysis implementation consists in a narrative, a text which describes the different components, thanks to the collected data. Systematised quantitative data related to the different past disaster events is collected within other activities of the PARATUS project.

2.2 Integration with Impact Chains

Forensic Analysis and Impact Chains share characteristics and work in a complementary manner. For instance, both strongly emphasise the social components of risk, vulnerabilities, and the underlying risk drivers. They are based on the relationships among composing elements and aim to identify adaptation/risk reduction options (e.g. updating building codes, investing in early warning systems, etc, depending on the specific context).

From a conceptual point of view, Forensic Analysis provides a comprehensive study of the materialisation of risk (disaster). It shows the temporal progression of a disaster event, including the pre-disaster conditions, the hazard and impacts, recovery and building resilience stages. Therefore, the connection with the risk analysis tool “Impact Chains” is evident because of the similarity of concepts and understandings of risk, such as hazards and impacts, vulnerabilities, and risk reduction/adaptation measures. Nevertheless, despite the similarity in terms and concepts, Forensic Analysis focuses on a past event, while Impact Chains focus on risk, mainly with a prospective vision.

The PARATUS approach uses a comprehensive risk analysis that leverages these two methods. It uses their synergies to overcome each method's bottlenecks and limitations, providing a clear picture of risk pathways and the role of underlying risk drivers and human-nature interactions in disaster risk materialisation. In practical terms, the output of the Forensic Analysis feeds the Impact Chains, providing them with evidence-based on past disaster events. Thus, the Impact Chains represent the dependencies and interconnections among risk elements identified in the Forensic Analysis. This combination helps identify the root causes and processes that shape vulnerability, analyse the measures taken to recover from the event's impacts, identify the measures implemented to build resilience for future events and point out the unaddressed vulnerabilities. This last point allows to understand which elements of the Impact Chain related to past events are still true today under current conditions and which have been addressed since the occurrence of the event. This way, the Impact Chains can be updated to represent the current risk situation.

The PARATUS Impact Chains, stored in the Impact Chain Wiki, available on the Disaster Risk Stakeholder Hub, constitute the knowledge base related to the examined past events and risk situation in Application Case Studies. Therefore, these should not only be seen as a visual illustration but also provide a semantic representation of risk components, where pre-defined elements and connection types are defined and described through metadata. The Impact Chains resulting from previous steps of the project (see Deliverable 1.1) presented several weaknesses, mainly related to their completeness. In some cases, elements were overlooked (mainly related to social aspects, such as vulnerabilities and impacts), and the metadata of the elements was not always present (Figure 2.3).

In this context, the Forensic Analysis contributes to the development of the Impact Chains by compiling evidence related to their elements and connections, providing the missing metadata (e.g. description, references, sources) (Figure 2.4) and identifying elements which were overlooked. Finally, the use of both methods amplifies our understanding of risk.

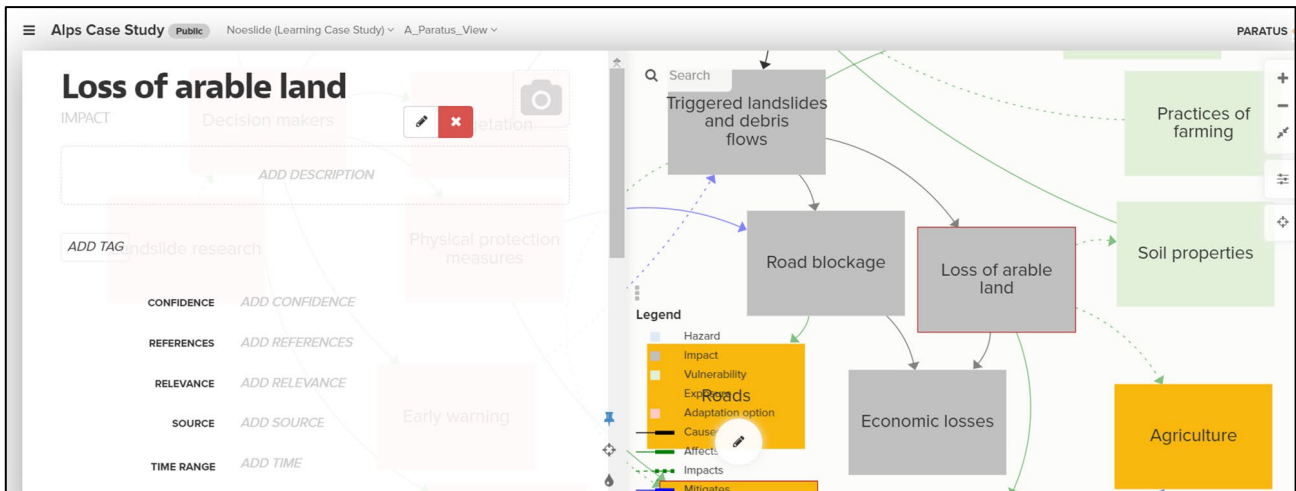


Figure 2.3 Example of unavailable KUMU metadata related to a specific Impact Chain element, before the work on the Forensic Analysis

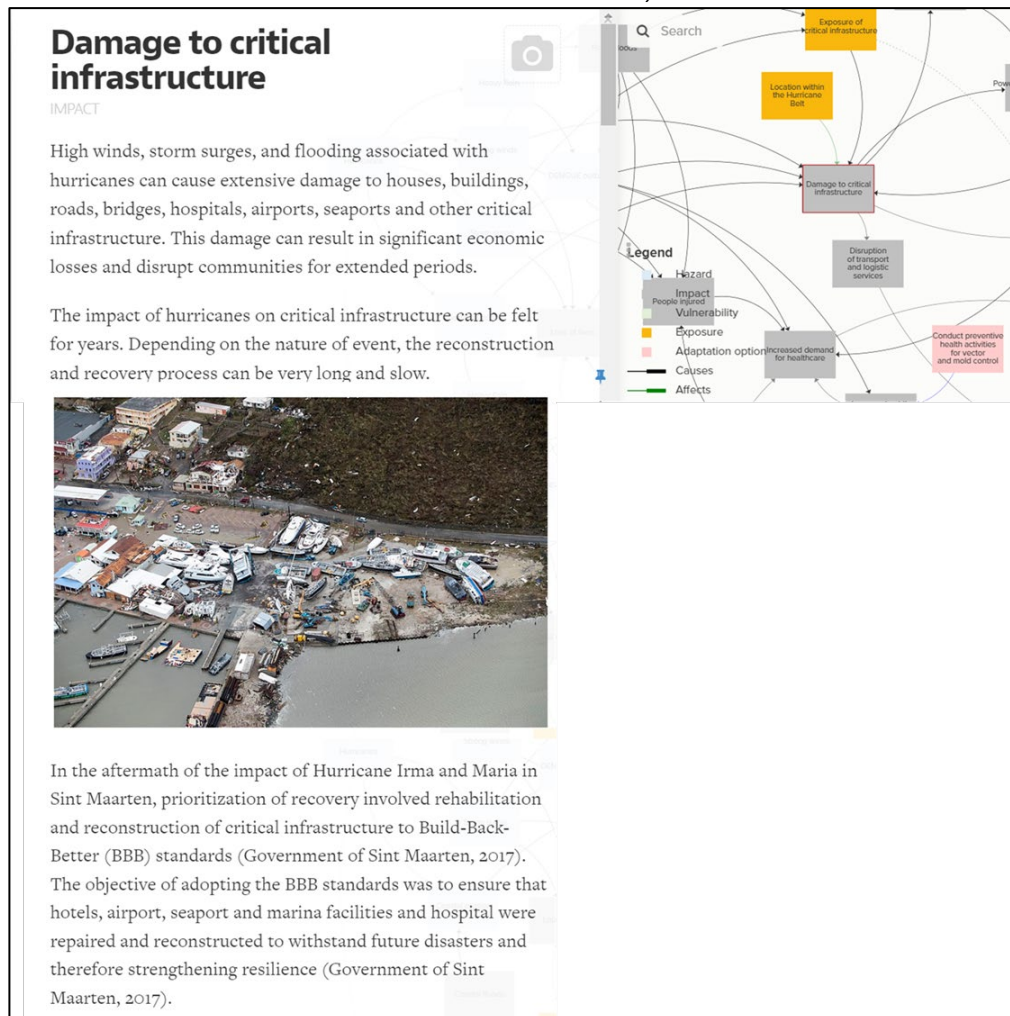


Figure 2.4 Example of available metadata on KUMU, after the work on Forensic Analysis

2.3 Participatory approach within PARATUS

The workflow presented in Figure 1.1 incorporates various participatory elements throughout. These are presented more in depth in Figure 2.3.

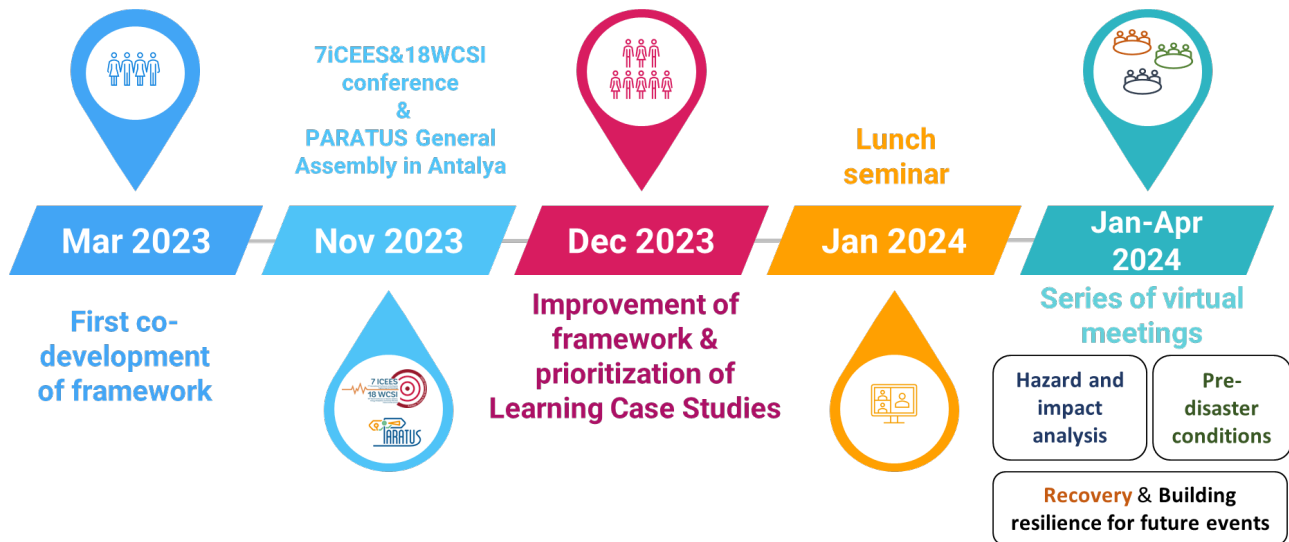


Figure 2.5 Overview of participatory elements within the Forensic Analysis workflow.

(i) Co-development of Forensic Analysis framework:

The framework was co-developed by a team composed by different members of the project consortium. Since the partners have diverse expertise and backgrounds, the framework was tested and discussed to ensure a shared understanding of the key points. A first draft of the Framework was presented in deliverable 6.1, at the 7ICEES&18WCSI conference and in the conference proceedings (Atun et al., in publication). Subsequently, a broader team adapted the framework, also including the feedback received after the General Assembly held in Antalya. Finally, a lunch seminar was organised to present the final outcome of the co-developed framework.

(ii) Prioritisation of Learning Case Studies

Overall, in PARATUS there are 18 Learning Case Studies. Among these we can distinguish between those which overlap partially or completely from the geographical point of view with the Application Case Studies and those with a different geographical scope. For this deliverable a selection of Learning Case Studies was made through a participatory prioritisation process carried out among project partners. The prioritisation process was based on the following criteria:

- **Data availability:** the Learning Case Studies (LCSs) responsible partners were asked to provide an indication on their knowledge regarding potential data availability for the different Forensic Analysis components (the results of this process are available in Annex I). Priority was given to those LCSs where more data was reported to be available or easily accessible.
- **Previous development of Impact Chain** (within D1.1): since the objective of the Forensic Analysis framework was that of improving the existing Impact Chains (including missing elements and better

defining the existing ones), the selection included LCSs which already developed Impact Chains in earlier stages of the project (e.g. in workshops, included in deliverable 1.1). To further test the methodology three new Learning Case Studies were also included in the selection.

- **Coverage of all Application Case Studies:** in line with the objective of leveraging the work in Learning Case Studies to support the understanding of current risk in Application Case Studies, the selection aimed at covering all the Application Case Studies. One LCS whose geographical scope was not overlapping with ACS was also included (Gloria storm), in order to potentially compare it, in the future, with a storm which occurred in a different context (Vaia storm).
- **Hazard type:** the selection aimed at including a variety of hazards, ranging from meteorological hazards (Irma/Maria hurricanes, Vaia and Gloria storms) to geological ones which can be sudden (Kahramanmaras and Vrancea Earthquakes) or have a slow onset (Landslide observatory).

Table 2.1 Overview of selected Learning Case Studies as frontrunners for Deliverable 1.2

#	Learning Case Study	Year	Associated Application Case Study	Hazards	Impact Chain in D1.1
1	Kahramanmaras Earthquake	2023	Istanbul	Earthquake, cold temperature/snow	X
2	La Soufrière Eruption	2021	Caribbean (St. Vincent)	Volcanic eruption, COVID-19, tropical cyclone	X
3	Hurricane Irma and Maria	2017	Caribbean (St. Maarten)	Hurricane (heavy rain, storm surge, strong winds)	X
4	Vrancea earthquake	1977	Romania	Earthquake	X
5	Landslides observatory	-	Alps	Heavy precipitation / snow melt, landslides	X
6	Vaia storm	2018	Alps	Intense rainfall coupled with strong winds	
7	Gloria storm	2020	-	Intense rainfall coupled with strong winds	

(iii) Writing consistent forensic narratives & improving / developing new ICs

The Forensic Analysis implementation was accompanied by regular virtual meetings in order to accommodate the high heterogeneity of the different Learning Case Studies as well as to achieve a shared understanding of the Impact Chains. The virtual meetings had different themes, covering the different components of the forensic framework. In particular, the first one covered the “Hazard and Impact Analysis” section of the Forensic Analysis, the second dealt with the “Pre-disaster conditions”, while the last focussed on the “Recovery” and “Building resilience” sections.

3 Kahramanmaraş Earthquake, 2023

3.1 Forensic Analysis

Hazard analysis

In February 2023, the South-East Anatolian Region of Türkiye experienced a sequence of three consecutive earthquakes (Figure 3.1). The first occurred on February 6th, 2023, at 4:17 am, with a Mw 7.7, striking the Pazarcık district in the city of Kahramanmaraş. Subsequently, nine hours later on the same day, the Kahramanmaraş Elbistan district was hit by another earthquake measuring Mw 7.6. Then, on February 20th, 2023, an earthquake with a magnitude of 6.4 struck Hatay-Yayladagi (AFAD, 2023). Seismic activity in February 2023 resulted in a fault rupture spanning over 300 km along the left-lateral East Anatolian Fault.

The earthquakes caused a displacement of approximately 3 to 5 meters on the fault. These seismic events impacted 11 provinces in Türkiye, namely Kahramanmaraş, Adıyaman, Hatay, Osmaniye, Gaziantep, Kilis, Şanlıurfa, Diyarbakır, Malatya, Adana, and Elazığ, and affected over 14 million people (AFAD, 2023). The 2023 Kahramanmaraş earthquakes occurred on the East Anatolian Fault (EAF), which is a major tectonic structure in the eastern Mediterranean, separating the Arabian and Anatolian tectonic plates along a boundary that spans nearly 600 km. Together with the North Anatolian Fault (NAF), the EAF enables the Anatolian plate (most of mainland Türkiye) to escape westward at about 20 mm yr⁻¹ from the collision between the Arabian and Eurasian plates in eastern Türkiye. This long-term motion of Anatolia is facilitated by repeated earthquakes along the North and East Anatolian Faults (Hussain et al. 2023). When examining historical seismic activity in the region, it is noted that the Antiochia Earthquake of 115 AD, with a Mw of 7.5, is estimated to have resulted in the loss of approximately 260,000 lives. Furthermore, seismic events above 5 on the Richter scale were recorded in the years 458, 588, 847, 859, 972, 1091, 1170, 1408, 1759, 1796, 1882, 1972, 1951, and 1997 (Tatar et al, 2024).



Figure 3.1 Geographical settings of considered seismic events (Goksu et al., 2023b).

Beyond the extensive damages to buildings, the 2023 Kahramanmaraş earthquakes had a significant impact on critical infrastructure systems, including bridges, viaducts, tunnels, railways, roadways, airports, and energy infrastructure, such as coal and gas power plants, electrical distribution and transmission networks, liquefied petroleum gas terminals, as well as water and wastewater systems (EERI, 2023). Furthermore, breakdowns in communication systems, including base stations, were notable. These complex challenges posed significant obstacles to recovery and response efforts in the aftermath of the earthquakes. After earthquakes, a critical challenge that frequently emerges is the occurrence of fires. Seismic activity has the potential to rupture gas and electrical systems, leading to leakages and short circuits, consequently sparking fires in vulnerable areas. Moreover, the collapse of buildings and infrastructure can impede firefighting efforts, intensifying the difficulty of extinguishing the fires.

During the seismic events, there was no warning system by means of communication (e.g. sound, sms, bell). On 6th February at 5:45 am, within the scope of Türkiye's Disaster Response Plan (hereafter TAMP), the earthquake's level was declared by the Ministry of Interior as Level 4 (Balaban et al. 2024). The implication of this declaration led to meetings with the Ministry of Foreign Affairs and the solicitation of international assistance through the Emergency Response Coordination Center (ERCC). The affected cities were announced in a series of updates by Disaster and Emergency Management Presidency of Ministry of Interior Affairs of Türkiye (hereafter AFAD). Initially, Hatay, Osmaniye, Gaziantep, Şanlıurfa, Diyarbakır, Malatya, and Adana were among the affected cities reported by AFAD. Later on, Adıyaman and Kilis were added to the list of affected cities at 10:00 am and 14:20 pm on the same day. On April 3, 2023, the cities of Bingöl, Kayseri, Mardin, Tunceli, Niğde, and Batman were also included in the list due to the identification of several damages. The earthquake triggered an immediate response, with numerous search and rescue teams mobilized and dispatched to the affected area. In order to carry out search and rescue activities and

subsequent work quickly, a State of Emergency (OHAL) was declared in the provinces in the earthquake zone for 3 months on February 8, 2023, based on Article 119 of the Constitution (Celiksoy, 2023).

AFAD, as a coordinating institution in the disaster risk management of Türkiye, is responsible for spreading the warning to the citizens of the earthquake-hit cities, residents of the country and the world press.

Short and long term impact analysis

The Ministry of Environment, Urbanization, and Climate Change (MoEUCC, 2023) is the official governing body in Türkiye responsible for determining the post-earthquake damage level of each building. According to the assessment carried out by MoEUCC, approximately 2.2 million structures were inspected. Among these, 1.7% completely collapsed, 0.9% required urgent demolition, 9.7% suffered heavy damage, 2.4% experienced moderate damage, 26.0% had minor damage, and the rest of the total remained undamaged (59.3%). The distribution of damaged health institutions, pharmacies and field hospitals by province is presented in Table 3.1 (Birinci 2023).

Table 3.1 Distribution of damaged health institutions, pharmacies and field hospitals by province (Birinci 2023)

	Percentage of damaged public hospitals (%)	Percentage of damaged private hospitals (%)	Damaged primary health care facility (%)	Percentage of damaged pharmacy (%)	Day 10 proportion of open pharmacies (%)	Field hospitals
Adana	6	7	12.3	1	98.7	0
Adıyaman	18	50	14.4	47	36.2	4
Diyarbakır	0	0	15.8	24	97.7	0
Gaziantep	50	0	3.3	5	92.1	3
Hatay	56	40	13	36	33.3	20
Kahramanmaraş	50	29	12.1	44	30.3	13
Kilis	0	0	3.8	0	97.9	0
Malatya	8	86	6.2	18	44.2	1
Osmaniye	14	0	1.5	4	95.2	0
Şanlıurfa	0	0	6	1	97.0	0

There were more than 53,000 casualties and 100,000 individuals sustained injuries (AFAD, 2023). Orhan (Orhan, 2024) discusses the aftermath of the first earthquake striking at night, resulting in significant fatalities due to sudden crushing and limb injuries among those trapped indoors. The subsequent earthquake, occurring the following day at noon, caused survivors near buildings to suffer head, neck, and chest traumas. The primary cause of death in crush injuries is rhabdomyolysis, triggered by the crushing of large muscle masses, particularly in the lower extremities, leading to various clinical complications such as acute renal failure or sudden cardiac arrest. Limited healthcare infrastructure in disaster zones often contributes to higher mortality rates, necessitating rapid surgical decisions like amputations or fasciotomies to preserve lives. Amputation becomes necessary when further treatment or follow-up is unfeasible for cases trapped for over

six hours with poor metabolic and general conditions. Fasciotomy may be considered for less severe cases with minimal systemic impact.

Birinci (Birinci 2023) highlights the swift response to the earthquake, detailing the mobilization of resources for immediate medical assistance. Within the first day, 38 ships, 78 aircraft, and 116 helicopters, along with 52,000 patients, were transported from the affected region to other cities for medical care. Over the following month, the Ministry of Health's SAKOM system facilitated the deployment of 32,335 individuals and 22,161 healthcare personnel to provide essential treatments and services. UMKE and ambulance teams focused on rescue operations, while field hospitals were promptly established in Hatay, Kahramanmaraş, Adıyaman, and Malatya. Given the predominant need for surgical and anesthesia services among rescued victims, comprehensive planning on the first day ensured the provision of internal medicine, nephrology, gynecology and obstetrics, urology, neurosurgery, ophthalmology, plastic and reconstructive surgery, cardiovascular surgery, pediatric surgery, thoracic surgery, intensive care, KVC intensive care, and emergency medicine. Pharmaceutical support, including mobile pharmacies and surviving local pharmacies, commenced on the second day. The Turkish Medicines and Medical Devices Agency (TİTCK) and the Social Security Institution (SGK) facilitated the provision of medicines and medical supplies, particularly for chronic disease patients. Ongoing needs were met through land, air, and sea transportation, with provinces categorized based on logistical considerations such as sea access, airport conditions, and road accessibility.

As previously mentioned, many buildings collapsed, and many buildings need to be urgently demolished. According to a study conducted by Xiao et al.(2023), rough estimates were made regarding the quantity of concrete and demolition waste (CDW) produced, as well as the proportion of waste components. The study indicates that the amount of CDW generated after earthquakes varies between 450 and 920 million tons.

According to Balaban et al. (2024), at 10:00 am on February 6, reports from the Disaster Energy Group indicated a disruption in natural gas supply to the Hatay/Hassa and Kırıkhan regions. As a precautionary measure, the Petroleum Pipeline Corporation (BOTAŞ) halted crude oil flow, while gas supply to the natural gas power plants in Gaziantep, Nurdağı, and İslahiye districts was also severed. This resulted in power outages affecting 27 areas, including Osmaniye Bahçe-Düziçi, Kahramanmaraş city center, and regions in Malatya such as Akçadağ, Doğanşehir, and Doğanşol. Despite the typically harsh winter conditions in the disaster-stricken region, heating options were unavailable for approximately 3–4 days. Although partial electricity restoration occurred in some areas in the following days, the heating issue remained critical, leading many residents to resort to outdoor fires for warmth. Initially, the precise reasons and impacts of the earthquakes on critical infrastructure were unclear. However, it is suggested that fault ruptures intersecting gas and electrical infrastructure networks could have caused these disruptions. Additionally, the earthquakes severely affected the potable water system, leaving disaster-stricken areas without access to clean water for drinking and sanitation due to damage to water infrastructure lines. While water tankers provided temporary support, the risk of hygiene-related outbreaks remained significant.

The economic losses of the earthquake disaster are estimated to be more than \$100 billion by Strategy and Budget Office of Presidency of Türkiye (SBO, 2023). The economic effects of earthquakes can be estimated through various approaches. The World Bank (1999) identifies three key aspects: direct costs (physical damage to assets), indirect costs (output losses, lost earnings, and emergency relief expenses), and secondary effects (short to medium-term consequences on overall economic performance, fiscal accounts, balance of payments, poverty rates, and government policies). Kundak (2010) offers a different perspective, categorizing economic losses as stock costs from immediate losses (e.g., building collapse), stock and flow costs from business activity losses or from infrastructure damage. The economic context of the 2023



Kahramanmaraş earthquakes is notable. The affected region, comprising 11 provinces, accounted for 9.8% of GDP in 2021, contributing approximately 79 billion USD to the national income. However, the per capita national income in these provinces falls below the national average, with an average per capita GDP of 5.924 USD in 2021. Despite this, the region played a significant role in national economic growth, contributing 0.98 points to the 11.4% growth recorded in 2021. According to the IMF report (URL 3), prior to the 2023 Kahramanmaraş Earthquakes, Turkey's growth rate followed a trajectory of 11.4% in 2021 and 5% in 2022, with an anticipated growth rate of 3.5% for 2023. However, considering the earthquakes that occurred on February 6th extending beyond the region and their negative impact both physically and humanly, it is estimated that this rate will decrease by at least half a percentage point (URL 4) (Yilmaz, 2023).

In terms of exports, the region held an 8.6% share in 2022, with Gaziantep standing out with a 4.4% share. The 11 provinces collectively represented 6.7% of the 2022 imports, with Gaziantep and Hatay leading with shares of 2.3% and 2.1%, respectively. Various organizations and public offices have presented divergent economic impact assessments following the 2023 Kahramanmaraş earthquakes. TURKONFED (2023) suggests an economic cost of 84 billion USD, equivalent to 10.3% of the 2021 GDP. SBO (2023) emphasizes housing damage as the primary economic burden, accounting for 54.9% (1,073.9 billion TRY; 56.9 billion USD), followed by public infrastructure and service buildings at 12.9 billion USD. Private sector damage, excluding housing, was estimated at 11.8 billion USD, covering various industries and sectors. Taking into account insurance sector losses, tradespersons' revenue losses, and macroeconomic impacts, the total financial burden was estimated at 2 trillion TRY (103.6 billion USD), equal to 9% of the 2023 GDP forecast. According to BETAM (2023), the total financial burden ranges from 77.4 to 104.8 billion USD, representing 8.6% to 11.6% of the GDP forecast for 2023. In the year preceding the earthquake, the 11 provinces collectively exported 11.1 billion USD between February and July 2022. However, after the earthquakes in 2023, total exports during the same months declined to 8.9 billion USD, marking a 20% decrease. Gaziantep, the leading exporter in the region, witnessed a decline of nearly 0.5 billion USD but displayed signs of recovery. In contrast, Hatay and Kahramanmaraş did not show similar signs of improvement. According to the TEPAV Employment Watch May 2023 Bulletin (TEPAV, 2023), the employment declined in the 11 provinces amounted to 374.5 thousand jobs, equivalent to around 1% of total employment, in the first five months of 2023. This decline varied across provinces, reaching 30% in Malatya, Kahramanmaraş, and Hatay due to life losses and migration. Elazığ, Kilis, Gaziantep, and Şanlıurfa experienced a 10% decline, while other affected provinces like Kilis, Adana, Diyarbakır, and Osmaniye saw a 5% decrease in employment.

Long-term impacts

Two different perspectives exist regarding the migration patterns following the earthquakes. According to Aslan (2023), approximately three million disaster victims, based on GSM signal data, evacuated the earthquake-affected area. Additionally, an estimated 600 thousand individuals relocated to Ankara, inferred from waste management data indicating population increases in certain urban centers. On the other hand, Kundak (2023) asserts that around five million people moved to other cities, primarily to Ankara, Antalya, and Mersin, following the earthquakes, as indicated by reports from real estate experts and local agents. The persistently challenging living conditions and ongoing aftershocks in the disaster areas have reportedly deterred individuals from returning.

The earthquake-affected regions, constituting 16.9% (equivalent to 40 million hectares) of Türkiye's total area, are vital for agricultural production. Within this zone, vegetable, fruit, and ornamental plant cultivation occupy 16.2%, 26.0%, and 3.3% of the agricultural area, respectively. Adana and Sanliurfa are key producers of grains and vegetables in the region. Livestock farming is significant, with Diyarbakir hosting the highest



number of sheep and goats, and Adana leading in beehive numbers. Akdemir et al. (2023) estimated a 30% wheat loss due to weed control challenges in earthquake-affected wheat fields. Farmers in Defne, Hatay, report a 50% product loss due to fungal drug supply issues in vegetable farming. Quality and yield losses are predicted in plant feeding products due to supply disruptions. The most significant agricultural disruption is observed in greenhouse production, where 40% of greenhouses are repurposed for accommodation, resulting in a 40% reduction in production. Reverse migration from cities to rural areas is substantial, potentially leading to a contraction in agricultural areas. Container-style structures on agricultural lands may exacerbate unplanned urbanization in rural areas.

First response

Figure 3.2 indicates the trends of activities and casualties during the emergency response stage (Balaban et al. 2024). As shown in the figure, the evacuation of earthquake survivors started approximately 72 h after the initial jolt. Disaster survivors were then transferred to dormitories and accommodation facilities on the fourth day in the predetermined cities outside of the disaster region.



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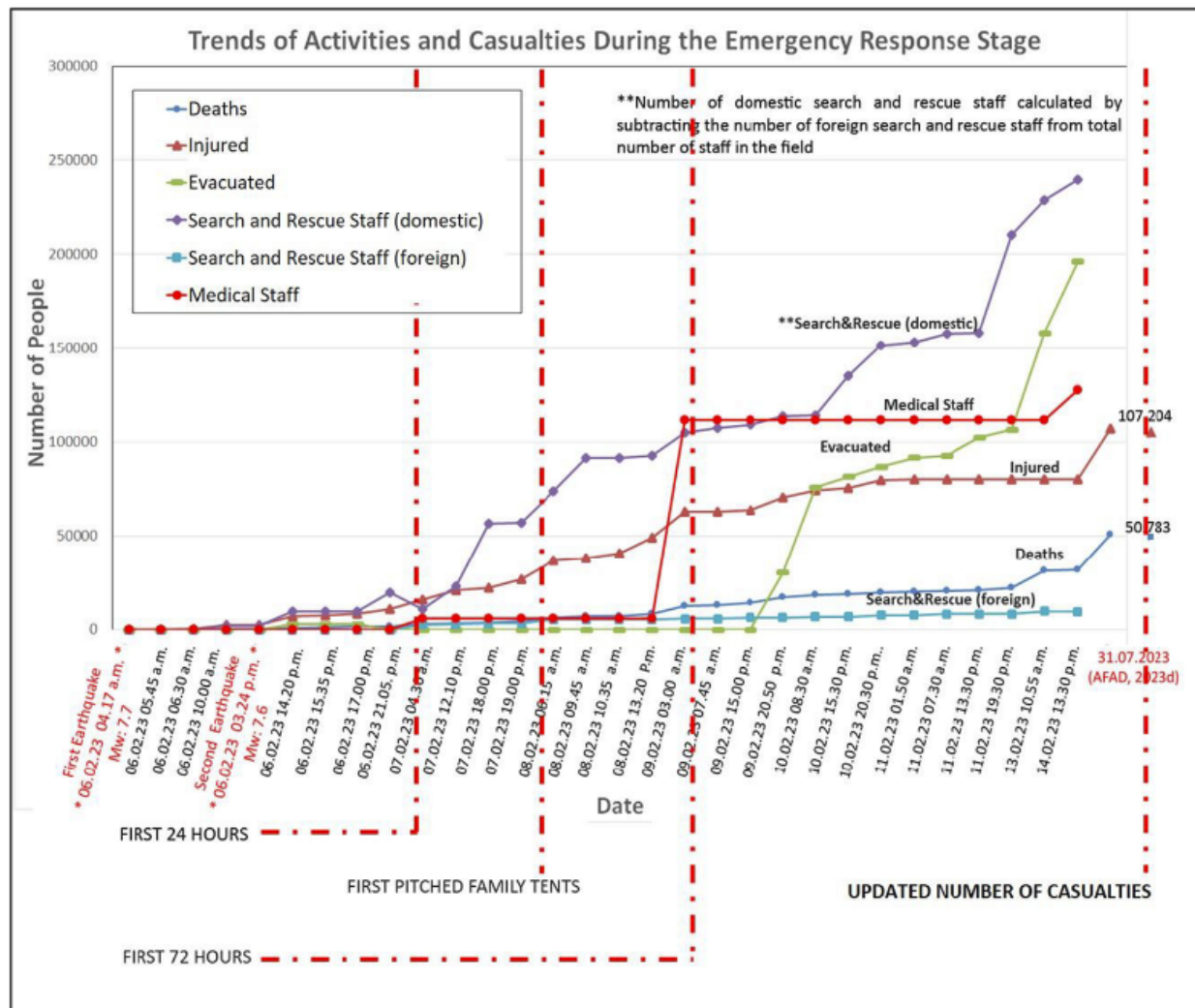


Figure 3.2 Map trends of activities and casualties between February 6 to 14, 2023 (Balaban et al. 2024)

As reported by Balaban et al. 2024, from the first day of the earthquakes until 2 weeks after the first earthquake, the regional sums of emergency response services and casualties have been declared in official announcements by AFAD; however, it was difficult to find provincial statistics which are necessary to analyze local deficiencies in a timely manner. As a result, a total of 29,622 search and rescue personnel, consisting of AFAD, Police Search and Rescue (PAK), Gendarmerie Search and Rescue (JAK), Gendarmerie Special Operations (JÖAK), Coast Guard, Natural Disasters Search and Rescue (DAK), Güven Timi, Fire Brigade, Rescue teams from NGOs, etc. and international search and rescue personnel, worked in the region. As a result of the meetings with the Ministry of Foreign Affairs, the number of search and rescue personnel from other countries was declared as 6479.

The earthquake response effort included providing shelter services to a total of 1,440,668 individuals in the affected region, facilitated through the establishment of 332 tent cities and deployment of 360,167 tents.

Additionally, ongoing initiatives involve the establishment of 189 container cities and the installation of 90,914 containers, accommodating 34,120 people. To enhance living conditions, 2,284 mobile showers and 5,058 toilet containers were deployed in shelter areas. Overall, shelter services catered to 1,593,808 individuals in the earthquake-affected region, with an additional 329,960 individuals receiving support in other provinces. Temporary accommodation and nutrition needs were met through various facilities such as hostels, teachers' houses, and hotels across Turkey. Furthermore, mobile kitchens provided by multiple organizations ensured the provision of nutritious meals to affected individuals until they could be relocated to permanent residences as part of the nationwide "Let my home be your home" campaign (Celiksoy, 2023).

Vulnerability analysis

According to the study by Tatar et al. (2024), the area contained around 2.6 million structures, with residential units accounting for roughly 90% of this total, commercial properties 6%, and government buildings 3 %. In 2022, there were 5.6 million houses in the provinces impacted, accounting for 14.05 % of Türkiye's total housing stock. Reconnaissance studies conducted in the affected regions have consistently identified that the inadequate seismic performance of numerous structures primarily stems from their failure to comply with seismic building codes (Goksu et al. 2023a-b; Ilki et al., 2023a-b, Binici et al., 2023; Vuran et al., 2024). Key vulnerabilities include soft-storey buildings, irregular structures, insufficient reinforcement detailing, corrosion of reinforcement, insufficient splice lengths, unconfined lap splices and poor material quality. In numerous structures, strong beams were paired with weak columns. In several instances, poorly designed infill walls restricted column height, leading to shear failures, known as short column. Transverse reinforcement was widely spaced with 90-degree hooks, lacking cross ties, thus failing to maintain sufficient ductility. Ground failures, such as liquefaction-induced soil movements and differential settlements, were widespread in certain areas. Similar damage patterns were observed in previous seismic events as well (Celep et al., 2011; Tapan et al., 2013; Gürbüz et al., 2023).

It is observed that liquefaction caused settlement in the field land zone and water saturated area. Landslides were observed mostly at mountainous areas where the roads were either physically damaged or blocked by rockfall.

In 2018, a construction amnesty was implemented to address illegally built structures, allowing contractors to seek legal exemption for pre-2018 buildings not meeting safety standards in exchange for a fee. As of 2021, more than 305,000 buildings across 11 Turkish provinces benefited from this initiative, as reported by the MoEUCC. However, during the 2023 Kahramanmaraş earthquakes, many older and supposedly compliant structures collapsed, indicating potential shortcomings in regulatory enforcement. Various earthquake reconnaissance efforts revealed that collapsed or severely damaged buildings often lacked compliance with modern seismic building codes, attributed to corruption, lack of awareness, or profit-driven motives of building owners and contractors seeking unauthorized expansions to maximize profits, as observed by Hussain et al. (2023) and Galasso and Opabola (2023).

The urban transformation process in Türkiye commenced with a significant legal milestone aimed at reducing seismic risk, namely the enactment of Law No. 6306 on the Transformation of Areas under Disaster Risk in 2012. This legislation is designed to mitigate disaster risk, ensure the safety of life and property, and foster the development of better environments and cities. Under the scope of this law, processes and procedures



are executed to identify areas for transformation, renovation, and transfer, as well as to identify risky buildings requiring urban transformation. The law categorizes buildings into three main groups:

- "Risky Buildings": These are structures that have reached the end of their economic lifespan or are deemed susceptible to collapse or significant damage during natural disasters.
- "Risky Areas": These are geographical zones that, due to local conditions, could experience loss of life or property during natural disasters.
- "Reserve Building Areas": These are designated as new settlement zones to accommodate the displacement caused by urban redevelopment initiatives.

Furthermore, the Ministry of Environment and Urbanization offers rent assistance for a period of 18 months to individuals participating in urban transformation projects under Law No. 6306. Those unable to receive rent or moving aid may benefit from interest support or loan opportunities. Currently, a total of 220,486 structures comprising 740,393 independent units have been identified as "Risky Buildings." Demolition has been carried out for 196,923 of these risky buildings, encompassing 633,186 independent units, representing an approximate demolition rate of 89.31%.

Regarding disaster preparedness, in Türkiye, Provincial Disaster Risk Reduction Plans (İRAP) serve as crucial documents aimed at comprehensively assessing and mitigating disaster risks at the provincial level. These reports are pivotal in identifying vulnerabilities and formulating strategies to enhance resilience against various hazards, including earthquakes, floods, landslides, and other emergencies. İRAP reports incorporate detailed analyses of the local context, infrastructure, population density, socio-economic factors, and environmental conditions to provide a comprehensive understanding of the existing risks and vulnerabilities within each province. By leveraging this information, authorities can prioritize investments, allocate resources efficiently, and implement targeted interventions to reduce the impact of disasters and safeguard the well-being of communities across Türkiye.

Analysis of underlying risk drivers

Demographic trends were discussed in detail by Terzi (Terzi, 2023). Based on this report, in Türkiye over 14 million people have experienced moderate to high levels of ground shaking, constituting almost 16% of the whole population in the country. After Adana and Gaziantep gained metropolitan status in 1986, Diyarbakır followed suit in 1993, and in 2012, Şanlıurfa, Hatay, Kahramanmaraş, and Malatya also became metropolitan municipalities. On the other hand, Kilis separated from Gaziantep in 1995, and Osmaniye separated from Adana in 1996, becoming separate provinces. In the 10 provinces affected by the earthquakes on February 6, 2023, there are 13.5 million people living. Approximately 30% of the population is under the age of 14, while the population aged 65 and over is around 3%. In the 10 provinces and 113 districts affected by the earthquake, the average household size is 3.96. The smallest household sizes (3 and below) are in Hekimhan, Arguvan, Arapgir, Kale, Kuluncak, Doğanyol, and Pütürge districts of Malatya, and Feke and Pozantı districts of Adana. However, in Şanlıurfa (Harran and Akçakale), there are households with 7 or more members. The districts with households consisting of 5 or more people are Ceylanpınar, Viranşehir, Siverek, Suruç, and Eyyübiye districts of Şanlıurfa and Hani and Kocaköy districts of Diyarbakır.

In 2020, the total dependency ratio in the region is 60%, while the average for Türkiye is 47.7%. This high ratio indicates that the earthquake region is quite weak and fragile regarding labor force. In other words, the population aged 0-14 and 65 and over is much higher than those aged 15-64. The total dependency ratios are very high in Harran and Akçakale districts of Şanlıurfa (109% and 102%). In only 7 districts (Defne and Arsuz in Hatay, Battalgazi in Malatya, Yumurtalık, Sarıçam, and Çukurova in Adana, Toprakkale in Osmaniye), the total dependency ratio is around or slightly below the average for Türkiye. The poverty, disadvantage,



and housing indicators of our 10 provinces, which suffered significant loss of life and property in the earthquakes centered in Kahramanmaraş on February 6, 2023, are statistically analyzed, their pre-earthquake situations are revealed, and mapped out. Social disadvantages are multidimensional, including insufficient income to attain an acceptable standard of living, inadequate resources, inability to access essential goods and services, and exclusion from fundamental activities in society. The 10 provinces affected by the earthquake are among the most disadvantaged 1st and 2nd percentiles. The most disadvantaged provinces are Diyarbakır, Osmaniye, Şanlıurfa, Kilis, Malatya, and Adıyaman. Disadvantaged provinces are Adana, Hatay, Gaziantep, and Kahramanmaraş (Terzi, 2023).

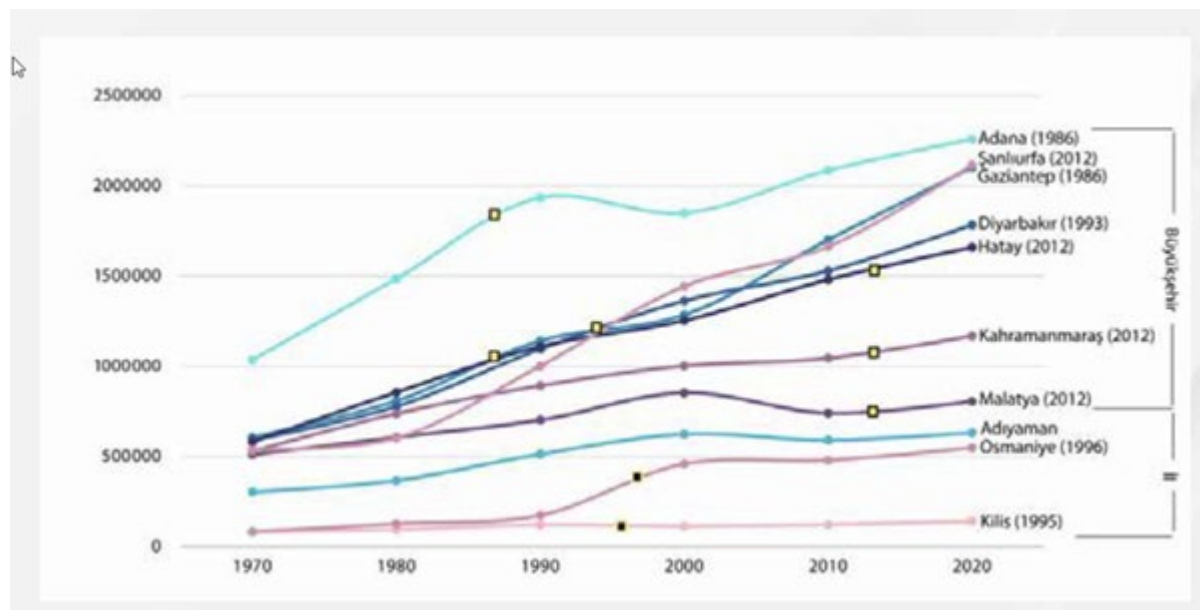


Figure 3.3 The population development of the earthquake-hit provinces (Terzi, 2023).

According to Terzi (Terzi, 2023), when the urban growth trends and dynamics of the 10 provinces affected by the earthquakes on February 6, 2023 are examined, it is observed that the agricultural sector plays an important role in the development of cities due to their location in areas with high agricultural production potential. With the encouragement of industrial investments in the country and the development of manufacturing industries in these regions since the 1970s, a rapid migration process from rural to urban areas has occurred, especially in cities such as Adana, Gaziantep, Diyarbakır, Hatay, and Şanlıurfa. After Adana and Gaziantep gained metropolitan status in 1986, Diyarbakır followed suit in 1993, and in 2012, Şanlıurfa, Hatay, Kahramanmaraş, and Malatya also became metropolitan municipalities. On the other hand, Kilis separated from Gaziantep in 1995, and Osmaniye separated from Adana in 1996, becoming separate provinces (Figure 3.3). Within this process, which showed rapid growth in the 1990s, a more interconnected urban system emerged along the main transportation arteries with the development of industrial zones in the cities.

These cities, consisting of traditional urban fabric, historical cores, and low-rise structures developed around them, initially spread towards agricultural, pasture, and forest areas (e.g., Adana & Gaziantep). However, in the last 20-30 years, to meet the housing demands of the migrating population, rehabilitate deteriorating and informal settlement areas, and promote the development of service sectors and amenities, they have

entered into both improvement, renewal, and urban transformation processes and urban sprawl processes. This period corresponds to the era of construction of high-rise buildings in city centers (Terzi, 2023).

Within this region, there are numerous nature parks, national parks, nature monuments, wildlife protection areas, nature reserves, forests, large plains, and pastures. These areas are protected under international agreements and national legislation and are defined within the scope of the Strategic Environmental Assessment Regulation. Due to the impact of migration and structures for energy, urbanization, and agricultural purposes, agricultural lands are being converted for non-agricultural use in these provinces. Absolute agricultural lands in rugged areas are limited both due to soil structure (sloping terrain, erosion, etc.) and climate conditions; therefore, they should be considered as scarce resources. Lands where plant production is not feasible are effectively utilized as pastures. With livestock farming emerging as an alternative to crop production, its continuity under changing climate conditions is expected to play a significant role in national food security. To meet the food needs of the region's population under changing climate conditions, integrated land use planning should be conducted in collaboration with other sectors, and the protection of the large plain lands, which are scarce resources, should be ensured. The forest cover in the region plays a crucial role both in reducing the impacts of climate change and in combating climate change (Terzi, 2023).

In 2021, more than 1.5 million individuals resided below the national poverty line in the earthquake-hit provinces (Hussain et al., 2023). As noted by Akar (2024), the 'Arab Spring' in 2010–2011 initiated a populist uprising in Syria, escalating into a prolonged civil war, significantly affecting Syria and its neighbouring nations. Following 12 years of conflict, the Syrian refugee crisis persists as the largest displacement crisis globally. Around 5.2 million registered refugees, including over 2.5 million children, reside in Egypt, Iraq, Jordan, Lebanon, and Türkiye. As of November 30, 2023, the total number of Syrian refugees in these countries stands at 5,184,938, with Türkiye hosting approximately 3.2 million of them, constituting the largest refugee population globally. Due to geographical proximity, initial Syrian refugee destinations in Türkiye after 2011 included Kahramanmaraş, Hatay, Gaziantep, Adıyaman, Kilis, Osmaniye, Malatya, Şanlıurfa, Adana, Diyarbakır, and Elazığ. The earthquake's extensive coverage resulted in a significant humanitarian crisis for both local populations and refugees due to delayed search and rescue operations. The earthquake zone hosts over 1.7 million Syrian refugees, comprising nearly 50% of Türkiye's total Syrian refugee population. Approximately 11.48% of the region's population consists of Syrians, with 46% being children aged 0–17 and 3% elderly individuals aged 65 and above. In Kilis, one in every two individuals and one in every four to five individuals in Gaziantep, Şanlıurfa, and Hatay are Syrian refugees. Post-earthquake, approximately 70,000 individuals returned to Syria, with around 16,000 returning to Türkiye. It is estimated that some refugees who went to Syria may not return to Türkiye, indicating the earthquake's influence on accelerating returns to Syria.

Analysis of root causes

Although seismic building codes have been improved for the well-being of structural design and construction since the mid-1900s, amnesty laws and regulations have encouraged unplanned development due to the construction of low-quality and vulnerable buildings by non-professionals. The Slum Law no. 775 enacted in 1966, aimed to rehabilitate such areas and took measure in prevention of un-planned development in the future. However, sluminisation could not be prevented and another amnesty was enacted in 1976. In 1983, slums built until 1981 were legalized. The 1984 amnesty law reduced the implementation difficulties in the previous laws, provided the right to obtain title deeds, and allowed squatters to build up to 4 storeys on their own land (Sönmez, 1996). Within the new millenium, some amendments were made to the articles of related



laws as amnesty. Finally, in 2018, a comprehensive amnesty law was enacted (Figure 3.4) (Goksu et al., 2023b).



Figure 3.4 Timeline of earthquakes larger than MW 7.0 and regulations (Goksu et al, 2023b).

Recovery analysis

Following the earthquake, Şen (2023) reported the declaration of a state of emergency to facilitate swift and effective search and rescue operations in the affected area. Subsequently, various preventive and corrective measures were initiated by public institutions such as the Ministry of Treasury and Finance, Ministry of Trade, Ministry of Agriculture and Forestry, Ministry of Labor and Social Security, Banking Regulation and Supervision Agency (BRSA), Capital Markets Board (CMB), Borsa Istanbul A.S. (BIST), and the Turkish Banks Association (TBA). These measures aimed to safeguard financial markets and the real sector from adverse effects, restore stability in stock markets, prevent volatility in financial markets, ensure the functioning of the credit mechanism in the banking sector, sustain real sector activities in the disaster area, and mitigate negative impacts on the overall economy. Notably, the establishment of the Natural Disaster Insurance Institution (DASK) in 2000 and the enforcement of mandatory earthquake insurance following the 1999 Marmara Earthquake were significant preparedness steps. DASK manages Mandatory Earthquake Insurance (MEI) activities, which cover independent sections within municipal boundaries and buildings constructed with state-provided disaster-related credits. However, MEI is not available for buildings in village populations lacking projects and engineering services. The number of MEI policies exceeded 10 million by December 31, 2021, with a notable increase post the February 6 Earthquakes, reaching over 11 million 224 thousand policies nationwide by February 2023, insuring 56% of total residences (Yilmaz, 2023).

As per Şen (2023), President Recep Tayyip Erdoğan, after a Presidential Cabinet meeting at the AFAD headquarters on February 14, 2023, addressed earthquake-related concerns in a press briefing. He announced financial assistance for affected citizens, stating that households rendered uninhabitable would receive up to 15,000 Turkish Lira (approx. 500 USD) for relocation, up to 5,000 Turkish Lira (approx. 160 USD) for rent, and 10,000 Turkish Lira (approx. 330 USD) in aid. Furthermore, fuel expenses for families relocating

to provinces outside the earthquake zone with their vehicles will be covered, and 100,000 Turkish Lira (3200 USD) in aid will be extended to the families of earthquake victims.

On the first anniversary of the earthquake, housing allocation was completed by drawing lots for 7,275 houses in Hatay, 10,698 houses in Gaziantep, and 9,289 houses in Kahramanmaraş. Additionally, the construction of 20,000 houses in Kahramanmaraş is progressing rapidly, with plans to deliver 200,000 houses and village homes to their rightful owners by the end of the year. President Erdoğan has stated that this number will swiftly reach 390,000 thereafter (URL 1)(Figure 3.5).



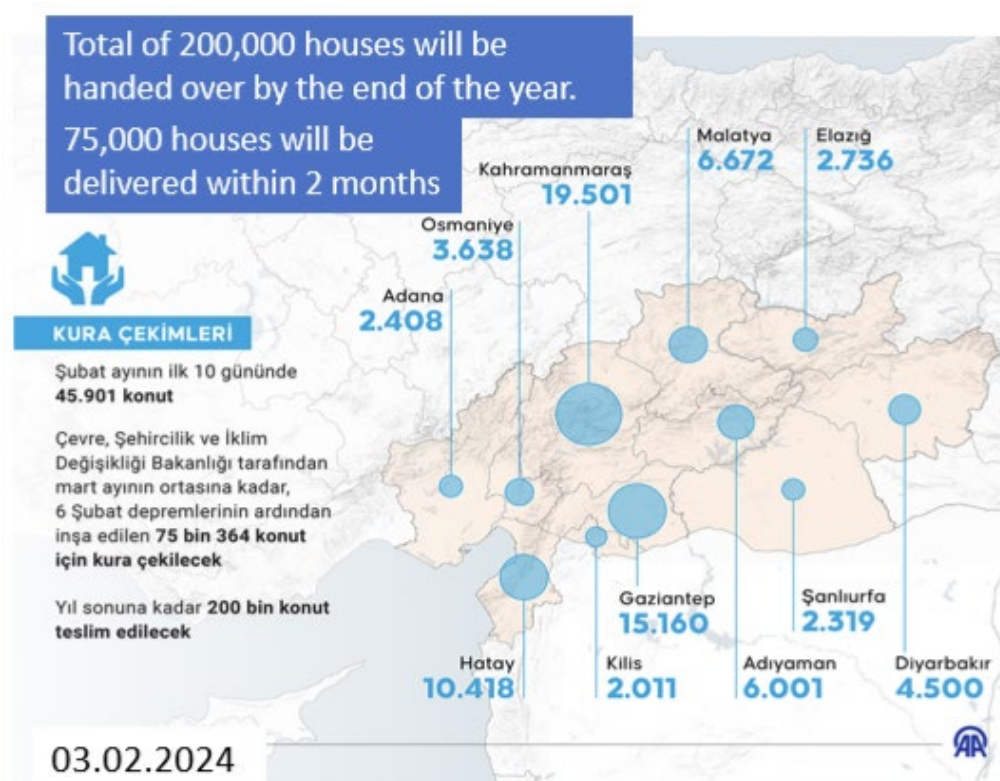


Figure 3.5 Financial and housing aids provided in the Kahramanmaraş earthquakes within the scope of the Disaster Law (7269:1959).

Building resilience for future events

The seismic building code of Türkiye, which was established in 2018, is under review, and it will be revised considering the seismic deficiencies observed during these seismic events.

On the other hand, in a study focusing on Istanbul conducted in 2019, it was revealed that out of the 1.17 million buildings in the city, 84% were RC. Among these RC structures, approximately 65% (631,000) were built before the year 2000 [23]. The majority of these buildings do not comply with the recent seismic building codes nor with the building codes in place during their construction and show similar structural deficiencies as observed in the recent February 2023 earthquakes. This raises concerns about their ability to withstand earthquakes and the potential risks they pose to life and property. Identifying these vulnerable buildings and implementing measures to mitigate potential damage is crucial. However, the conventional approach of conducting performance analyses according to the seismic building code for such a large number of buildings is impractical due to the considerable time and cost involved. Moreover, the existing regulations in Türkiye categorize buildings as either risky or non-risky based on specific performance criteria. This leads to a situation where a substantial number of buildings in Istanbul would be classified as risky when assessed using these current regulations, creating an overwhelming scenario. To address this issue, a methodology which aims to provide a simplified, cost-effective, yet reliable and realistic seismic assessment of buildings to categorize their risk levels and prioritize them for risk mitigation interventions was developed and applied to over 22,000 RC residential buildings, specifically targeting those constructed before the year 2000. The

collected data from these buildings was evaluated, and the results indicated that approximately one in every four buildings falls into risk class E category, signifying a very high-risk level for these structures (Ilki et al. 2023; Aydogdu et al, 2023a, 2023b; Aydogdu and Ilki, 2024).

As declared by Official Gazette 23 Feb 2024, support will be provided for construction for urban transformation applications in Istanbul. The right holder can be supported up to:

- **700,000-TL** (approx. 22.000-USD) as a grant
- **700,000-TL** (approx. 22.000-USD) as a loan } **for a residence**
- **350,000-TL** (approx. 11.000-USD) as a grant
- **350,000-TL** (approx. 11.000-USD) as a loan } **for an office**
- **1,400,000-TL** (approx. 44.000-USD) as a loan **for each additional residence**
- **700,000-TL** (approx. 22.000-USD) as a loan **for each additional office**
- One-time, non-refundable evacuation support of **100,000-TL** (approx. 3200-USD) can be given to property owners, tenants.
- Loan repayments begin from the first month after the interest-free period, with the first 12 installments being interest-free, and are completed in a maximum of **120 months**.

3.2 Impact Chain (incl. improvement of previous IC)

The improved Impact Chain diagram for the 2023 Kahramanmaraş earthquakes based on the results of the Forensic Analysis is given in Figure 3.6. In the IC diagram presented, exposure is defined in five main categories with a delineation of vulnerabilities which led to adverse consequences in the 2023 Kahramanmaraş earthquakes. Even though exposures are labelled similarly in each case study, the pre-conditions enhancing the weaknesses may be different according to the political, institutional, cultural and economic conditions of the affected geography. Herein, vulnerabilities are considered as vulnerability to stress, which refers the background of the intense damage. From a broader perspective, vulnerability to losses needs to be mentioned in medium to long term aftermath of the peril which would be examined in the next couple of years. The Forensic Analysis of the 2023 Kahramanmaraş earthquakes has contributed to fulfil the Impact Chain diagram with some latent root causes associated with a couple of vulnerabilities at the same time.

Physical exposure covers vulnerabilities defined as aging of structures, illegal development, unauthorized structural intervention, wrong location choice and lack of maintenance. In many cases of structural failures, it is observed that more than one type of vulnerability coincided in the field. For instance, illegal development usually meets with wrong location choices. The exposure related to the population of the affected area is evaluated according to the population growth process and identification of the most fragile groups in the society, including foreign inhabitants and tourists. Accordingly, economic exposure and related



vulnerabilities are represented at both individual and community levels. Vulnerabilities related to environmental exposure cover sensitive ecosystems, natural assets and the carrying capacity of the environment, which could be associated with the optimum level of urban development. Institutional structure could be evaluated either as a system of exposure which represents vulnerabilities related to deficiencies in decision-making or as a tool for adaptation that varies according to the achievements accomplished. In the 2023 Kahramanmaraş earthquakes case, the institutional structure represented an important vulnerability to address, considering the structured deficiency of building codes.



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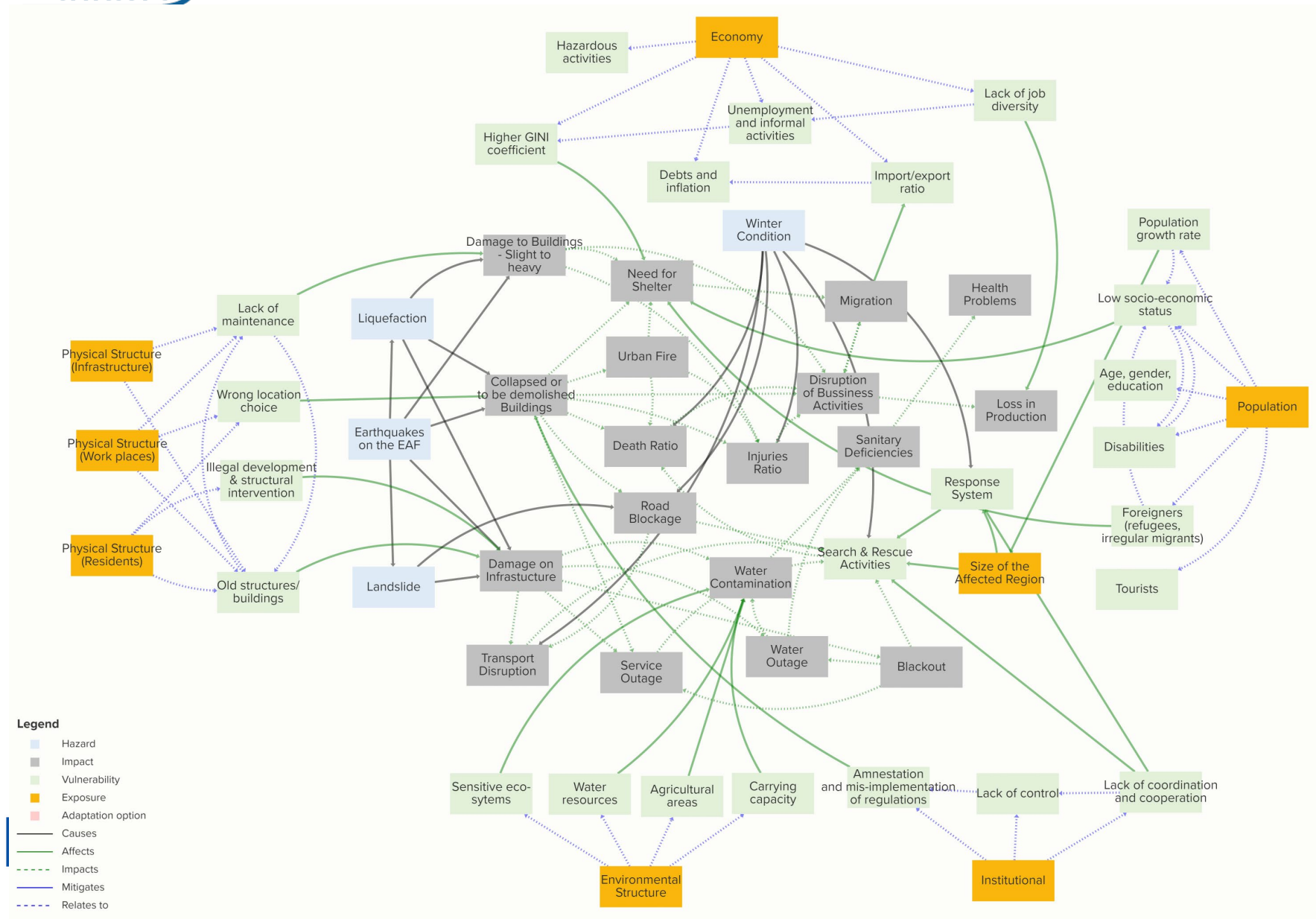


Figure 3.6 Improved Impact Chain for the 2023 Kahramanmaraş earthquakes.
The Impact Chain content can be explored interactively through the [Impact Chain Wiki](#).

4 St. Vincent and the Grenadines (SVG), 2021

4.1 Forensic Analysis

Hazard analysis

Saint Vincent is the main island of Saint Vincent and the Grenadines, an archipelagic state in the Eastern Caribbean (Figure 4.1). The northern part of the island is occupied by an active volcano, La Soufrière, making volcanic hazards one of the island's main hazards (Figure 4.2). Aside from that, according to EM-DAT (the Emergency Events Database), storms have been the most frequent hazard event in Saint Vincent.

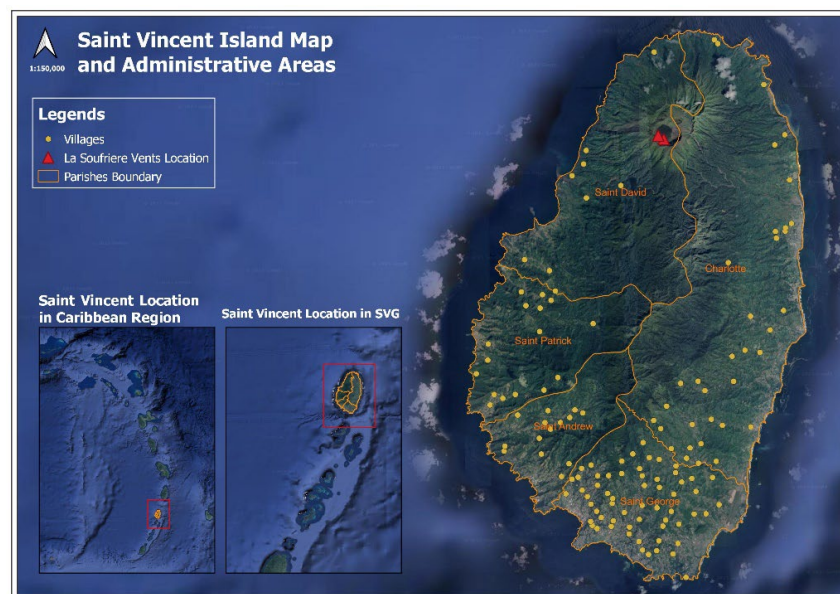


Figure 4.1 St. Vincent Island Map and Administrative Areas

Source based on own elaboration.

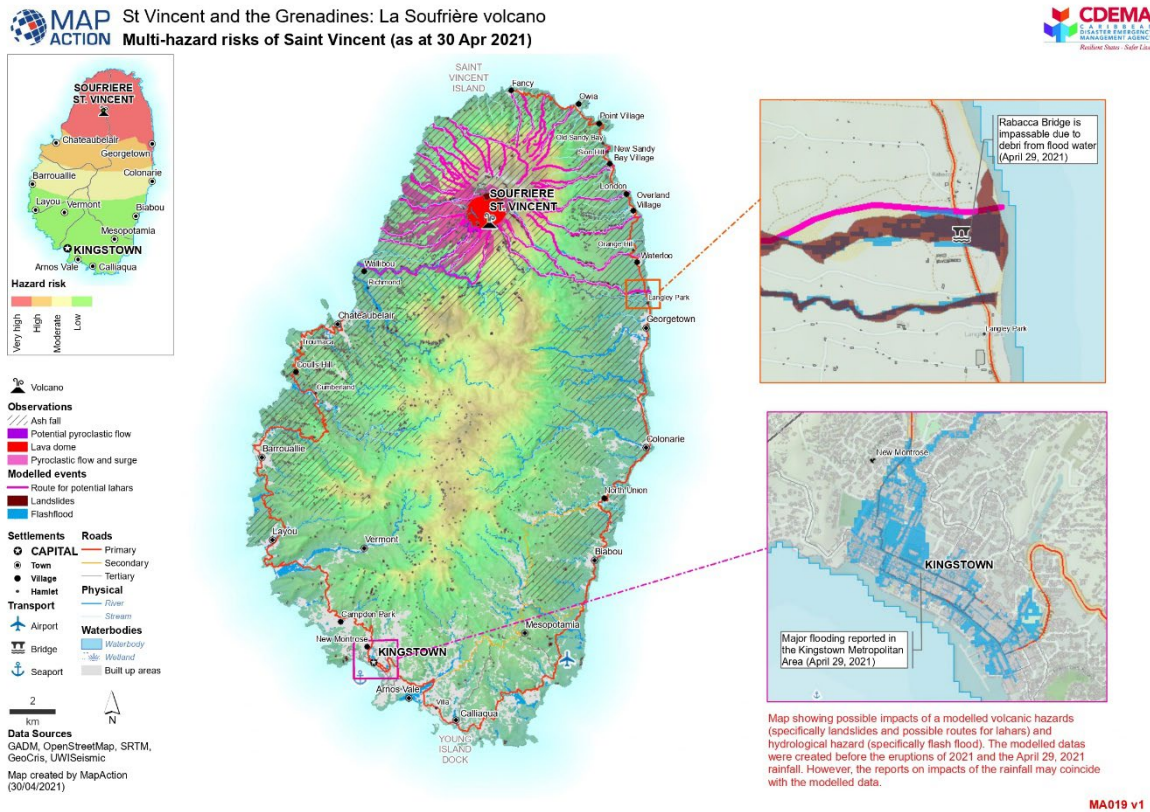


Figure 4.2_Source MapAction, 2021 showing multiple volcanic hazard risks in Saint Vincent, including other geological and hydrological hazards such as landslide and flash flood.

General Information of the Eruption

Saint Vincent faced a devastating event in 2021. La Soufrière volcano, which occupies 1/3 of the island, erupted for the first time in the 20th century, approximately forty years after the last eruption in 1979. A spike in seismicity was recorded in June and July 2019. However, the activity decreased significantly, and no cause was reported. The number of recorded events continued sporadically until it picked up in November 2020. In December, eruptive activity was noticed through visual observations of the crater with a new lava dome growing, increased seismicity, crater incandescence, and gas-and-steam emissions. Following these observations and satellite data showing a thermal hotspot in the crater, the Volcanic Alert Level (VAL) was raised to Orange (Global Volcanism Program, 2021).

After around four months of effusive activity, the activity started to increase (the eruption timeline is presented in Figure 4.3). Volcano-tectonic earthquakes, gas emissions, and rapid dome growth were recorded in early April 2021. These activities led to an explosive eruption with accompanying ash cloud on the morning of 9th April 2021. That evening, the VAL was raised to Red, the highest volcano alert level. The explosive eruption phase produced approximately 40 explosions with ash clouds, causing ashfall across the island. The explosions frequently continued throughout the month until the 22nd of April, ending on the 24th with steam plumes. During the ash venting events, some tremors also happened (Global Volcanism Program, 2021).

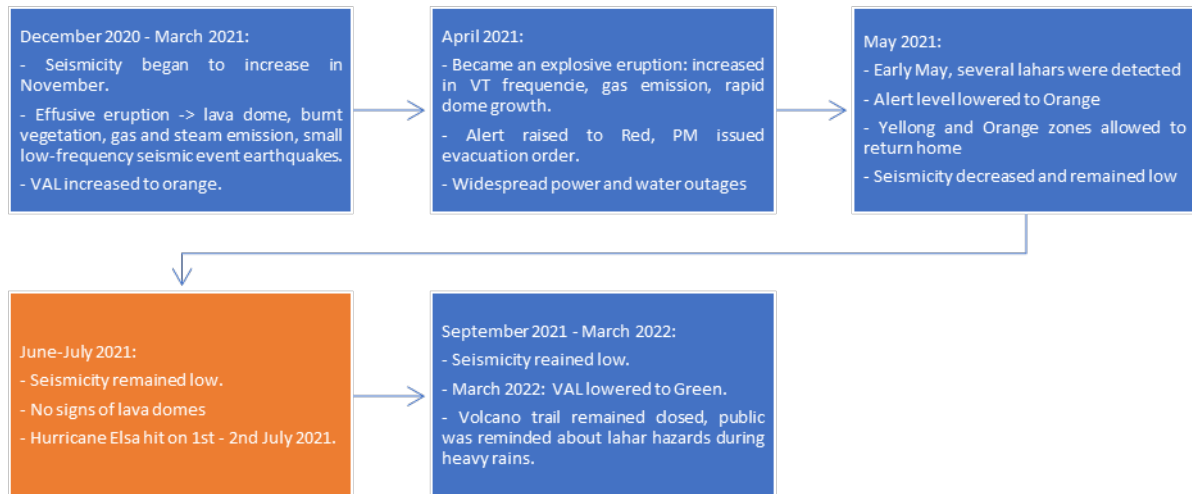


Figure 4.3 Adapted from: *Global Volcanism Program, 2021*

Explosive Eruption

PDCs: Several Pyroclastic Density Currents (PDCs) were recorded during the explosive period. The first PDCs were observed on 10th April by eyewitness accounts and later, in the following days, recorded by stratigraphic studies. The next PDCs were mainly recorded using visual observation, fieldwork, or satellite imagery. As mentioned in the literature, the PDCs occurred from 10th - 14th April 2021, with most routes going in south and west directions from the volcano. In some cases, the PDCs were emplaced in the east direction from the volcano. Most of these PDCs were noticed to be formed by column collapse. They have different footprints according to the material characteristics, such as dense PDCs reached the sea only in Larikai and Roseau valleys, whereas dilute PDCs were restricted within 2.5 km of the summit crater rim (Gueugneau et al., 2024).

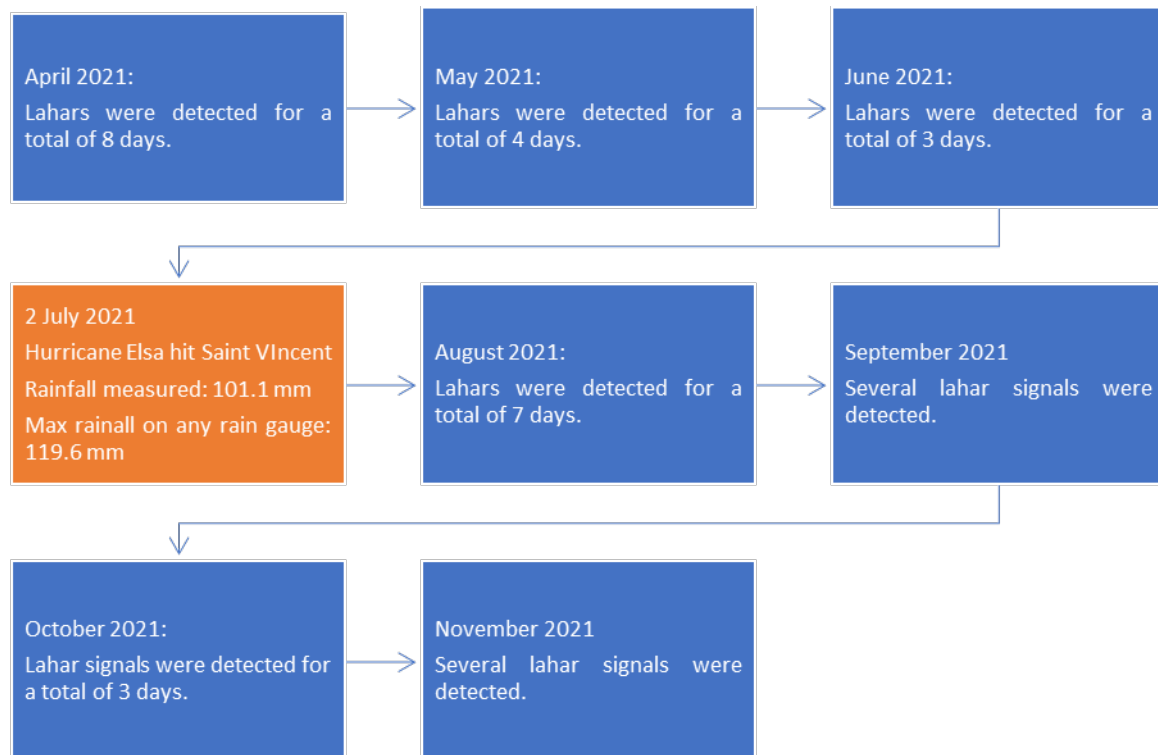


Figure 4.4 Adapted from (Phillips et al, 2024)

Lahars: Lahars were also recorded during the explosive phase of the eruption. Since lahars are energetic flows of loosely consolidated volcanic debris and water, their occurrence is usually frequent, especially after rainfall events. In Saint Vincent, for the 2021 event, lahars occurred frequently since the April 2021 explosive phase (Phillips et al., 2024). Around twenty-five lahars events were recorded in 2021. These lahars are not restricted to the explosive phase in April 2021 only, but continue up until November according to what was recorded in 2021. However, due to the dynamic processes of a lahar and the accumulative sediments that are still existing, lahar threat continues to pose especially during significant rainfall event. The summary of lahar events in 2021 and the associated rainfall event is presented in Figure 4.4. The rainy season in Saint Vincent and the Grenadines usually occurs from June to November; it is expected that during these months, the rainfall rate will be higher than the previous months (World Bank, 2022). Hence, the possibility of lahars to happen is also higher.

Compounding Hazards Event

Saint Vincent is highly susceptible to natural hazards due to its geomorphological characteristics as well as geographic settings. Exacerbated by climate change, the frequency and intensity of hazard occurrences are changing and tend to increase over time (National Emergency Management Organisation (NEMO), 2014). According to our interviews with several government entities in Saint Vincent and the Grenadines, compounding hazards often happen in this country as well. For instance, an extensive period of drought followed by heavy rain could result in landslides and flooding. The slow onset of sea level rise resulting in coastal erosion, potentially worsened by a storm is also a threat for Saint Vincent. The 2021 event is another

example of a compounding hazard that happened in Saint Vincent, regardless of its low probability of occurrence but high in impacts caused.

The 2021 event was devastating for Saint Vincent not only because of the complex and extensive volcanic eruptive activity. 2021 was also the year that Saint Vincent was hit by Hurricane Elsa, the 5th tropical cyclone in the 2021 Atlantic Hurricane Season. On 2nd July, Elsa passed through Saint Vincent and continued spreading throughout the Windward Islands. When passing through Saint Vincent, what was initially identified as Tropical Storm Elsa reached maximum sustained winds of 75 mph (120 km/h), giving it a hurricane 4 level status (CCRIF, 2021). Elsa also increased the rainfall intensity, creating a peak in the rainfall rate. A lahar was observed on 2nd July corresponding to the hurricane (see the orange box in Figure 4.4). Aside from that, Elsa came when the seismicity was low for La Soufrière (see the orange box in Figure 4.3&4.4), therefore only interacting with the volcanic material deposited.

Additionally, Saint Vincent was also faced with a dengue outbreak and COVID-19 during the crisis (Government of SVG, 2021). In March 2020, the first COVID-19 case in Saint Vincent and the Grenadines was confirmed (Search Light, 2020). During the eruption in January 2021, there were frequent reports of COVID-19 cases and deaths and it kept going until early 2022 (Johns Hopkins University of Medicine, 2023). This means that during the eruption, the COVID-19 cases were evident. It was also mentioned in the PDNA report that as of January 2021, there were 1,790 confirmed dengue cases with eight deaths, and it was increasing since October 2020 (Government of SVG, 2021). These outbreaks complicated evacuation efforts by the need to conduct testing and vaccination before entering neighbouring islands. Also more attention needed to be considered focused towards the hygiene and sanitation inside the shelters (Straker, 2021)

Short and long term impact analysis

Long- and short-term impacts of the compounded events (COVID-19 La Soufrière Eruption – Elsa Hurricane) have been extensively discussed in the deliverable 1.1. In order to not be redundant, we summarize here the most significant impacts as well as losses and damages. The contemporaneity of COVID-19 and La Soufrière eruption caused a major block in two main leading economic sectors, agriculture and tourism, causing a strong reduction of more than 30 % of the GDP (UNOCHA, 2022). Further than affecting the productive economic sector, COVID-19 had important impacts on the public expense, increasing the public debt up to 89 % of the GDP (IMF, 2022a).

The volcanic eruption had remarkable impacts in multiple sectors and disrupted the livelihood of the local population. The post-disaster needs assessment reports that more than 20.000 people were evacuated from their houses. The estimated economic impact amounts to more than 234 million of US \$ (Government of Saint Vincent and the Grenadines, 2021a), composed by approximately US\$ 150 million of direct damages equivalent to more than 20.5% of the overall GDP (IMF, 2021) and more than US\$64 million of losses (World Bank, 2021). Most affected sectors were housing and agricultural sectors that totalled respectively more than US\$97 million and US\$30 million of damages.

The overall economic situation presented is even more impressive if we consider that, according to the last poverty country assessment, the poverty headcount rate equalled 30% of the overall population (Ministry of Finance and Planning San Vincent and Grenadines, 2007).

Impacts on critical infrastructures and buildings

Among the critical infrastructures, roads and transportation networks have been those mostly affected. In particular, bridges and river crossing infrastructures totalled around US\$11 million in physical damages



caused by pyroclastic density flows and ash deposits (Government of Saint Vincent and the Grenadines & United Nations Development Programme, 2021). Ash accumulation proved to be the most relevant impact leading to road blockages and subsequent disruption of logistic and humanitarian actions. Despite the fact that ashfall was not the primary source of damage in the transportation infrastructure it caused several losses in the transportation sector as cleaning costs amounted to more than US\$5 millions. Ashfalls also affected WASH (Water, Sanitation and Hygiene) in particular for what concerns water supply as ash contaminated water sources and blocked sanitation filters. It was estimated that, in the red zone, inhabitants suffered from 91 to up to 150 days of water interruption (Government of Saint Vincent and the Grenadines & United Nations Development Programme, 2021). Furthermore, scarcity of water forcedly led to decrease in water use, including for personal hygiene, increasing the challenges to cope with the spreading of COVID-19.

Housing and building sectors were among the sectors mostly impacted. Damages to the housing sector amounted to more than 97 million of US\$. The majority of the house in the red and yellow zones were highly or moderately affected by ashfalls and ash accumulation leading to the displacement of 18% of the population.



Figure 4.5 Damages to houses due to ash load. Source: NewsAmericaNow

In certain cases, house damaging and subsequent population displacement led to the complete relocation of families. On the one hand, those families being relocated improved their housing conditions; on the other hand, they can lose their close social, supportive networks, such as family and community members. Thus, according to key informants' opinion, impacts on the housing sector have, in some cases, long-term impacts on social networks as well as on local communities' development.

Environment, agriculture and fisheries

The environment was deeply affected by the volcanic eruption. Both aquatic and terrestrial ecosystems were strongly damaged. More than 23.000 hectares of forest were destroyed (WWF, 2021). As well, marine and riverine ecosystems were contaminated by ashfall. Despite no exact estimates on impacts on biodiversity have been found, the contamination of water ecosystems by ash strongly affected the fisheries reducing fish export and directly affecting the livelihood of rural communities which have fishing as their main economic resource (Government of Saint Vincent and the Grenadines & United Nations Development Programme,

2021). A relevant secondary impact connected to contamination of water source has been the reduction in provision of fresh water. The island mainly relies on surface water and during the eruption there was a reduction of 80% of drinking water due to ash presence in water reservoirs (Government of Saint Vincent and the Grenadines, 2021).

The agricultural sector suffered the highest level of damages as the red and orange zones provide 40% of the countries' agricultural production. The eruption damaged the totality of the production in the red and orange zones producing a loss of almost 4 million of US\$.

The loss caused by the volcanic eruption was predated by a strong contraction of agricultural exports due to the COVID-19 Pandemic. These two compounded events strongly shrank the revenue coming from the agricultural sector directly affecting the overall country GDP and also the livelihood of farmers in rural areas (IMF, 2022b). Disruption in the agricultural production together with the difficulties in importing goods due to pandemic restrictions resulted in food shortages and an increase in commodity prices, strongly affecting the food security in the island (UNOCHA, 2022)

Health sector

COVID- 19 posed strong pressure on the health sector already under pressure due to a dengue outbreak that hit the country in 2020. The sanitary emergency characterizing the island posed strong pressure on the human and financial resources of the health sector. The subsequent volcanic eruption and the health and safety measures implemented strongly overwhelmed the capacity of the health sector to provide basic health services, causing delays in medical consultation and a shortage of medical supplies (PAHO, 2021a).

Population health and livelihood

Promptness of governmental institutions lead to a satisfactory management of COVID-19 pandemic as well as of a prompt emergency response soon after the volcanic eruption. Thanks to that, the COVID-19 fatality rate was equal to 0,57% and thanks to a good alert and evacuation plan there were no casualties due to the eruption.

Nonetheless population health and livelihoods were strongly affected. The health risk was extremely high for respiratory and irritation problems connected to ashfalls and on due to high infection risk due to shelter living conditions. More than 20.000 people have been evacuated in shelters that proved not being able to ensure the adequate sanitary conditions in terms of personal hygiene, supply of sanitary kits, food disposal and general living conditions (PAHO, 2021b). Livelihoods, especially of the people living in the red and orange areas, have been strongly disrupted. People in the high-risk area were dislocated in shelters from four up to six months. Displacement led to increase in unemployment rate and lack of financial resources to recover once back home. To this respect, the area evacuated also corresponds to the areas with higher poverty rates, characterized by economy based on agricultural and fishing sectors (Government of Saint Vincent and the Grenadines & United Nations Development Programme, 2021). Thus, loss of income and worsening of livelihood conditions in some cases corresponded to tilting of vulnerable households and individuals from being just above the poverty line to falling below the line, and those who were surviving in poverty to falling into indigence, with significant consequences for wellbeing.

First response

Responding to the effusive activity, on 29th December 2020, the Volcano Ready Communities Project (a collaboration between NEMO and UWI-Seismic Research Center) distributed their volcano hazard map in preparation for a potential evacuation. Approximately nine new seismic stations were installed around the



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crater in January 2021. The effusive phase of the eruption alerted all entities in Saint Vincent, as well as the Caribbean. Massive monitoring was done during the effusive eruption period from January to March 2021. Those monitoring works include field observations through drone video, helicopter flight, measurements on lava extrusion rate, dome growth rate, SO₂ flux and emissions, and the speed of pyroclastic flows. Rock samples were also collected to analyse and compare the composition with earlier eruption composition. In addition, remote monitoring was also done using webcam images, satellite imagery, and seismic stations (Global Volcanism Program, 2021).

After the VAL was raised to Red, the Prime Minister of Saint Vincent and the Grenadines issued evacuation orders for communities in Red and Orange Zones (Global Volcanism Program, 2021). The evacuation went fast, and later that day, most of the residents were evacuated.

Vulnerability analysis

Vulnerability is crucial to understanding, assessing, and reducing risk. Due to its complexity, vulnerability is addressed in this Forensic Analysis of Saint Vincent in five dimensions: physical, environmental, social, economic, and institutional. In the case of the volcanic eruption of Saint Vincent, these dimensions were identified through a combination of Impact Chains and a Forensic Analysis approach. Each element of vulnerability is intricately linked to specific impacts and underlying risk drivers, which we will explore further in this document.

Physical dimension

The vulnerability element identified in the physical dimension is the **“poor quality of construction materials,”** which is directly linked to structural damage to buildings. The quality of these materials plays a crucial role in mitigating the impact of natural hazards like landslides and ashfalls. During the La Soufrière volcanic eruption in 2021, the material of the roofs was a critical factor in the damage to the houses during the ashfall. Metal-sheet roofs, the most common type on the island, are highly vulnerable to significant impacts from volcanic ashfall due to the additional loads they must bear (Government of Saint Vincent and the Grenadines & United Nations Development Programme, 2021). Census data from the Post Disaster Risk Assessment (PDNA) reveals that 90.8% of the houses on the island have metal-sheet roofs, 7.3% are built with concrete, and only 1.8% are constructed with other materials (Government of Saint Vincent and the Grenadines & United Nations Development Programme, 2021).

Environmental dimension

In this dimension, three elements were identified. The first is **“Steep slope prone to shallow movement”**, a susceptibility element linked to landslides and debris flows. Due to its mountainous morphology and volcanic origin, the island is highly susceptible to landslides, mainly in the north-central portion near the La Soufrière volcano (National Emergency Management Organisation (NEMO), 2014). Additionally, the west central coast of Saint Vincent is highly susceptible to landslides.

The second element identified is **“Limited land availability and pressure for agricultural land”**, linked to reduced agricultural production. This element is associated with the small size of the island, which leads to the competition for available land for different uses. According to the National Adaptation Plan, stakeholders are concerned that converting agricultural lands into residential construction may lead to land degradation in agriculture (Government of Saint Vincent and the Grenadines (a), 2019).

The third element is **“Endangered ecosystems”**, which exacerbate the damage to aquatic and terrestrial ecosystems. Degradation of coastal ecosystems like dunes, mangroves, and reefs, which, in the presence of a natural hazard, makes them more vulnerable to the coastal infrastructure (Government of Saint Vincent and the Grenadines (a), 2019). Additionally, according to the Revised National Biodiversity Strategy and Action Plan 2015 – 2020 (Ministry of Finance, Economic Planning, Sustainable Development, and Information Technology, 2017), some of the main anthropogenic threats to biodiversity consist of **unsustainable practices** that affect the ecosystem health, such as:

- Habitat destruction and modification due to inappropriate land clearance for agriculture, fuelwood, illegal cultivation and settlement, and development in coastal areas
- Agricultural practices such as shifting cultivation and inappropriate use of agricultural chemicals.

Institutional dimension

Six elements have been identified within this dimension. The first element refers to the **ineffective implementation of disaster risk reduction in urban and land planning**. This, in turn, increases the impact of buildings and critical infrastructure as the lack of control over their location makes them more susceptible to specific hazards. Saint Vincent and the Grenadines' physical planning is regulated by the Town and Country Planning Act of 1992. This official document argues that the Physical Planning Unit (PPU) uses landslide susceptibility maps for subdivision decisions; however, due to the scale differences, the maps can only provide a broad overview of the situation, thus limiting their effectiveness (Charisse Griffith-Charles & Mujeeb Alam, 2015). However, this act does not include specific provisions for incorporating hazard and risk information into development planning.

The lack of planning often leads to **settlements being established in areas that are classified as high-risk or highly exposed to hazards**. For instance, in 2014, the National Emergency Management Organisation (NEMO) identified certain regions along the western coast of St. Vincent as hotspots for coastal erosion (National Emergency Management Organisation (NEMO), 2014). Some houses in these regions have already been relocated to reduce the risk of damage, while many more still need to be moved. Furthermore, significant disparities remain in developing the rural, northern census divisions of St. Vincent, particularly in the northernmost division, where most indigenous Caribs reside. This division has high unemployment rates, low school attendance, and lower housing standards (Lowe, 2010). It has been observed that inadequate disaster risk reduction in urban planning is associated with poorly designed and constructed buildings. Moreover, the National Adaptation Plan (NAP) emphasises **the need to enforce resilient building codes** as well as monitor their implementation (Government of Saint Vincent and the Grenadines (a), 2019).

During the development of the Impact Chain and review of documentation of the volcanic event, it became evident that the volcanic eruption posed significant **challenges in waste management and monitoring and controlling water and air quality**. Despite the existence of the Waste Management Act No. 31 of 2000 by the Government, the magnitude of the event resulted in complications during the emergency response, highlighting the need for a dedicated plan to address such crises (Government of Saint Vincent and the Grenadines & United Nations Development Programme, 2021). Additionally, OCHA reported in 2021 that the absence of an air monitoring station exacerbated difficulties in managing the emergency effectively (UNOCHA, 2021). Although the Disaster Management Plan of Saint Vincent and the Grenadines addresses volcanic risk and its management, it does not provide clear and specific guidelines on managing water and air quality post-eruption, especially concerning ashfall. This omission represents a significant vulnerability, given the adverse health effects of volcanic ash inhalation and its impact on surface water quality.

Additionally, this study's interviews stressed **the need to improve infrastructure and data for forecasting natural hazards**, i.e., in the early warning systems in a multi-hazard context. For instance, the absence of monitoring stations in certain areas makes it difficult to accurately track rainfall and its consequences, such as debris flow and lahars. A comprehensive digital transformation is necessary to address these deficiencies and facilitate better data sharing and coordination among relevant government and non-government institutions. Strategic investments in digital infrastructure and expertise are critical to enhance disaster response.

Finally, the most significant institutional vulnerability is the **limited availability of human and financial resources for disaster risk management**, which can lead to various impacts. While efforts are being made to address these challenges, progress needs to be accelerated to be more effective, according to the Disaster Risk Reduction Country Document (National Emergency Management Organisation (NEMO), 2014). In interviews with stakeholders from the government and NGOs on the island, it was mentioned that there is a severe lack of resources, including human expertise, equipment, and training.

Economy dimension

The economic vulnerability of Saint Vincent and the Grenadines (SVG) is underscored by **its heavy reliance on subsistence agricultural and livestock activities**, which form the backbone of livelihoods on the island (National Emergency Management Organization (NEMO), 2014). According to the Disaster Risk Reduction document of the Island, agriculture, fisheries, tourism, and small-scale artisanal endeavors are the primary economic drivers, providing employment opportunities and contributing to rural livelihoods. However, the economy's dependence on subsistence agriculture, particularly banana production, exposes it to various challenges, including international competition and natural hazards such as droughts and floods. The emergence of tourism as a growing economic sector offers promise, but it is also vulnerable to natural hazards.

This dimension also **addresses the need for better Disaster Risk Finance mechanisms and access to insurance**. According to a report by Advancing in Disaster Risk Finance, Saint Vincent and the Grenadines (SVG) has made significant progress in managing disaster risk financing. However, there is still room for improvement in ensuring that financing is timely, flexible, equitable, and cost-effective (World Bank, 2023). The report emphasizes the need for more robust social protection systems to support vulnerable populations affected by disasters. While the government does provide some support through traditional social protection mechanisms, these often fall short of addressing the extensive economic and social costs caused by disasters. The report recommends integrating inclusive insurance schemes tailored to the needs of marginalized population segments, such as those with low incomes or living in hazard-prone areas.

Social dimension

This study documented four elements of vulnerability in this dimension. The first one is related to **high poverty levels and dependence on poor relief** (Lowe, 2010). As reported in interviews, a significant part of the population relies on government subsidies to meet their basic needs during disasters. The situation is worsened by inadequate support for elderly care despite some new caregivers emerging. Mental health problems are also increasing during these challenges, underscoring the need for comprehensive support systems to address the multifaceted vulnerabilities faced by the population of SVG.

Based on the interviews, it was found that in SVG, the **population's lack of awareness of disaster risk** represents an issue. To overcome this second element of vulnerability, the interviewers claim capacity-building initiatives to empower communities with knowledge about preventing damage and losses due to

various hazards. Educating residents on the actions they can take to mitigate risks and protect their livelihoods can help communities better prepare for and respond to volcanic hazards.

The third element identified as contributing to social vulnerability in SVG is the **high population density** in areas such as Kingstown and coastal villages (National Emergency Management Organisation (NEMO), 2014). These regions are prone to natural hazards such as storm surges and are also exposed to increased risk due to their high concentration of residents.

Finally, the fourth element mentioned during the interviews and identified by Lowe's thesis (2010) is **the lack of a skilled workforce**. This shortage directly affects the availability of expertise, equipment, and training for institutions. Lowe (2010) states that many citizens leave the island because they cannot find education and employment opportunities. This factor is related to the age-dependent ratio (47), as it removes the educated and skilled population, leaving behind women, children and a highly dependent population that relies on remittances from abroad (Lowe, 2010; UNDP et al., 2020).

Analysis of underlying risk drivers

The underlying risk drivers (URD) concerning St. Vincent and the Grenadines (SVG) are described below.

Demographic Patterns

Demographic patterns in SVG exhibit a notable population decline over recent decades (World Bank (b), n.d.). According to the World Bank's digital population platform, the island's population peaked at 114,290 in 1996 but has since steadily decreased. By 2022, it had dropped to 103,948.

Migration emerges as a significant factor driving this trend, as highlighted by research conducted by Lowe in 2010. The departure of young people seeking better opportunities elsewhere poses a challenge, contributing to the reduced youth population. The St. Vincent and the Grenadines Migration, Environment, Disasters, and Climate report underscores the importance of enhancing migration-related data collection and establishing robust databases (International Organization for Migration (IOM), 2021). Such efforts are crucial for informing evidence-based policy, development planning, climate change adaptation, and effective disaster preparedness and response. Moreover, according to the International Organization for Migration, data from the Internal Displacement Monitoring Centre suggests that approximately 1000 individuals face the risk of displacement annually due to sudden-onset hazards in Saint Vincent and the Grenadines.

Population and Social Organizations: Inequalities & Resource Distribution

Living conditions

SVG is a middle-income country in terms of gross domestic product per capita, and its poverty rate is 30.2% (UNDP, UNICEF, UN Women Eastern Caribbean, 2020). According to the Country Poverty Assessment, the physical living conditions in St. Vincent and the Grenadines vary in infrastructure and access. While almost 70% of households have a consistent water supply throughout the week, this number drops significantly to 36% in the Grenadines (Ministry of Finance and Planning San Vincent and Grenadines, 2007). Access to electricity is higher, with approximately 85% of the population connected to public sources, but there are still disparities, especially in the lowest income quintile. Cooking fuel is primarily gas/LPG, particularly prevalent among the lowest-income households. Despite significant improvements to the road network, some areas lack basic facilities like streetlights, and high utility costs limit access to public services (Ministry of Finance and Planning San Vincent and Grenadines, 2007).

Labor Market



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In St. Vincent, the labor market is primarily composed of three sectors: tourism, offshore financial services, and manufacturing (to a lesser extent) (Ministry of Finance and Planning San Vincent and Grenadines, 2007). While formal jobs are available, the number of informal jobs is increasing. Households rely on various sources of income, including formal employment, informal sector activities, and migration. Due to the decline of traditional industries such as banana farming, there have been changes in the labour market dynamics, especially among young men. Gender segregation is still prevalent, with women having fewer opportunities and receiving lower rewards (Ministry of Finance and Planning San Vincent and Grenadines, 2007).

Land Tenure

The history of colonialism and slavery on the island has resulted in limited access to land for certain social groups (Lowe, 2010). St. Vincent and the Grenadines' current land tenure arrangement does not adequately support comprehensive disaster management due to national spatial data infrastructure gaps (Browne, 2013). The deeds registration system is also unresponsive to society's current socioeconomic demands, indicating that households with deeds rely less on government assistance for disaster recovery and mitigation and instead use personal funds (Browne, 2013). Therefore, documented and respected land tenure systems increase investment in mitigation, recovery, and reconstruction, ultimately reducing vulnerability to natural hazards.

Resource distribution

The legacy of colonialism has resulted in an uneven distribution of resources and development between the north and south islands of the region (Lowe, 2010). Moreover, Smith & Rhiney (2016) contend that the indigenous Caribs in northeastern St. Vincent are vulnerable due to economic neglect and political marginalization that has persisted for centuries. This factor is compounded by the lower socioeconomic status of the communities, their geographic location, and heavy reliance on land-based resources that affect their ability to adapt to a changing and variable climate. Additionally, migration has created barriers to human capital development, where some 84.5% of the tertiary educated population lives abroad, and remittances represent a stable source of foreign exchange earnings and support domestic consumption, contributing almost 25% of GDP (UNOCHA, 2021).

Unemployment

The unemployment rate in the country is at a high of 23% (UNDP, UNICEF, UN Women Eastern Caribbean, 2020). The data shows that women and young people, mainly those aged 15-29, are the most affected, with joblessness rates at 30.1% and twice the national average, respectively. Due to the difficulty of finding formal employment, many individuals in the country are forced to work in the informal sector. However, these jobs are often unstable and do not provide adequate social security coverage, leaving workers vulnerable. It is worth noting that the informal sector makes up around 38.1% of the entire economy, including family businesses and self-employed individuals. In addition, approximately 18% of women in Saint Vincent and the Grenadines work part-time (UNDP, UNICEF, UN Women Eastern Caribbean, 2020).

Urban-Rural land use patterns and process

Urban and rural land uses are mainly influenced by the limited availability of land, given the island's small size and mountainous morphology. This has led to a housing deficit and land use disputes in coastal areas for agricultural, residential, or tourism use.

In addition to limited suitable land for development, several interconnected factors influence the housing deficit on the Island. These include soaring land prices, a significant low-income population, high construction costs, insecure land tenure, and difficulties accessing finance. The proliferation of informal settlements



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exacerbates these challenges, impeding access to credit and financing for property improvement and leading to numerous abandoned properties in rural communities (Government of Saint Vincent and the Grenadines (b), 2021).

On St. Vincent, flat, fertile cropland availability is limited, primarily concentrated in coastal regions (Government of Saint Vincent and the Grenadines (b), 2021). Likewise, settlements are typically found within 1km of the shoreline. This land scarcity triggers intense competition fueled by demands from tourism and residential sectors, particularly around Kingstown and the southern coast. The Grenadine Islands face similar constraints, with agricultural activities contending with tourism-related uses, resulting in notable land use shifts in recent decades (Government of Saint Vincent and the Grenadines (b), 2021).

The high concentration of activities in coastal areas puts pressure on coastal and marine ecosystems through developmental activities, sand mining, waste disposal, and pollution. Tourism is a critical part of the economy, particularly in the Grenadines and Tobago Cays, which makes it even more important to have sustainable land use policies that protect coastal resources and livelihoods (Government of Saint Vincent and the Grenadines (b), 2021).

Failures in Governance

Failures in governance in the context of disaster risk management have been driven by the political and historical emphasis on reactive measures rather than proactive preparedness (Lowe, 2010). According to interviews conducted in this study, relevant stakeholders have pointed out the lack of adequate human and financial resources, further aggravating the problem. Additionally, there is a significant brain drain due to the island's lack of work and study opportunities, which has worsened the scarcity of expertise, equipment, and training.

The interviews have revealed that despite wanting to move from a reactive to a prepared state, insufficient funding and expertise pose significant challenges. SVG relies heavily on external aid, consultations, and projects, operating within silos where ministries often duplicate efforts without coordination. Additionally, a culture of dependency on government assistance among vulnerable groups such as farmers and fishermen perpetuate financial unpreparedness and undermines resilience. A concerted effort is required to foster collaboration, allocate resources effectively, and promote self-sufficiency among the population through enhanced financial literacy and preparedness initiatives.

Financial and Economical Process

Saint Vincent and the Grenadines has faced challenges affecting its financial and economic stability, including the COVID-19 pandemic, the volcanic eruption, and fluctuations in agricultural products. Moreover, the small size of the island leads to experiences of disadvantages such as limited job opportunities and a narrow economic base (Government of Saint Vincent and the Grenadines & United Nations Development Programme, 2021; Lowe, 2010). The COVID-19 pandemic has made things worse, causing a financial crisis that has affected different sectors (UNDP, UNICEF, UN Women Eastern Caribbean, 2020). The global economic landscape's fluctuations have also led to lower prices for agricultural products, which has significantly impacted the island's agrarian economy. Furthermore, because the soil near volcanoes is fertile, people have been tempted to occupy these areas despite the inherent dangers (Lowe, 2010). These factors indicate the urgent need to develop diversified economic strategies and resilience-building measures to secure Saint Vincent's future prosperity.

The annual fiscal costs of disasters are expected to be 1.4 per cent of GDP, featuring the need for improved financing mechanisms, transparent budgetary operations, and strategic planning to effectively support long-term recovery and reconstruction efforts in the face of future hazards ((World Bank, 2023).

Environmental Degradation and Ecosystem depletion

This risk driver is directly linked to the environmental dimension of vulnerability, associating with components related to both natural and anthropogenic dynamics of environmental processes. The anthropogenic that contribute to the environmental degradation in Saint Vincent encompass a range of issues, including global climate change, habitat destruction, the spread of invasive alien species, unsustainable agricultural practices, unregulated land use, poaching, inadequate enforcement of environmental policies, the development of tourism, intensive grazing, illegal harvesting, forest fires, pollution, poverty, limited environmental awareness, and constrained biodiversity research (Ministry of Finance, Economic Planning, Sustainable Development, and Information Technology, 2017).

Analysis of root causes

The abovementioned risk drivers are rooted in historical processes that have shaped SVG's vulnerability. Lowe's (2010) doctoral thesis, applying the Pressure and Release framework, identified the root causes described below.

Colonialism heritage

The division of St. Vincent into its northern and southern regions has its roots in the country's colonial history and land ownership. In earlier times, most of the cultivable land was controlled by plantation owners, while the indigenous Caribs were confined to the productive areas on the windward coast. The Caribs were expelled from St. Vincent in the late 18th century, and the north became a region of large plantations operated by wealthy colonials. The few remaining Caribs were restricted to reserves in the north. Over time, the north-south divide has slowly decreased, with improvements in infrastructure and access to resources in the rural north. However, in the event of volcanic eruptions, the people in the poorer, rural north will likely be the most affected and forced to evacuate (Lowe, 2010).

Out-migration patterns

The history of colonization in St. Vincent has resulted in an emigration trend where skilled workers have had to move to other Caribbean islands to find work. Due to its small size and lack of opportunities for large industries, the current workforce is compelled to seek job prospects beyond the country's borders. As a result, the remaining population may require additional support and resources. Furthermore, people move abroad for education as St. Vincent does not have a university. This phenomenon has existed in the population for centuries (Lowe, 2010).

Progression of Vulnerability in Saint Vincent: from root causes to vulnerability

The synthesized vulnerability progression depicted in Figure 4.6, derived from both forensic and Impact Chain analysis methodologies, illustrates the intricate nature of vulnerability dynamics within the context of disaster risk. The 'Underlying Risk Drivers' influence vulnerability across their various dimensions, illuminating the multifaceted interplay of socioeconomic processes over time. Within the scope of this study, 'Failures in Governance' and 'Population and Social Organization' emerge as the primary influencing drivers



with extensive linkages to vulnerability elements. At the same time, limited human and financial resources stand out as the vulnerability element with the most associated underlying risk drivers.

One of the key insights from the examination of Governance Failures is the urgent need for a paradigm shift in disaster response strategies. The shift should move from reactive approaches to proactive preparedness and risk reduction measures. This calls for a realignment of policies towards building robust operational frameworks alongside sustained efforts in continuity, long-term planning, and rigorous monitoring and evaluation. Given SVG's historical context and present realities, the effective implementation of development, risk reduction, and adaptation initiatives must prioritize inclusion, equity, and diversity principles.

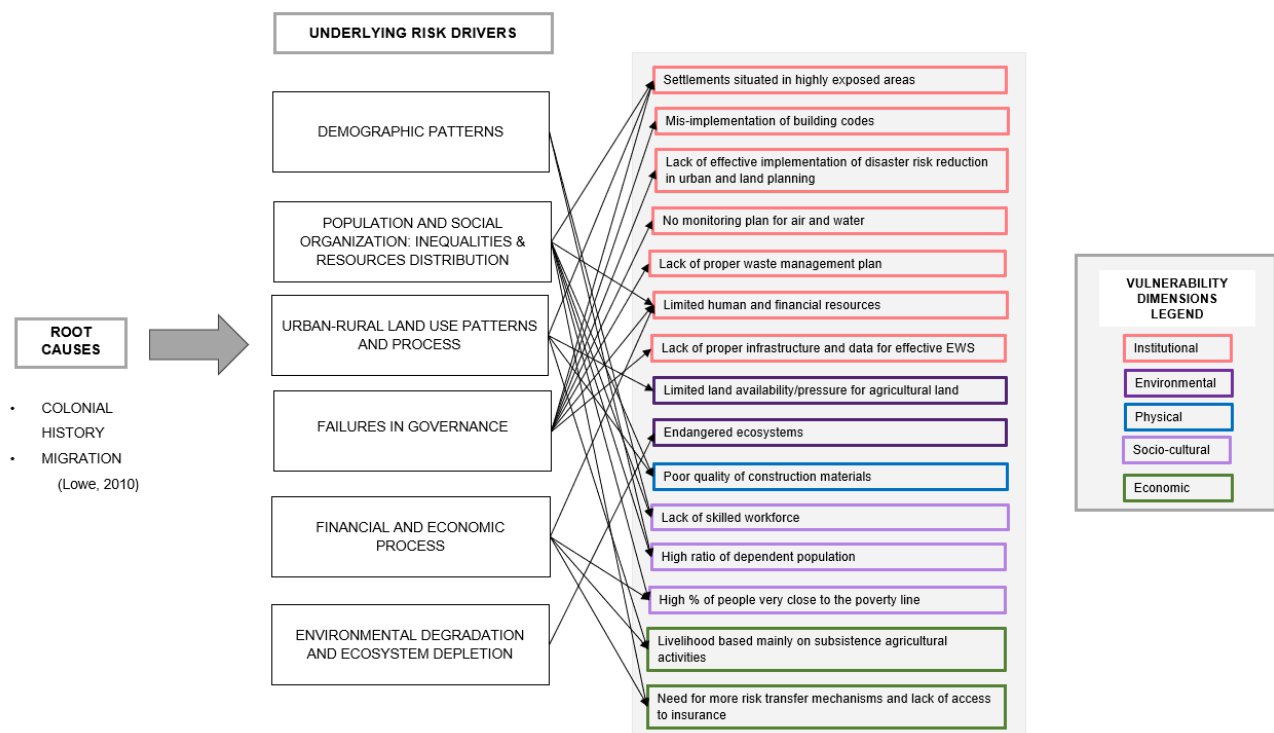


Figure 4.6 Progression of Vulnerability identified through Forensic Analysis in the St. Vincent and the Grenadines case study. This figure is adapted from the 2012 Disaster Root Cause Analysis Framework for the German Committee for Disaster Reduction (DKKV).

Recovery analysis

Recovery needs

Based on the post-disaster needs assessment for the Volcanic eruption on the Island (Government of Saint Vincent and the Grenadines & United Nations Development Programme, 2021), recovery needs have been identified and categorized into three primary sectors: social, infrastructure, and productive. The largest area of concern is the social sector, which accounts for 52% of the total recovery needs. Housing is the main issue within the social sector and requires the highest allocation of resources. The infrastructure sector accounts

for 13% of the identified needs, with transportation being the most significant priority within this domain. Agriculture is the principal demand driver in the productive sector, encompassing 35% of the recovery needs.

Table 4.1 Table 1. Summary of recovery needs reported in the PDNA (Government of Saint Vincent and the Grenadines & United Nations Development Programme, 2021).

SECTOR	Recovery needs (XCD'000')
Social	384,565.07
• Housing	355,994.87
• Health	10,329.10
• Education	18,241.10
Infrastructure	92,434.21
• Wash	1,890.43
• Transport	89,327.03
• Electricity	1,216.75
Productive	260,353.54
• Agriculture, Forestry, Fisheries	258,855.29
• Tourism - Accommodation	-
• Tourism - Parks	1,498.25
Cross-Cutting	2,375.27
Total	739,728.09

Source: PDNA Assessment Team

Recovery needs by sector

This section is based on the Report of the Post Disaster Needs Assessment by sector (Government of Saint Vincent and the Grenadines (c), 2021).

- **Education:** Total recovery needs amounted to XCD 18.2 million, with XCD 17.5 million allocated for educational facilities improvement and XCD 0.7 million for additional expenses. Priority for intervention was determined by referencing the volcanic hazard map, with divisions marked within the red and orange zones receiving the highest priority.
- **Health:** The recovery needs assessment involves estimating the costs of facility damage and implementing improvements to mitigate risks from future eruptions, including retrofitting and upgrading infrastructure. Costs for upgrading technology, improving data management, and conducting information campaigns are also factored in. Immediate priorities include restoring healthcare services and reducing vulnerabilities. This includes emotional support, safe water, air monitoring, and measures to minimize Dengue outbreaks. Strengthening the Health Sector's capacity to prepare for future emergencies is highlighted for the first two years (2021-2023) with short-term funding needs of XCD 7,235,065.37.
- **Housing:** The assessment for housing recovery is based on registered damages and losses. An additional 20% of funds are allocated to replacement values. The total needs amount to XCD 355.9 million, which includes home improvement (XCD 296.4 million), expenses incurred (XCD 30.4 million), and house relocation (XCD 29.1 million for 375 homes). The expenses for debris removal and shelter operation are included. However, damages to household goods and private losses from rental housing are not considered due to the lack of government programs.



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- Agriculture: The agricultural sector's recovery needs to focus on restoring service delivery and production capacity and strengthening governance, including Disaster Risk Management. Total recovery needs amount to XCD 258.85 million, with 40.1% allocated for damage, 48.8% for loss, and 11.1% for Building Back Better efforts.
- Infrastructure: The total cost of the recovery efforts amounts to XCD 89.327 million. Of this, XCD 36 million is needed to repair the physical infrastructure damage and XCD 53.3 million is required to cover the losses due to cleaning and ash removal needs caused by the disaster. It is important to note that around XCD 79.6 million of the recovery costs relate to the needs of the hazard red zone specifically.
- Wash-Sector: Recovery needs totalling XCD 1,890,426 are identified, with XCD 365,436 allocated for physical infrastructure damage and XCD 434,990 for ongoing cleaning and water testing. An additional XCD 1,090,000 is required to enhance the sector's resilience to future disasters. The prioritization matrix outlines short-, medium-, and long-term interventions focusing on restoring water systems, maintaining water quality, conducting public education campaigns, and improving data management for water resources. Additionally, discussions are ongoing to secure XCD 5,500,000 for alternative water sources, which are not included in the current plan.
- Electricity sector: The recovery cost is XCD 1.216 million, with XCD 0.130 million for repair/reconstruction and XCD 1.086 million for losses. A 20% increase will cover modernizations, including electrifying new developments, which accounts for over 40% of the total cost.
- Environment sector: The recovery needs in forestry, including monitoring and reforestation efforts, are crucial for controlling invasives and investing in economic plantation forests. Additionally, strategies for areas in the red zone of the volcano may involve converting farmed areas into conservation areas, necessitating new governance structures and financial support for affected individuals. Furthermore, soil conservation measures and ash retention strategies must address the potential impacts of increased soil erosion and decreased water retention in agricultural land.

PDNA Recovery Strategy

The Post-Disaster Needs Assessment (PDNA) in St. Vincent and the Grenadines (SVG) has developed a recovery strategy focusing on good governance principles and addressing poverty alleviation and environmental protection. The strategy seeks to establish resilient-building policies and coordination mechanisms by allocating funds for Disaster Risk Management (DRM) and Climate Change Adaptation (CCA) at national and local levels. The primary objective of this strategy is to integrate DRM and CCA measures into various development processes, including policy formulation, socio-economic planning, and budgeting, with a special emphasis on critical sectors such as agriculture, water, energy, health, and infrastructure.

The recovery strategy is guided by three-line actions: reducing risks and building resilience, promoting accessibility and equity, and rebuilding people's livelihoods. To achieve these goals, specific strategic lines of action have been outlined. These include re-engineering economic growth to ensure sustainability and inclusivity, enhancing human and social development to improve the quality of life for all citizens, and improving physical infrastructure while preserving the environment to mitigate climate-related risks.

The recovery strategy aims to streamline the recovery process by outlining five key steps. These steps include developing an actionable recovery plan that takes into account the impacts of both the COVID-19 pandemic and the hurricane season, identifying resource gaps for funding, harmonizing assessment processes



throughout the humanitarian response and recovery phases, improving data collection and management systems, and strengthening capacities for recovery efforts.

Recovery Implementation

Information regarding the implementation of recovery efforts is challenging to obtain, likely due to the involvement of multiple organizations without centralized coordination or possibly because of limited accessibility to data. We found some progress regarding the recovery based on a review of official documents, interviews, and press releases. It is important to acknowledge that, given the recent occurrence of the event, the recovery phase remains ongoing, with various initiatives still in motion.

According to an article on the United Nations' Sustainable Development Goals, the UN organizations, along with their government and regional partners, have taken swift action to provide both immediate relief and long-term recovery support (UNSDG, 2021). They reported progress on the life condition of the SVG population in the six months of the aftermath of the disaster. The report emphasized the need for ongoing efforts, including providing cash transfers, academic support, water access, agricultural assistance, mental health services, and infrastructure reconstruction.

After the disaster event, the World Bank launched the project “Saint Vincent and the Grenadines Volcanic Eruption Emergency Project”, which aims to support Saint Vincent and the Grenadines to (i) provide short-term income support, (ii) improve the capacity of the government to prepare for and respond to emergencies, and (iii) build back better critical services in the wake of the La Soufrière volcano eruption (World Bank, 2022).

The project has a duration of four years (2022 to 2026). It has already achieved some results, such as 4030 households impacted by the volcanic eruption and climate-related events benefiting from a short-term income support program, a number that overcame their original target of 4000, and 623 households provided with support services to enhance household self-agency, and volcanic ash, debris and floodwater cleared following the volcanic eruption and/or climate-related events (in critical spots/segments, houses, and public buildings). The project soon will restore utility/infrastructure services, such as water systems, repair five public buildings in accordance with volcanic eruption risk and climate and disaster-resilience improvements and support the government in improving command and control systems in place to better prepare for and respond to emergencies such as volcanic eruption, as well as climate change-related disasters such as hurricanes.

Progress on Recovery in SVG

The International Monetary Fund (IMF) underscored the crucial need for disaster risk recovery in St. Vincent and the Grenadines (IMF, 2022a). According to the IMF's findings, the government has proactively implemented various strategies to strengthen the nation's financial and structural resilience. These efforts include legislation establishing the Contingencies Fund (CF) and enhancing the National Emergency Management Organization (NEMO) capabilities. Additionally, the authorities have introduced several initiatives, such as regional risk-sharing facilities and contingent credit lines. They are also exploring innovative solutions like the Caribbean Regional Catastrophe Bond to manage fiscal risks associated with disasters effectively. The report also encourages private sectors, especially agriculture and fisheries, to utilize insurance coverage.

Recovery conclusion

Since the volcanic eruption is relatively recent, it is plausible that long-term recovery efforts are still underway. However, even though it is a disaster of this magnitude, there is a shortage of information on



recovery. Despite the limited available data, a post-disaster needs assessment has grouped together the recovery needs of different sectors and developed a strategy to achieve them.

A holistic recovery approach is imperative, encompassing environmental rehabilitation, fostering social cohesion, and nurturing individual well-being (Quinn et al., 2021). The approach must underscore the importance of understanding how ecosystems can be restored and conserved after a disaster and empowering communities to participate in decision-making processes for their recovery. Furthermore, good recovery practices should address individual needs for recovery, including mental and physical health as well as ensuring access to resources and knowledge during the post-disaster is crucial.

Building resilience for future events

This part of the report is based on the information collected during interviews with key informants. Interviews were conducted during the field visit in March and involved officials belonging to different agencies and governmental departments that have a leading role in the area of disaster risk reduction and prevention in St. Vincent. People interviewed highlighted how the context of multi-hazards that characterized La Soufrière eruption strongly put under pressure the capacity of the government and of institutional actors to provide adequate response and recovery measures. Nonetheless, despite being extremely challenging in terms of management and organization, various interviewee affirmed that through this event they have learnt several lessons to improve risk preparedness as well as disaster management. In particular, the eruption has been critical to pinpoint bottlenecks and limitations that hindered the response and to identify data and information needed to improve risk prevention measures. Below are reported the most relevant aspects that have been capitalized to improve risk management and preparedness.

- **Adjustments of physical assets**

Several departments (e.g. transportation, disaster management, health) reported that this event stressed the unsuitability of buildings to accommodate and resist ashfall. This unsuitability was particularly evident for private houses and for shelters. The acknowledgment and recognition of those aspects have positively influenced building codes as well as the identification of most resistant materials for buildings and building techniques. Even more important, NEMO (National Emergency Management Organization) and Health Ministry recognized the unsuitability of shelters to ash-related problems. The inappropriateness was made explicit in the shelters assessment report and would likely lead to an improvement in shelters' physical characteristics.

- **Creation or changes to strategies and action towards prevention and towards response management**

The La Soufrière eruption and the compounded events that hit the island in 2021 acted as a stress-test for governmental measures and strategies implemented in the different phases of the risk and disaster management cycle. It allowed to identify lacking points and increase awareness of bottlenecks affecting risk prevention, mitigation, and adaptation measures. Hereafter the major points of improvements highlighted in the post-event consultations are identified and grouped according to the specific dimension they belong to.

- **Institutional Communication for risk awareness**



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Experiencing a multi-hazard situation has allowed to identify how to better target communication campaigns for risks prevention. Feedback from the population during and soon after the emergency allowed to identify which type of information was unclear and which were the limitations of the communication campaign. These considerations have been included in the new risk communication plan and communication tools that have been updated after the eruption and COVID-19, that included more information on health-related hazards and on cascading hazards related to the volcanic eruption. The alert system proved its adequacy and its strong relevance in spreading information and instructions on how to behave in case of evacuation. As well the risk awareness campaign carried out by multiple ministries proved its relevance and effectiveness. The population was indeed fully responsive and ready with necessary items when they were evacuated.

- **Emergency management**

The knowledge and expertise acquired during the emergency have improved the management of the overall response, especially for what concerns evacuation procedures, shelter management and logistics of aid items. The experience of the La Soufrière eruption, highlighted that: i) a better organization of the action and efforts of volunteers is needed, ii) collaboration among international aid and government agencies must be improved, iii) the influx of aid items as well as the storage of essential goods within shelters and warehouses has to be re-organized.

All the lessons learnt in terms of technical and financial resources needed, stakeholders' coordination and collaboration as well as emergency procedures have been included in a new volcano eruption response plan that also includes a plan for Continuity of Operations during disasters. Continuity of Operation during disasters resulted in a critical aspect that affected both COVID-19 and livelihood during the Eruption and that in previous emergency plans have been undervalued.

- **Risk Prevention**

After the eruption, several risk prevention and mitigation measures have been undertaken:

- A mapping of underground water sources and springs was done to decrease the risk of water shortage caused by water pollution.
- Building codes were improved for identifying new risk areas and identifying characteristics that buildings should have to accommodate ashfalls and ash accumulation.

- **Risk finance: Cash Availability**

La Soufrière eruption highlighted the need of sensitizing and increasing the awareness of the population regarding the need of having financial coverage and liquidity. Agencies offering communities support realised that a big share of the population, especially those more in need, do not have any awareness on how to be prepared "financially". Namely, the importance of having some savings to be used in the aftermath of the event to recover and being able to bounce back. This type of information will be included in governmental risk awareness and communication campaigns.

- **Major unaddressed vulnerability factors: points to be still improved**

- **Data management**

The compounded hazard that affected St. Vincent in 2021 highlighted the challenges of working in a multi-risk environment. Multiple departments have stressed that data collection, systematization and accessibility

are problematic aspects that have been overlooked. Lack of data sharing among ministries has been reported as one of the most relevant problems, that has important repercussions on risk assessment and hazard monitoring procedures and that causes misspending as well as poor capitalization of financial resources. Similar issues are verified in the data collection, where information during and after the eruption have been poorly systematized and shared among different ministries.

In addition, the government of Saint Vincent is not lacking in data availability. They have collected many data as well in the past. However, most of the data are still on paper which makes it prone to be physically damaged. Digital transformation of these data is still under proposal and has not yet been prioritized. Digitalization is important as a form of data backup especially considering that Saint Vincent is under threat of many hazard events.

- **Risk awareness**

Despite the fact that the risk awareness campaign proved to be effective, there is the feeling that a lot of work still has to be done to get people prepared to bounce back after the event. There is a strong need to implement anticipatory actions that raise awareness on the importance of being financially prepared. A strong focus for anticipatory action has to be placed on families along the poverty line, tailoring specific actions to increase financial coverage and liquidity. Furthermore, a strong capacity building campaign is needed to inform the population on how to prevent damages / loses and impacts on livelihood depending on the different hazards.

Concerning the hazards side, information on meteorological and geological hazards is widespread, but there is lack of information related to health-related hazards, such as vector- borne diseases or infections.

Furthermore, better coordination in institutional communication is needed. Considering that multiple government education programmes provide information related to the same hazard, a common institutional line must be adopted.

- **Risk prevention**

Despite a few advances , a comprehensive multi-hazard risk assessment strategy, that includes adequate and accurate impact- based forecasting methodologies, still has to be drafted and implemented. However, there is a lack of experts in risk and hazard assessment in Saint Vincent. NEMO relies on hazard models and assessments from the regional institutions for several hazard events. These assessments are highly related to GIS (Geographic Information System). Nonetheless, there are still very few experts in GIS in Saint Vincent itself. Therefore, investment in human capacity development needs to be taken into account as well.

- **Final considerations**

The efforts from the government (local and regional) for the awareness of the Vincentian deserve to be acknowledged. For over 40 years they have organized programs in this issue and the improvement in people's awareness is noticeable. Regarding the management during the 2021 crisis, a lot of people showed their satisfaction towards the government action during the response phase of the disaster. Those that showed disappointment, mainly mentioned the poor hygienic and sanitary conditions in the shelters, and the lack or delays of financial aids after the eruption. Despite the successful monitoring and management of the evacuation phase that luckily led to any casualties, different government departments and functionaires have identified several aspects that are still to be improved to better handle such crisis in the future.

Overall, the government of Saint Vincent and the Grenadines still must learn from past experiences and address the areas where the resilience gaps and bottlenecks remain. There is a strong need to tackle these gaps, especially in terms of prevention and preparation for an eruption (risk plans, building maps and housing, evacuation, etc.), but also of data sharing among different departments to design a suitable multi-risk plan to be adopted in situations of compounded hazards. Key stakeholders in the government acknowledge that they are still far from reaching those goals, partly due to a lack of data, information, and resources. They argue that they do not feel fully prepared to handle a potential eruption if it were to occur in the near future.

4.2. Impact Chain (incl. improvement of previous IC)

The Impact Chains produced for Deliverable 1.1 were developed with desk-based research due to the impossibility of organizing stakeholders' workshops before the due date of the deliverable.

The main sources of information were:

- reports of inter-governmental organizations (e.g. UN OCHA, JEU, FAO, IMF, UNICEF, paho), inter-governmental agencies (e.g CDB, CDEMA) and non-governmental organizations (e.g. IFRC) involved in the emergency management and in the recovery process.
- reports of governmental agencies (e.g. NEMO, BRAGSA, CWSA) and ministries that have been managing the response phase.
- reports of Universities and monitoring centres involved in the monitoring of seismic and volcanic activities (e.g. WI-SRC, NEMO.)
- Scientific articles produced after the eruption.

The two Impact Chains developed aimed at unravelling the complexity of the multi-hazard context that affected Saint Vincent in 2022, analysing the interactions among COVID-19, the La Soufrière eruption and Elsa storm and the relation of cause- effect consequences that determined the overall impacts of this combination of disastrous events. The Impact Chains developed had two main focuses:

- Gain an overall understanding of the complexity which arises from the interconnections/overlapping of the three compounding hazards as well as identifying the main direct and indirect impacts of the key sectors affected. Furthermore, we show the most relevant cause-effect relations and feedbacks loops connecting multiple sectors.
- Understand cause-effects impacts characterizing the waste management and sanitary/health sectors by performing an in-depth analysis of how the COVID-19 pandemic influenced the response activities carried out to respond to La Soufrière eruption.

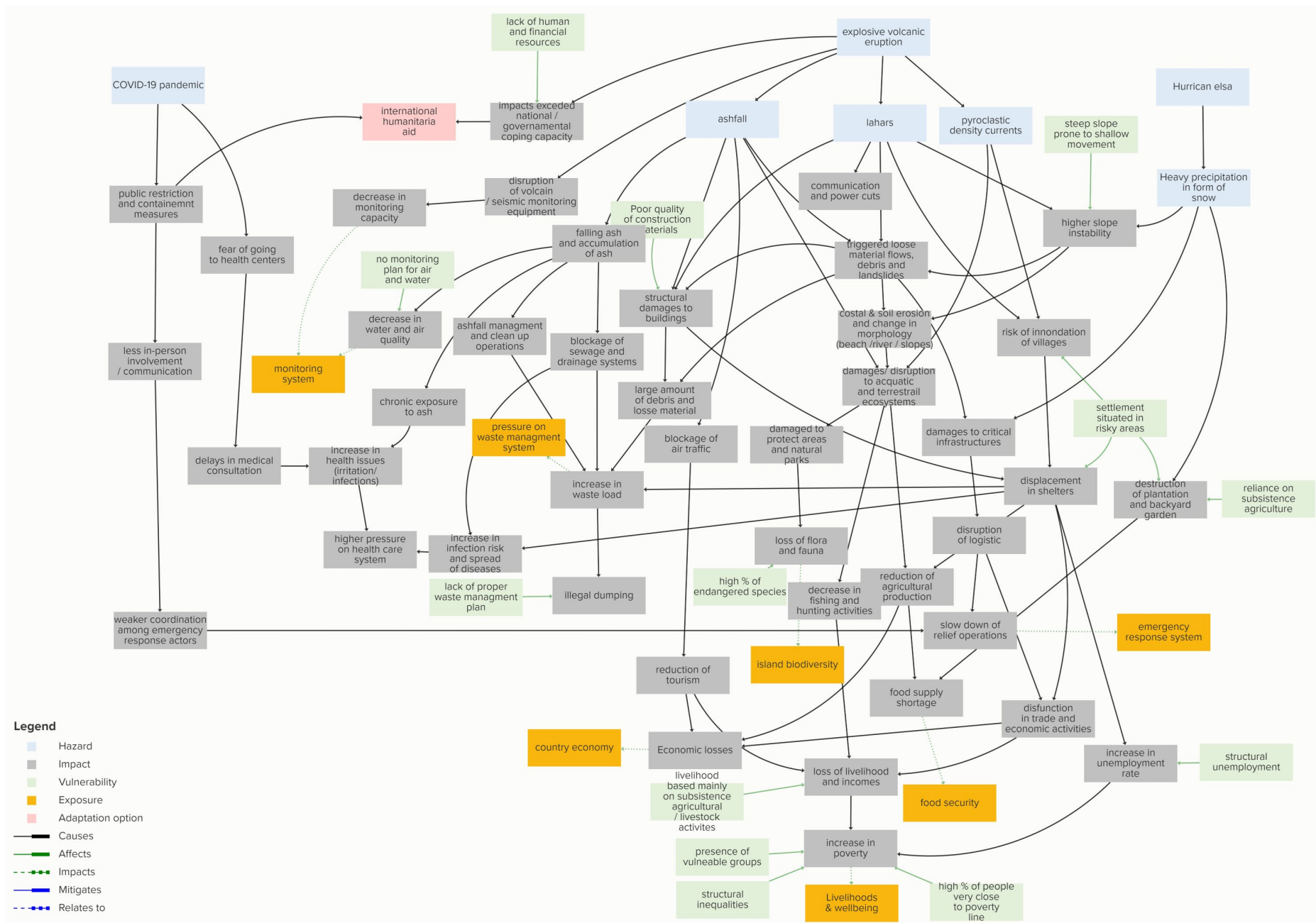


Figure 4.7 Systemic Impact Chains for multi hazard context in St Vincent

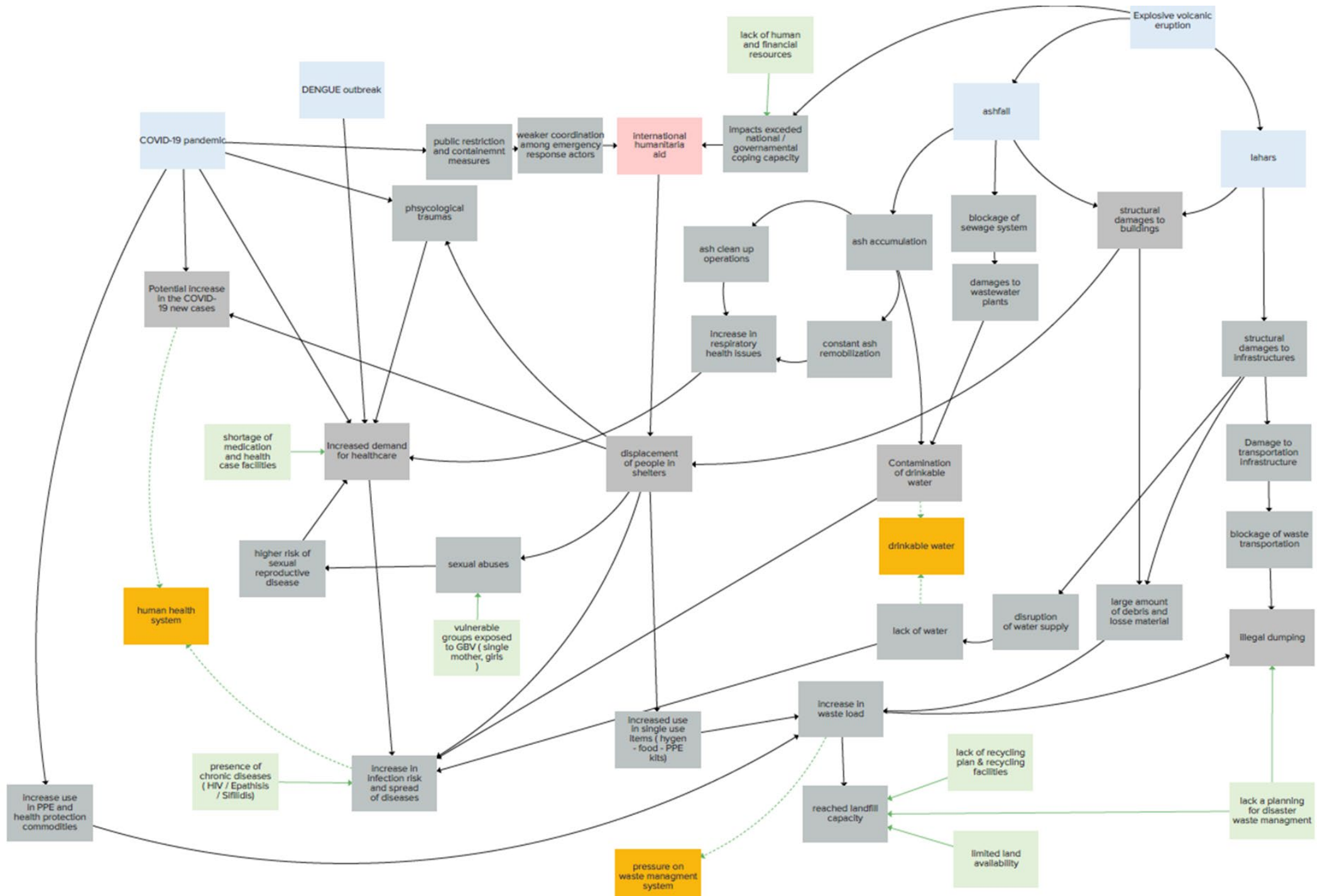


Figure 4.8 Systemic Impact Chains on interconnections between COVID- 19 and La Soufrière Response

The Impact Chain methodology allowed to understand and delineate the cascading nature of hazards, identifying connections among the risk components and deepening how the impacts of multiple events reciprocally influenced each other. Even though the Impact Chains disentangled the complexity and interconnections characterizing multi-hazards context, there have been no validations of the content by stakeholders. Content validation is fundamental for three reasons:

- Ratify and confirm the relevance of the direct and indirect impacts mentioned in the literature as well as the connection of the related vulnerabilities.
- Allow stakeholders to gain a full understanding of the different interconnections that characterize risk and grasp the relations among multiple risk elements.
- Enrich the Impact Chain with relevant information that could improve the comprehension of multi-hazard context and hazards interactions.

To reach these objectives, we undertook several interviews with key informants during the field visit to Saint Vincent, from 1st to 10th of March 2024. The information gathered was fundamental to delineate better the different dimensions outlined in the Forensic Analysis, validate the impacts identified and better adjust the connection among the different risk elements.

Further than constituting the key inputs for the Forensic Analysis, the information gathered with the interviews allowed to improve the Impact Chains and provided the grounds for building a generalized Impact Chain, that abstracts from the specific events, but delineate risk pathways staying connected with the context of reference (in our case, multi-risks situations affecting Saint Vincent) and the risk under analysis.

The Impact Chain improvements concentrated on representing the complex vulnerabilities that characterise Saint Vincent. The information gathered allowed for a deep understanding of the sources of vulnerabilities, identifying the risk drivers deeply rooted in Saint Vincent that hindered the capacity to manage and mitigate risks.

The main vulnerabilities in Saint Vincent were related to a lack of resources both at institutional and household levels. At the institutional level, the lack of resources strongly limited the data collection activity to monitor risk-prone areas and to put in place adequate risk reduction measures. Furthermore, an important aspect that came out from stakeholders was the inadequateness of the shelter management procedures and the shelter facilities in hosting the population in need. Institutional vulnerabilities concern also the lack of collaboration and cooperation among different governmental departments that hinder the adoption of regulatory plans and building codes.

The lack of resources at the household level led to the impossibility of implementing anticipatory action that would allow adequate financial coverage in the aftermath of the disaster to start the recovery process. Furthermore, Saint Vincent's colonial past shaped the overall economy, leading to a poor diversification of income and a strong dependency on remittances, which also influenced the overall resource availability.

Figure 4.9 shows the improved Impact Chain where vulnerabilities and also exposed systems have been better identified and examined with a systemic perspective.

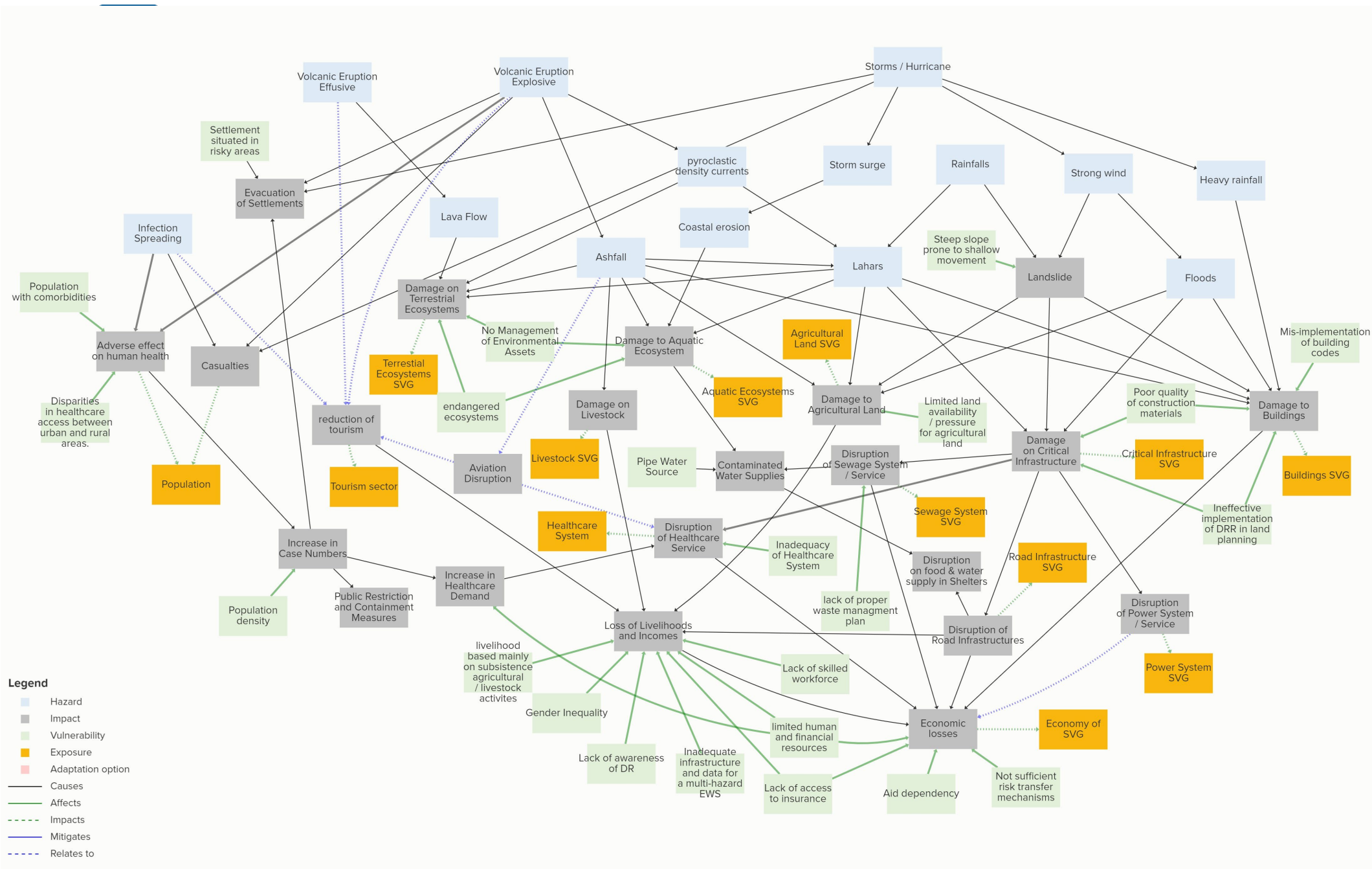


Figure 4.9 Improved Impact Chain for La Soufrière Eruption and Infection spreading. The Impact Chain content can be explored interactively through the [Impact Chain Wiki](#)

5 Irma and Maria in Sint Maarten, 2017

5.1 Forensic Analysis



Map Sources: OCHA, OSM.
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations. Map created in Mar 2023.

Figure 5.1 Sint Maarten Location Map

Sint Maarten, a constituent country of the Kingdom of the Netherlands in the Lesser Antilles, is located in the northeastern Caribbean Sea. The country occupies the southern part of the island shared with the French overseas collectivity of Saint Martin (Government of Sint Maarten, 2017; UNDRR, 2022).

The island covers an area of 34 km², characterized by a hilly terrain which limits available flat land for development. Consequently, development on the island is limited to pockets of areas in the low-lying valleys and coastal zones such as Philipsburg, Lower Prince's Quarter, Cul de Sac and Cole Bay (World Bank, 2020).

Sint Maarten is the most densely populated island-nation in the Caribbean (1,180 persons per square kilometer). It has a population of over 40,600 and a per capita GDP of \$25,358 (World Bank, 2020). Sint Maarten has a small, open, tourism based economy which accounts for the greatest contribution to

the country's GDP and employment (Government of Sint Maarten, 2017; World Bank, 2020).

The narrative for Sint Maarten has been constructed based on the methodology developed EURAC and ITC . The Forensic Analysis aligns with the Impact Chains which have been developed for hurricanes, with a focus on the health and food supply sector. The Impact Chains for Sint Maarten are developed based on insights from a stakeholder workshop held in 2023, which marked the beginning of the co-developing phase in the PARATUS project for the Caribbean Application Case Study. The initial Impact Chains developed based on the stakeholder input have been improved based on a desktop analysis with the aim of including additional elements on hazard, vulnerability, exposure, impact, adaptation and resilience. The Impact Chains have informed the narrative for the Forensic Analysis in Sint Maarten by making use of the elements already identified during the stakeholder workshop and desktop analysis. Further information has been sourced from literature and reports to further improve the narrative for the Forensic Analysis.

Hazard analysis

Sint Maarten shares many characteristics of small island states, including its susceptibility to natural disasters. The country's geographical location makes it vulnerable to major natural hazards such as tropical cyclones, hurricanes and earthquakes. In addition to this, Sint Maarten is also particularly sensitive to the risk of torrential flooding due to its steep slopes and low valleys (World Bank, 2020).



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As a part of the Atlantic hurricane belt, Sint Maarten on average experiences severe hurricane conditions at least once every 4-5 years (World Bank 2020). Some examples of hurricanes that have made landfall include Luis in 1995 (category 4), Lenny in 1999 (category 3), and Irma in 2017 (category 5+).

On 6 September 2017, the Islands of Sint Maarten, Saba and St Eustatius were struck by Hurricane Irma (Figure 5.2). Sint Maarten sustained the most damage. Although St Eustatius and Saba were affected to a lesser extent, their dependency on Sint Maarten created challenges for the various sectors. Hurricane Irma was a category 5 hurricane with sustained winds of 185 mph (296/h), making Irma the strongest hurricane ever observed in the open Atlantic Ocean, and one of the only 5 hurricanes with measured winds of 185 mph or higher in the entire Atlantic basin.



Figure 5.2 Hurricane Irma captured by NOAA National Weather Service National Hurricane Center

Less than two weeks after Sint Maarten was struck by Hurricane Irma, Hurricane Maria (category 5) made landfall, exacerbating Irma's devastation (Government of Sint Maarten, 2017). Figure 5.3 shows the categorization of hurricanes and their subsequent impact based on the well-known Saffir-Simpson hurricane wind scale.

Hurricane Category	Impacts
1	Wind 64-82 knots, storm surge 1.0-1.6 m, no real damage to building structures, damage to trees
2	Wind 83-95 knots, storm surge 1.7-2.5 m, some roofing and window damage, considerable damage to trees
3	Wind 96-113 knots, storm surge 2.6-3.8 m, some building damage, large trees blown down
4	Wind 114-135 knots, storm surge 3.9-5.5 m, complete removal of some roofs, extensive window damage, most trees blown down
5	Wind 136+ knots, buildings fall over, storm surge 5.6+ m, widespread loss of roofs, some buildings destroyed, all trees blown down

(a wind speed of 100 knots = 185.2 km per hour = 51.4 metres per second)

Figure 5.3 Hurricane Classification Wind Scale

Hurricanes Irma and Maria brought about hurricane related hazards after making landfall. As the eye of the hurricanes passed directly over Sint Maarten, the island was exposed to the highest wind velocities for more than two hours. This was accompanied by storm surges coupled with high and low incoming waves, which provoked flooding of the lower coastal areas (Government of Sint Maarten, 2017).

Short and long term impact analysis

According to UNDP (2017), 4 people died, 34 people were wounded, and 11 people were seriously injured because of Hurricane Irma. About 5000 people were displaced in the aftermath of the hurricane. Overall, Irma affected the entire population of Sint Maarten, which at the time was estimated at around 40,000 people. The impact of hurricanes on hospitals and health centers in the form of structural damage, flooding, and power outages has rendered many facilities inoperable or severely limited their capacity to provide medical care.

About 90% of the infrastructure on the island was damaged by hurricanes Irma and Maria (Government of Sint Maarten, 2017). Based on the assessment done by UNDP, Sint Maarten experienced 90% of property destruction, with 3863 buildings destroyed, 2425 highly damaged houses, and 6263 houses with slight or no damage.



Figure 5.4 Physical damage caused by Hurricane Irma. Source: An aerial photograph taken by the Dutch Ministry of Defense shows the devastation caused by Hurricane Irma in Philipsburg, on the Dutch Caribbean island of Sint Maarten, Photo Date: 9/7/17 (WHSV):



Figure 5.5 Damage to the harbour caused by Hurricane Irma. Image source: <https://commons.m.wikimedia.org/wiki/File:Alh-08-09-sint-maarten-foto-6-duo.jpg#mw-jump-to-license>

Communications companies such as TELEM Group and UTS also suffered significant damage to their mobile telecommunications infrastructure and distribution networks. The loss of single towers affected multiple operators, and remote sites that had not been damaged were temporarily out of service due to the loss of power.

Hurricane Irma and Maria caused widespread devastation to Sint Maarten's natural environment. Many large trees, some of which hold historical and cultural significance, were uprooted, while landscapes were stripped of foliage. Although some growth is slowly returning, the recovery process is expected to be lengthy. The nesting sites of the Brown Pelican, the island's National Bird, were severely affected, and the restoration of these areas will require considerable time (Government of Sint Maarten, 2017).

The storm destroyed approximately 90% of the mature mangroves, a significant blow to the island's coastal ecosystems. The hurricane also resulted in a substantial fuel spill in the Simpson Bay Lagoon, posing a risk of oil contamination in both the lagoon and the Oyster Pond wetlands. Run-off from hills has led to water quality issues at beaches, and erosion has further impacted coastal areas (Government of Sint Maarten, 2017).



Figure 5.6 Coastal erosion due to Hurricane Irma. Image source: <https://nltimes.nl/2017/09/07/videos-hurricane-irma-leaves-trail-destruction-sint-maarten-saba-sint-eustatius>

Based on the [post hurricane coral assessment](#) conducted by St. Maarten Nature Foundation, the hurricanes caused a reduction in coral cover on St. Maarten reefs. However, reef health improved due to a decrease in coral bleaching. Macro algae cover increased after the hurricanes which threatens coral recruitment and coral growth. Since the hurricanes, there has been a notable decline in coral cover, dropping from 6.1% to 3.7%. The powerful surges and swells of the storms caused significant damage to gorgonian corals and fleshy algae, exposing more coral recruits, sponges, and calcareous coralline algae (St. Maarten Nature Foundation, N.D). Following the hurricanes, there was an increase in the biomass of larger carnivorous fish on the reefs, particularly groupers and snappers, with particularly high numbers observed in Marine Protected Areas like Proselyte Reef and Mike's Maze. While there was no significant change in the biomass of herbivorous fish after the hurricanes, there was a decrease in the number of fish species present (St. Maarten Nature Foundation, N.D).

A comprehensive assessment conducted by the Government of Sint Maarten and the World Bank estimated total damages and losses of 1.4 billion dollars resulting from the impact of Hurricane Irma and Maria (Government of Sint Maarten, 2017). The impacted sectors included WASH, health, food, education, environment, tourism, infrastructure and communications. Tourism was the most affected sector sustaining 21.2. per cent of the damage and accounting for 86.6 per cent of the total losses (US \$855.5 million) (Government of Sint Maarten, 2017). Table 5.1 shows an overview of the damage and losses accounted following the impact of hurricanes Irma and Maria.

Table 5.1 Summary of Damages and Losses across the three National Recovery and Resilience Plan Components

SECTOR	COST (USD)	
	DAMAGES	LOSSES
Community		
<i>Housing</i>	442,000,000	22,101,000
<i>Health</i>	4,267,000	1,916,000
<i>Education, Culture, Youth and Sport</i>	60,228,000	1,711,000
<i>Sanitation and Solid Water Management</i>	604,000	-
<i>Employment, Livelihoods and Social Protection</i>	-	91,004,000
<i>Environment, Ecology, and Biodiversity</i>	574,000	5,423,000
Community Total	507,673,000	122,155,000
Economic		
<i>Tourism and commerce</i>	367,746,000	740,465,000
<i>Finance</i>	-	143,000,000
<i>Airport</i>	173,345,000	29,500,000
<i>Ports and Marinas</i>	208,750,000	50,000,000
<i>Roads and Drainage</i>	103,000	-
<i>Electricity</i>	5,920,000	24,476,000
<i>Water</i>	6,529,000	9,896,000
<i>Telecoms/ICT</i>	50,661,000	-
Economic Total	813,054,000	997,437,000
Government		
<i>Disaster Risk Management</i>	1,453,000	97,000
<i>Governance and Public Financial Management</i>	3,000,000	230,000,000
<i>Justice, Public Safety, and Security</i>	-	-
<i>Additional Public Buildings</i>	45,517,000	-
Government Total	49,970,000	230,097,000
Grand Total	1,370,697,000	1,349,689,000

Source: Government of Sint Maarten, 2017. *Sint Maarten National Recovery and Resilience Plan: A Roadmap to Building Back Better*

Early Warning System

Sint Maarten does not have an established early warning system which enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risk and impact. Early warning actions taken before Irma included sending out of radio messages to warn people of the approaching hurricane as well as awareness campaigns conducted by various ministries and departments. Although warnings were disseminated, the use of English for communication meant that Spanish and French-speaking immigrant communities, who make up 20% of the total population, had challenges properly understanding the warning and evacuation information about Irma.

Early warning activities in Sint Maarten start at the beginning of each hurricane season (June), when the Meteorological Department sends out warning advisories, which intensify when a storm or hurricane is approaching (Hamer, 2019). As there is no formalized national public information and awareness strategy, warning dissemination is not streamlined, with citizens getting their information largely from social media (UNDRR, 2022).

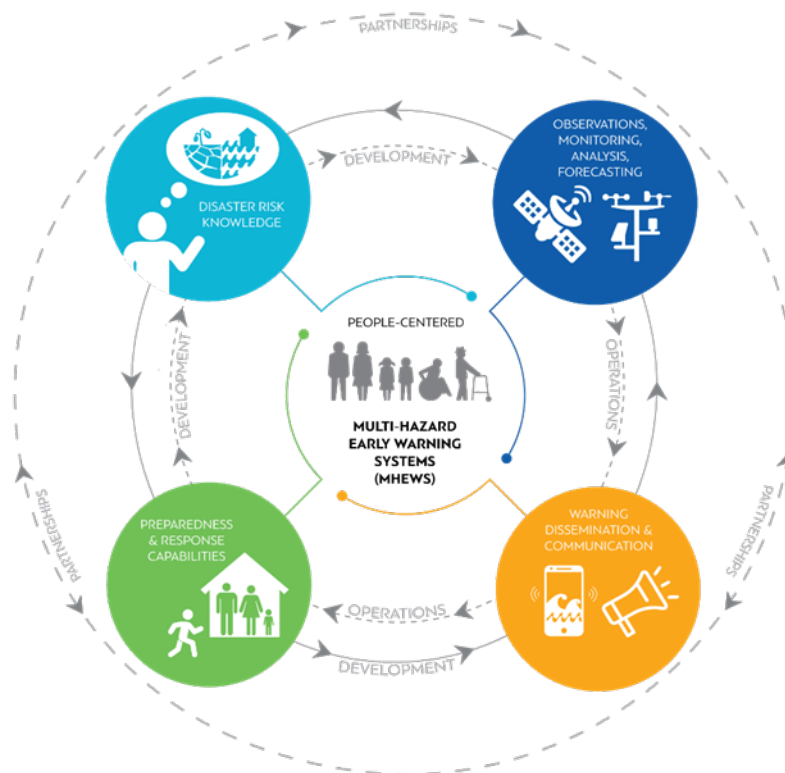


Figure 5.7 Multi-hazard Early Warning System Component. Source: WMO (2022)

A 2021 report on a Situation Analysis of Disaster Risk Reduction in Sint Maarten (Sahar & Darwish, 2021) assessed the country's Multi-Hazard Early Warning System (MHEWS) under four components (see Figure 5.7):

- Disaster risk knowledge
- Hazard detection, monitoring and forecasting
- Warning dissemination and communication
- Preparedness and response capabilities

For the disaster risk management component, the analysis found that there is minimal or no progress, with challenges evident in the lack of risk data collection, data management and sharing amongst institutions. The analysis makes recommendations, which include the production of useful and understandable hazard, vulnerability and risk information for hurricanes, flooding, and tsunamis and the development of legislation or government policy mandating the preparation of hazard, vulnerability, and capacity assessments for all areas.

For hazard monitoring and detection, the analysis found that there have been a few upgrades to the monitoring and forecasting technologies and equipment in Sint Maarten following Hurricane Irma. In addition, equipment such as the radar and an automatic weather station were damaged during Hurricane Irma and have yet to be replaced.

The analysis also found that improvements have been made with regards to warning and dissemination of warnings as the telecommunications sector has worked on its infrastructure resilience by burying more telecommunications lines underground, and also repairing cell towers that were damaged during Irma. Preparedness and response initiatives have focused on awareness programs on hurricanes. However, there is a need for increased public education for other hazards, particularly tsunamis and earthquakes.

Overall, the EWS for hydrometeorological hazards is more advanced than for other hazard types, highlighting the need to strengthen mechanisms and build capacities for all hazard categories (UNDRR, 2022). Based on a more recent interview with the disaster manager in Sint Maarten, there are plans to improve some of the early warning components in Sint Maarten as part of the EU RESEMBID “Resilient Crisis Management Project” under the joint partnership of the Sint Maarten Government in partnership with VNG International. Through the project, cell broadcast infrastructure will be set up to improve warning dissemination on the Island. The MET office in Sint Maarten is also installing a network of rain gauges on the island to support flood monitoring.

First Response

Shortly after Irma struck, a state of emergency was declared by the Government, prompting the setup of a National Emergency Operation Centre (NEOC) to be used as a central meeting point for responders and stakeholders (UNICEF Netherlands, 2017). The initial emergency response to aid St. Maarten faced significant challenges due to the destruction of communication networks and damaged infrastructure which hindered relief effort, isolated the island and also impacted the supply routes to Saba and St. Eustatius (Government of Sint Maarten, 2017). To address these challenges, the Dutch Army prioritized reconstructing critical infrastructure to facilitate the delivery of humanitarian aid. This involved clearing the landing strip at Princess Juliana Airport to enable the arrival of essential supplies and additional military personnel (Hamer, 2019).

Aside from the damage to critical infrastructure, the threat of additional storms from Hurricane Maria and Jose further disrupted emergency operations. Public disorder and looting followed in the aftermath of hurricane Irma, and measures had to be taken to maintain security and restore public order on the Island. Restoration of public order and security was done by the Police Force of Sint Maarten together with support from the Police forces of Aruba and Curaçao, the Dutch marines, and the Volunteer Korps Sint Maarten (Government of Sint Maarten, 2017).



Citizens alongside the Government, civil society organizations, non-governmental organizations (NGOs) and the private sector came together to support cleaning up, distributing relief items, and restoring public order and security. The Netherlands Red Cross, which worked alongside the Sint Maarten Red Cross distributed around 116,738 liters of water, 8,088 food parcels and 11,828 tarpaulins (Netherlands Red Cross, 2017). These tarpaulins were needed as around 90% of the housing had been damaged severely. Next to the Red Cross, other organizations such as the United Nations Disaster and Coordination Assessment Team (UNDAC), the Netherlands Urban Search and Rescue (USAR), UNDP, IOM, WFP, UNICEF, Cordaid, Samaritan Purse, Caritas International, and K1 Britannia provided emergency aid and assistance. Despite the presence of the various institutions, effective coordination between the organizations and the local government was a challenge which further complicated relief efforts (Hamer, 2019).

Vulnerability analysis

Social Dimension

Social vulnerability takes into account various socio-economic and demographic factors that influence an individual or communities ability to cope with hazards and their subsequent impacts.

Sint Maarten has a high migrant population with the civil registry showing that about 104 nationalities have legally settled on the Island (PAHO. u.d. SINT MAARTEN). Migrants are uniquely vulnerable to disasters, as they usually face a number of barriers with regard to accessing information, resources and opportunities, which reduces their ability to prevent, mitigate, prepare for, cope with, and recover from disasters (UNDRR, 2022). During Hurricane Irma and Maria, the multilingual nature of Sint Maarten was a source of social vulnerability given that many Spanish-and French-speaking immigrant communities did not properly understand warning and evacuation information disseminated in English (UN OCHA, 2022).

Disaster management acknowledges gender considerations, with female-headed households being particularly vulnerable due to societal challenges. In Sint Maarten, 38% of households are female-headed (UNICEF, 2020), with women often bearing responsibility for essential tasks like water supply and food security, yet facing limited access to resources and decision-making. Recognizing these vulnerabilities, efforts are underway for gender mainstreaming and understanding residents' needs to improve disaster preparedness. Recent initiatives include a gender assessment survey in collaboration with PAHO, EU, and the Government of Sint Maarten, aiming to inform the 'SMART' Shelters Project, which includes constructing resilient shelters and providing training in disaster management (UNDRR, 2022).

There is limited data showing the relationship between age and vulnerability to disasters in Sint Maarten. However, globally, studies have shown that there is a correlation between age and susceptibility to the impacts of natural disasters, including the likelihood of injuries or death (UNDRR, 2022). During emergencies, chronic health conditions, impaired cognitive abilities, and decreased sensory awareness associated with ageing put older people at a disadvantage. Although the majority of Sint Maarten's population is comprised of the productive age group (20-64), the percentage of elderly residents is slowly increasing. Aside from the elderly population, people living with disabilities are also disproportionately affected in disasters. Sint Maarten recorded 11.4% of its population having disabilities in 2014, with visual impairments being the most common. Despite the low numbers, the extent of inclusivity for persons with disabilities at all stages of the disaster management process in Sint Maarten remains unknown (UNDRR, 2022, p. 19).

Physical Dimension

Sint Maarten, like many other Small Island Developing States (SIDS) is prone to disasters owing to its geographical location, small country size and high population density in a low-elevation coastal area (UNDRR,



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2022). Given the island's location, critical infrastructure is particularly at risk during disasters. The vulnerability of road infrastructure in Sint Maarten is exacerbated by the fact that the island has an older road network constructed around the 1950's which lacks modern building materials and construction techniques designed to withstand the forces of extreme weather events. This old road network makes them more susceptible to damage or collapse during hurricanes, storm surges, and heavy rainfall, leading to disruptions in essential services such as water, power, and transportation.



Figure 5.8 Housing construction on hilly terrains. Source: World Bank (2020,p.38) Rapid Housing Sector Assessment: Sint Maarten

Aside from the poor road infrastructure, most buildings in Sint Maarten particularly before Irma were not designed nor constructed with the objective of making them hurricane resilient. In Sint Maarten a Building Ordinance (Bouw en Woningverordening, AB 2015, no.9) as well as a Building Decree (Bouwbesluit, AB 2013, GT no. 146) are in place. Both have not been reviewed and/or revised for a long time and have (very) old norms which stem from 1935. Therefore, although spatial plans and building regulations are in place in St. Maarten, the force of hurricane Irma showed that more could be done to make new and/or existing buildings more resistant against future hurricanes (or other disasters) (VNG International, 2018, Enhanced resilience to respond to disasters: Recovery project Sint Maarten). After hurricane Irma, the government of Sint Maarten planned for the construction and outfitting of a new disaster resilient hospital designed to withstand new windspeed standards post-Irma (Government of Sint Maarten, 2017).

Other services such as electricity and water are also vulnerable since power generation is almost completely dependent on imported heavy fuel oil (HFO), and 100 percent of the public drinking water is produced by desalination. When these facilities are damaged, services are lost until repairs can be completed (Government of Sint Maarten, 2017, p. 12).

Environmental Dimension

Population growth in Sint Maarten in recent years has resulted in rapid unplanned development and land use changes that have impacted the environment and altered ecosystems. Natural ecosystems are particularly at risk in Sint Maarten as development related activities such as land clearing result in deforestation and destruction of mangroves (UNDRR, 2022). In Sint Maarten, natural ecosystems play a crucial role in protecting coastlines from erosion and flooding by serving as barriers against storm surges. Deterioration of ecosystems therefore leaves coastal areas more vulnerable to the impacts of storms. During hurricane Irma, the accompanying strong winds and storm surges resulted in coastal erosion and flooding which not only affected the coastal ecosystem but also led to the damage of infrastructure and loss of property. In addition to the impact on natural ecosystems, unregulated development practices in Sint Maarten exacerbate flood risk through the expansion of impermeable surfaces that prevent rain absorption by the soil (UNDRR, 2022).

Institutional Dimension

After Hurricane Luis in 1995, a Disaster Management Strategy and structure (see Figure 5.9) were setup and put in place in Sint Maarten.

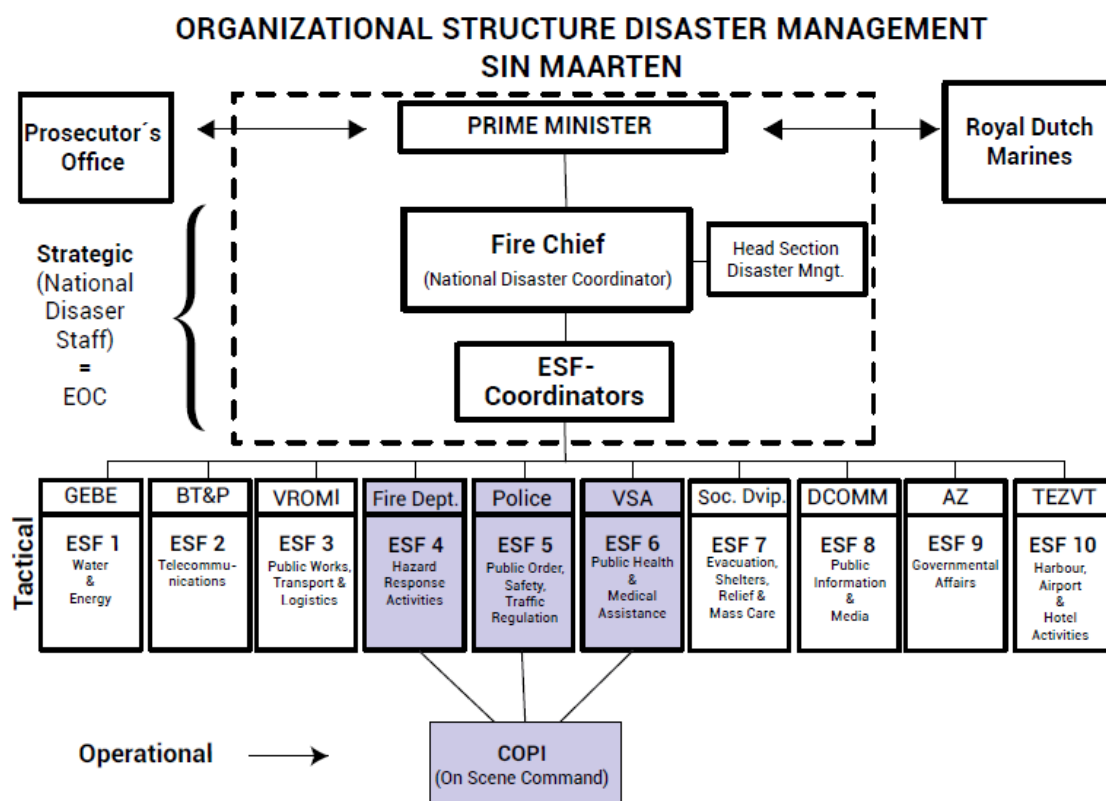


Figure 5.9 Organizational Structure Disaster Management in Sint Maarten. Source: UNDRR, 2022

Since Sint Maarten became a country within the Kingdom of the Netherlands in 2010, the disaster management structure has been translated and adapted to the new functions that were created, but the legislation and strategy have not been updated (VNG, 2018). The lack of legislation and an updated strategy creates gaps within the disaster management system with regards to internal and external communication

and coordination (VNG International, 2018). The gap in the coordination mechanism was particularly evident during the response to Irma.

During the first emergency response to hurricane Irma, a lot of organisations were present to provide support within the different affected sectors, however one major issue that emerged was the lack of coordination between the local government and these organisations (Hamer, 2019). Although the support from the organisations was needed, Sint Maarten did not have in place standard operating procedures (SOPs) that would enable proper coordination amongst different agencies and the government during disaster response, which in turn affected the delivery of the aid (Hamer, 2019). Aside from lack of coordination in the initial stages of the response after Irma, not all Emergency Support Function (ESF) groups had action plans/operational manual in place to support the disaster management system that has been setup on the Island. Consequently, although the disaster management system that has been put in place was working properly during the response, the people on the ground who form part of the ESF groups did not know what to do (Hamer, 2017).

Economic Dimension

According to the 2011 census data for Sint Maarten, about 20-25% of households had a monthly income of Netherlands Antillean guilder (NAf) 1,000 or less per month (equivalent to USD 550), essentially placing them below the poverty line. Additionally, a socio-economic survey from 2013 found that 43.1% of respondents considered themselves to be living in need, while 28.5% considered themselves poor (UNDRR, 2022, p. 18). In addition to the surveys, a poverty benchmark study conducted by the United Nations Development Programme (UNDP) in 2017 showed little improvement from the 2011 census results, with approximately 27% of households being classified as poor and living on or below the minimum wage up from 20-25% (UNICEF, 2020).

Poverty and inequality emerge as significant drivers of vulnerability that results to a considerable proportion of households lacking resources to afford basic necessities that would enable them to address risks and lacking the coping capacity for quick and effective recovery when a disaster occurs (UNDRR, 2022).

Analysis of underlying risk drivers

Sint Maarten's coastal location makes it susceptible to the impacts of hurricanes, including storm surges, flooding, and wind damage. Since 1995, Sint Maarten has been exposed to numerous hurricanes whose tracks have passed within 40 kilometers of the country, including Luis in 1995 (Category 4), Lenny in 1999 (Category 3), Irma and Maria in 2017 (Category 5+).

Sint Maarten is a small and open economy, one that is essentially tourism-based, with the sector contributing at least 70% to the foreign exchange income (Government of Sint Maarten, 2017). The island's heavy reliance on tourism leaves it susceptible to external shocks such as declines in tourism revenue following a natural disaster. In addition to the over-reliance on the tourism sector, the island also depends heavily on imports for essentials like food, energy and goods (World Bank, 2020). Disruption of transportation and logistics due to the damage of critical infrastructure leads to the disruption of the supply of food, energy and goods which in turn affects individuals and businesses.

Around the 1950's, Sint Maarten shifted focus from exporting products such as sugar, coffee, tobacco to tourism. The initial construction of luxury villas for tourism was mostly made by a small group of people considered "gatekeepers" who made decisions on who got access to particular resources and opportunities (Hamer, 2019). As the tourism sector grew, other sectors, such as agriculture, started to fall behind. As



tourism increasingly became an important sector in the 1970's, more tourism-related infrastructure was built, resulting in the 1980s being a virtually free-for-all time in tourism construction (de Albuquerque & McElroy, 1995). As construction boomed during this time, building codes were not being enforced with spatial planning and permit processes also being neglected (de Albuquerque & McElroy, 1995). Thus, the unplanned growth and development have not only resulted in unregulated and unsustainable development practices but also increased the vulnerability of the population to the risk of natural disasters.

With tourism growth also came the attraction of a lot of migrant workers which contributed to population growth. As Sint Maarten does not have a migration policy in place, the flow of migrants was not regulated. Currently, Sint Maarten has a population density of approximately 1,180 persons per square km and is the most densely populated country or territory in the Caribbean and within the kingdom of the Netherlands (Government of Sint Maarten, 2017). Population density pushes the limits of the island in terms of expansion or upgrading of the physical infrastructure, such as roads, and inadequately planned urban expansion in the riskiest areas, such as hillsides.

Recovery analysis

After Hurricane Irma and Maria, initial recovery began with citizens, civil society groups, government entities, non-governmental organizations (NGOs) and the private sector pitching in, aided by external support, including from Aruba, Curaçao, the Netherlands, and international organizations (Government of Sint Maarten, 2017). During early recovery, the Government of Sint Maarten initiated a range of projects, including repairing schools and other critical buildings and removing debris. Funding support was also provided to NGOs by the government to support the reconstruction of houses, and the generation of employment through a cash-for-work program.

The government of Sint Maarten, with support from the funding of the Dutch Government and strategic support from the World Bank Group, prepared the Sint Maarten National Recovery and Resilience Plan (NRRP). The NRRP provides guidelines for the following;

- a. Sustainable recovery of social sectors in affected communities;
- b. Restoration of business continuity combined with a strategy for fostering and broadening business activity.
- c. Rehabilitation and reconstruction of critical infrastructure to Build-Back-Better (BBB) standards and
- d. Strengthening of the country's social, economic and governmental readiness to mitigate, respond to and recover from future impacts of natural disasters and climate change.

The NRRP (2017) estimates that \$ 2.3 billion will be required for recovery and resilience interventions over the next seven years. The sectors with the largest needs include: Housing (22.8 %), Tourism and Commerce (19.0%), Governance and Public Financial Management (9.4%), Sanitation and Solid Waste Management (8.3%), Airport (7.6%), and Education, Culture, Youth and Sport (5.1%).

A trust fund of \$580 million, the Sint Maarten Recovery, Reconstruction and Resilience Fund, was established in 2018 through an agreement between the Netherlands and the World Bank to support Sint Maarten's recovery and resilience. Figure 5.2 provides the summary of the sector recovery needs as prioritized in the national recovery and resilience plan.



Table 5.2 Summary of sector recovery needs prioritization. Government of Sint Maarten, 2017. Sint Maarten National Recovery and Resilience Plan: A Roadmap to Building Back Better

	Needs (USD)				
	Immediate	Short-term	Medium-term	Long-term	Total Needs
Community recovery					
Housing*	105,350,000	213,400,000	215,000,000	-	533,750,000
Health	5,204,000	35,104,000	9,904,000	-	50,212,000
Education, Culture, Youth and Sport	9,981,000	24,914,000	81,779,000	3,304,000	119,978,000
Sanitation and Solid Water Management	11,000,000	128,860,000	55,500,000	-	195,360,000
Employment, Livelihoods and Social Protection	20,030,000	43,960,000	35,704,000	2,073,000	101,767,000
Environment, Ecology, and Biodiversity	30,000	2,180,000	1,870,000	1,760,000	5,840,000
Community recovery Total	151,595,000	448,418,000	399,757,000	7,137,000	1,006,907,000
Economic recovery					
Tourism and commerce	168,000,000	109,100,000	116,000,000	52,750,000	445,850,000
Finance	35,000,000	26,000,000	2,500,000	1,000,000	64,500,000
Airport	67,300,000	111,897,000	-	-	179,197,000
Ports and Marinas	1,500,000	74,500,000	5,750,000	10,500,000	92,250,000
Roads and Drainage	-	1,600,000	34,400,000	-	36,000,000
Electricity	7,629,000	13,670,000	35,420,000	-	56,719,000
Water	9,829,000	13,108,000	13,028,000	-	35,965,000
Telecoms/ICT	-	15,246,000	8,080,000	1,200,000	24,526,000
Economic Recovery Total	289,258,000	365,121,000	215,178,000	65,450,000	935,007,000
Government Recovery					
Disaster Risk Management	12,435,000	24,897,000	10,160,000	3,700,000	51,192,000
Governance and Public Financial Management	7,500,000	160,794,000	36,794,000	15,544,000	220,632,000
Justice, Public Safety, and Security*	10,380,000	37,436,000	36,000,000	-	83,816,000
Additional Public Buildings*	6,183,000	17,356,000	10,978,000	11,000,000	45,517,000
Government Recovery Total	36,498,000	240,483,000	93,932,000	30,244,000	401,157,000

Grand total	477,351,000	1,054,022,000	708,867,000	102,831,000	2,343,071,000
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*Additional analysis and investigation was needed.

Some of the proposed interventions in the NRRP (2017) under the disaster risk management, housing, health and tourism sectors included:

Sector	Proposed Intervention for Recovery
Housing	• Repair damage to housing. • Conduct engineering review of the sustainability of existing building codes. • Conduct a pilot informal settlement upgrading project and explore informal settlement upgrading options to increase disaster resilience. • Capitalize housing mortgage guarantee fund to encourage home ownership.
Health	• Support the construction and outfitting of a new disaster resilient hospital. • Conduct preventative health activities for vector and mold control. • Purchase ambulances to replace damaged vehicles. • Develop and procure health information systems.
Tourism and commerce	• Repair/reconstruct damaged hotels, including making. Available conditional financing for sustainable recovery of tourism sector. • Create a post-emergency marketing/PR strategy. • Create a tourism resilience strategic plan.
Disaster risk management	• Promote Sint Maarten's engagement with international initiatives aimed at enhancing DRM and Climate Change adaptation (CCA). • Conduct an assessment of Sint Maarten's disaster risks and develop a digitized/updatable national atlas of disaster risk profiles. • Develop emergency preparedness and contingency plans at all levels. • Improve emergency preparedness and response capacity by conducting regular emergency preparedness/response drills at national and subnational level. • Improve DRM governance by promoting the active participation of vulnerable groups and communities in disaster risk management



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Building resilience for future events

The principle of Building Back Better (BBB) has been placed at the centre of recovery and reconstruction in Sint Maarten, Saba and St. Eustatius in order to build long-term resilience. Through the Build Back Better principle, recovery, rehabilitation and reconstruction phases after a disaster are used to increase the resilience of a country and communities by integrating disaster risk reduction measures. These measures aim to restore the physical infrastructure and societal systems, and also revitalize livelihoods, economies and the environment ([UNDRR Sendai Framework Terminologies](#)). UNDP in partnership with the government of Sint Maarten, specifically, the Ministry of Public Housing, Spatial Planning, Environment and Infrastructure (VROMI) provided technical assistance for the development of a Building Back Better Manual (UNDP, 2018). St Maarten, Saba and St. Eustatius received funds to finance investments in infrastructure based on BBB standards. This includes work on the airport, harbor, school areas, and public houses and government buildings (VNG, 2018). As a priority for recovery under the health sector, St Maarten aims to construct and outfit a new disaster resilient hospital designed to new windspeed standards post-Irma (Government of Sint Maarten, 2017).

In addition to adopting BBB standards to increase resilience, updating of building regulations and advocating for their compliance is proposed (VNG, 2018). Hurricane Irma and Maria exposed the vulnerability of physical infrastructure in St. Maarten. Physical vulnerability is exacerbated by the non-compliance with spatial plans and building regulations. Although building regulation exist i.e. a Building Ordinance (Bouw en Woningverordening, AB 2015, no.9) as well as a Building Decree (Bouwbesluit, AB 2013, GT no. 146), these need to be updated as they are based on old norms which stem from 1935. According to VNG (2018,p. 16), the Ministry of Public Housing, Spatial Planning, Environment and Infrastructure has been working on modernizing the ordinances, and a new Building Decree has been drafted (the so called “National Decree”, entailing general measures: Building technical norms).

Strengthening disaster preparedness capacities enables government institutions in Sint Maarten to anticipate better, adapt, and respond to future disasters. Among the prioritized initiatives to build resilience is the improvement of the disaster management structure, including legislation, and ensuring that politicians, civil servants of line ministries and police, fire brigade, as well as community representatives have been trained on the structure (VNG, 2018).

After Irma and Maria, UNDP conducted an evaluation to help improve preparedness and overall disaster management. The evaluation which was informed by a wide range of stakeholders (i.e. government, the private sector, NGO's and affected communities) made recommendations with regards to improving community awareness, enabling community development and establishing an emergency telecommunications system that can withstand disaster, and a reliable and formal system of giving warnings island wide (UNDP, 2018).

5.2 Impact Chain

The initial development of Impact Chains for Sint Maarten was based on a stakeholder workshop held in St. Maarten in 2023, which marked the beginning of the co-developing phase in the PARATUS project for the



Caribbean Application Case Study. The input from stakeholders (i.e. practitioners involved in prevention, response and recovery from major disaster events) during the workshop provided insights into the previous hazards that have affected the island, the direct and indirect impacts that the hazard have had on the people of Sint Maarten, Saba and St. Eustatius. Aside from the hazard and impact definition, the workshop also provided inputs on the vulnerabilities and underlying drivers of risks. The input from stakeholders was used to develop the initial Impact Chains for Sint Maarten with a focus on hurricanes (using hurricane Irma as an example) and COVID-19 as the hazards impacting the food supply/logistics, health and telecommunications sector Figure 5.10 and Figure 5.11 show the Impact Chains developed for the hurricane * food supply and hurricane * health sector in KUMU.

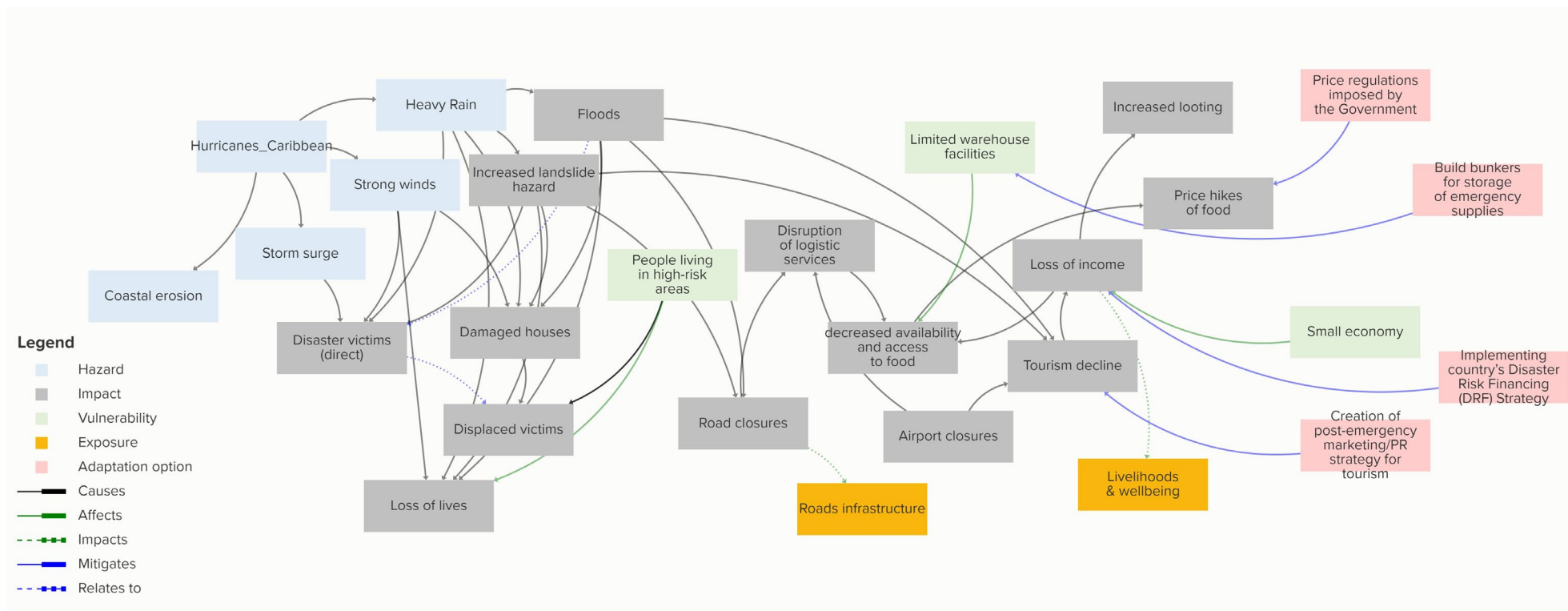


Figure 5.10 Impact Chains for Hurricane and the Food Supply Sector

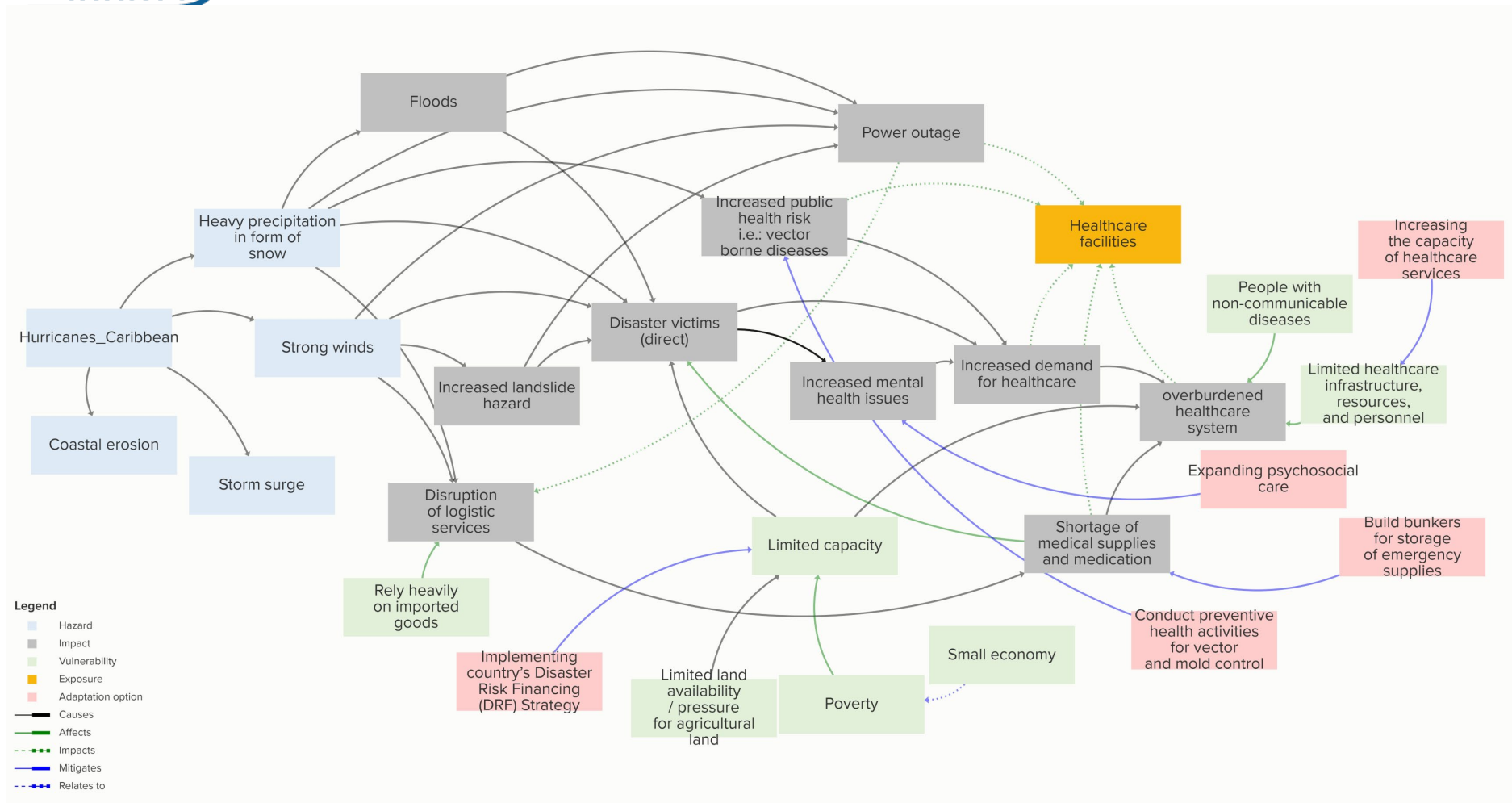


Figure 5.11 Impact Chains for hurricanes and the health sector

While the initial Impact Chains covered the cascading nature of hazards and the impacts, there was not an extensive coverage of the vulnerability, exposure and underlying risk drivers. The adaptation options while proposed were also not complete and not directly addressing the impacts or vulnerabilities highlighted in the ICs. Aside from the incomplete coverage of the elements, the connections between the different elements was in most cases not clear. The descriptions for each element and the literature sources also needed to be included as this description provides the context for users of the Impact Chains.

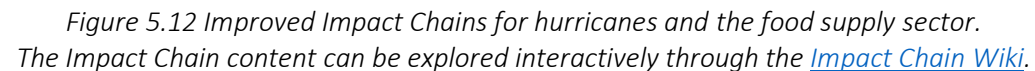
Improvement of the Impact Chains for Sint Maarten has focused on hurricanes as the main hazard and hurricane impacts on the food supply/logistics and health sector. Although Saba and St. Eustasius were considered in the initial geographical scope, the improvements and the descriptions of elements have been limited to Sint Maarten as information was available for Sint Maarten in comparison to the other two Islands. In addition to the limited information on Saba and St. Eustasius, the impact of hurricane Irma which informs the narrative constructed was significantly worse in Sint Maarten, whilst the two other islands were mostly affected due to the dependency on Sint Maarten.

The improvement of the Impact Chains has mainly been done with the use of desktop analysis. Following Irma, a lot of studies were conducted by government, international organizations and research institutions on the magnitude of the hazard, the impact of the hurricane assessed through the post-damage assessment studies as well as the recovery and resilience studies which were used to inform the national recovery plan. The culmination of the different studies has allowed for drawing insights useful to complement the stakeholder workshop input used for the development of the initial Impact Chains. The confidence and relevance for the various elements has also been informed by the source of the evidence, with scientific papers, official government reports considered as providing more robust evidence (relevance and confidence ranging between 4-5).

The focus on the improvement has been to add more vulnerability, exposure and underlying risk drivers which provides more context and a better understanding of the factors that influence coping capacity and long-term resilience to hazards. For Sint Maarten, vulnerability aspects of lack of effective building codes, limited urban planning, poor road networks, population density and high migrant population need to be considered as factors that contribute towards the overall physical, socio-cultural and institutional vulnerability of the island. In improving the Impact Chains, these vulnerability elements have been described in order to build further context for Sint Maarten in general, and with a particular focus the susceptibility of the Island to the impact of hurricane Irma.

Exposure elements such as Sint Maarten having a mono-economy, the location of the island within the hurricane belt which results in the exposure of critical infrastructure, people living in high risk areas and the growth of informal settlements have also been added to the improved Impact Chains to show the different ways in which people, infrastructure and housing are located in hazard-prone areas.

Underlying risk drivers which include the geographic location and the small size of the island, the dependency on imports and poverty have been integrated into the Impact Chains as crucial factors that influence the level of disaster risk in Sint Maarten by increasing the levels of vulnerability and exposure or reducing coping capacity. Figure 5.12. shows the improved Impact Chains for hurricanes and the food supply sector with additional elements on vulnerability, underlying risk drivers and exposure. The adaptation options which are also improved highlight the recovery and resilience plans put in place by the Government of Sint Maarten as part of the process of recovery and building long term resilience after hurricane Irma and Maria.



6 Vrancea earthquake, 1977

6.1 Forensic Analysis

Hazard analysis

Romania is a country that can be significantly affected by earthquakes originating in (Figure 6.1):

- the Vrancea Source at the curvature of the Carpathian Mountains. Here, earthquakes with magnitudes up to 7.9 Mw occur at intermediate-depths (typically between 60 – 180 km) and generate significant ground-motion shaking on more than half of Romania's territory. According to statistics, earthquakes with Mw > 7 occur here 2-5 times per century. Among the cities in Romania, Bucharest holds the greatest potential to be affected by earthquakes originating in Vrancea. The most damaging earthquakes occurred in 1738, 1802, 1829, 1839, 1940, and 1977.
- other crustal sources across the country, such as Făgăraș-Câmpulung, Gorj, Banat, Crișana-Maramureș, Bârlad Depression, North Dobrogea or Shabla or Dulovo in north-eastern Bulgaria. Moderate or major earthquakes from these sources generally do not occur very often (1-2 per century).

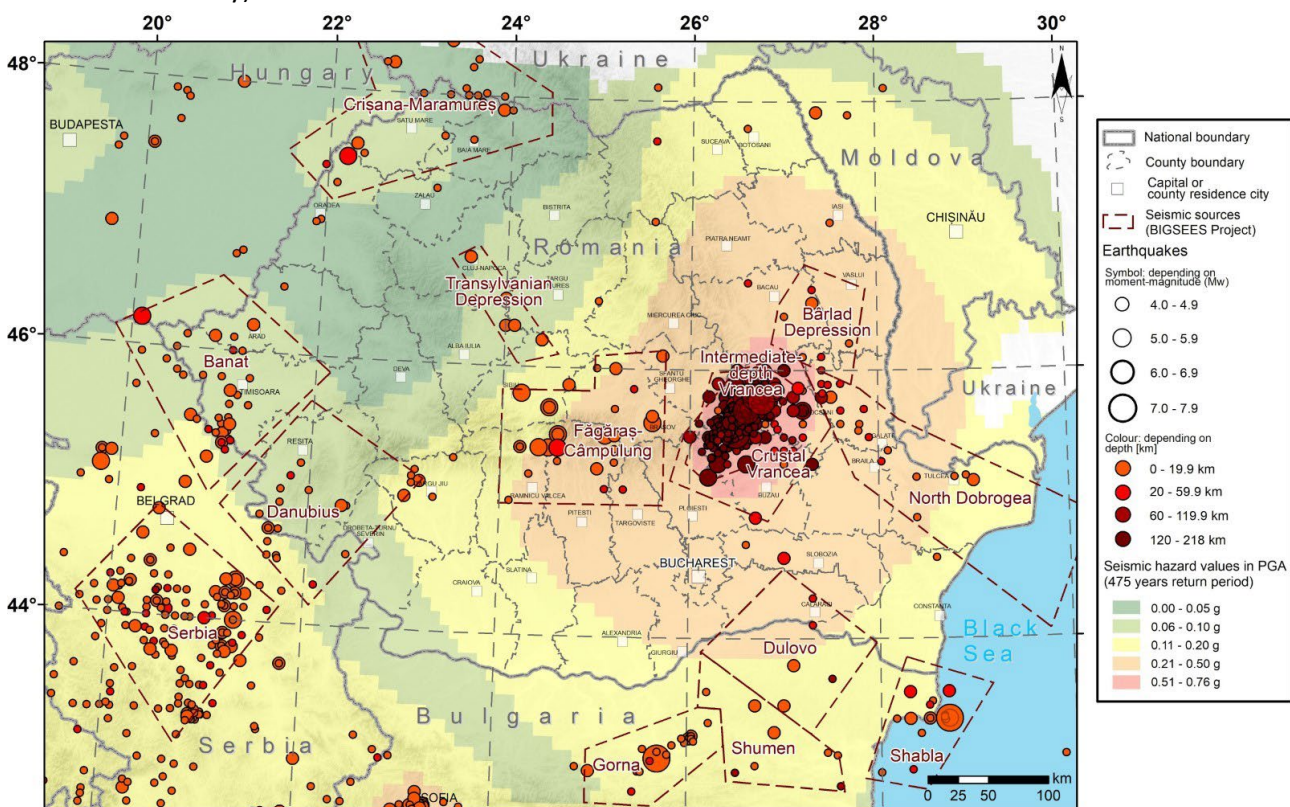


Figure 6.1 Map of earthquakes in Romania, seismic sources and seismic hazard values in PGA (475 years return period, according to the European Seismic Hazard Model, 2020)

On the 4th of March 1977, at 21:21 local time, an earthquake of 7.4 Mw and a focal depth of 94 km occurred in the Vrancea Source. The sole full recording of the earthquake, obtained in Bucharest at the INCERC free-field station, showed a duration of approximately one minute and a maximum peak-ground acceleration (PGA) of 0.2 g, but also high spectral acceleration values in the 1.2 - 1.5 s domain (Figure 6.2). The values of these parameters partially explained why so many high-rise or moderate-rise buildings were affected by the seismic hazard. During the earthquake, the seismic stations across the country broke down, except for the SMAC-B accelerometer that was installed at the URBAN-INCERC station in the Pantelimon neighborhood (Pantea and Constantin, 2013).

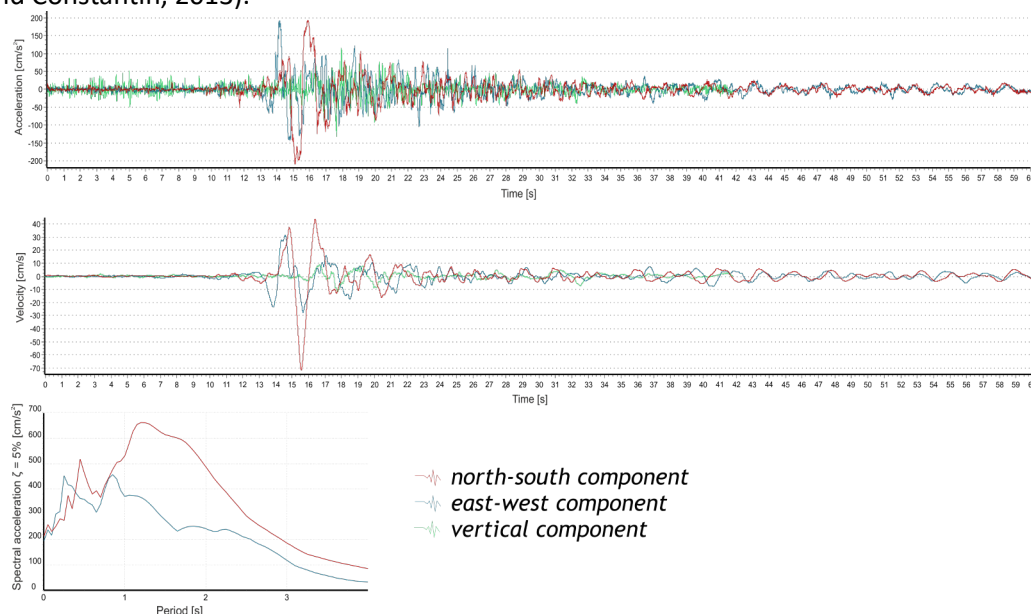


Figure 6.2 The accelerogram and response spectrum of the 1977 earthquake, recorded at the INCERC station in Bucharest

Analysing the impact of this earthquake across the cities in Romania, Bucharest ranks at the top of the list (Balan et al., 1982; Pantea and Constantin, 2013). The human toll raised to 1,424 casualties (accounting for 90% of the deaths recorded at the national level), 7,598 injured people (accounting for 67% of the injuries recorded at the national level), and 1,500 hospitalization cases (Balan et al., 1982). In Bucharest, over 10,000 people were found trapped under debris from collapsed buildings (Pantea and Constantin, 2013).

The earthquake caused the partial or total collapse of 32 high- or moderate-rise buildings (Balan et al., 1982) – although other sources mention more than 33 collapsed buildings (Pantea and Constantin, 2013). Most of them were constructed before the 1940 earthquake (7.6-7.7 MW) and three of them were constructed in 1962-1974 (having 10 and 11 storeys and a concrete shear wall structure) (Georgescu and Pomonis, 2012). Nineteen of the collapsed buildings had 7 to 14 storeys and were particularly vulnerable due to their reinforced concrete frames which can sustain only gravity loads. The pancake collapse mechanism was specific to buildings constructed before 1940, while shear-wall failure and soft-storey failure pertain to low-code buildings with lower levels of volume loss (Georgescu and Pomonis, 2012). Hundreds of thousands of other buildings were also moderately or severely damaged, including churches, public buildings (e.g., the Ministry of Metallurgy, Faculty of Chemistry, and the Computer Centre) (Georgescu

and Pomonis, 2012), and industrial units (producers of rayon fabrics and machine tools) (World Bank, 1978). Among the landmark buildings impacted by the earthquake, Pantea and Constantin (2013) mention the Telephone Palace, the Palace of Justice, the Faculty of Medicine, City Hall, the Romanian Railways Palace, and the Museum of History. The larger part of the buildings damaged by the earthquake to different extents cluster in the center of the capital, as shown in Figure 4. The historical center that stands out today in terms of high physical and social vulnerability levels (Armaş, 2008) was severely affected even in 1977, especially around Calea Victoriei, Magheru Boulevard, Calea Moşilor, as indicated by Pantea and Constantin (2013). Additional damage was caused by cascading hazards triggered by the powerful earthquake, namely fires that occurred especially at the collapsed buildings (Georgescu and Pomonis, 2012).

Other notable tangible impacts refer to the damage to buildings hosting key emergency services, such as hospital buildings. Floreasca Emergency Hospital and Colentina Clinical Hospital were particularly affected, as their buildings partially collapsed, and patients had to be relocated to other medical units in the short term. Industrial buildings were also impacted, as the roof of the thermoelectric Bucharest West plant collapsed. At this industrial unit, the personnel prevented an explosion that could have resulted from pressure accumulation (Buhoiu, 1977).

The reported economic loss reached 2 billion dollars at the national level (which would represent 9 billion dollars nowadays), with 70% recorded in Bucharest (World Bank, 1978; Balan et al., 1982). The World Bank report (1978) intended to propose a loan for post-earthquake reconstruction noted that “the damage left thousands of families homeless and destroyed US\$95 million worth of the population’s possessions” across the country, with most of this loss being recorded in Bucharest.

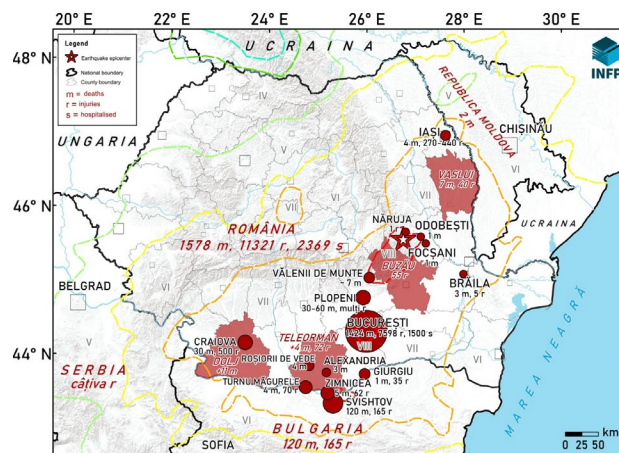


Figure 6.3 Distribution of casualties and intensity values in Romania, for the 1977 Vrancea earthquake (source: INFP, 2022; lines for intensity are based on Kronrod et al., 2013)

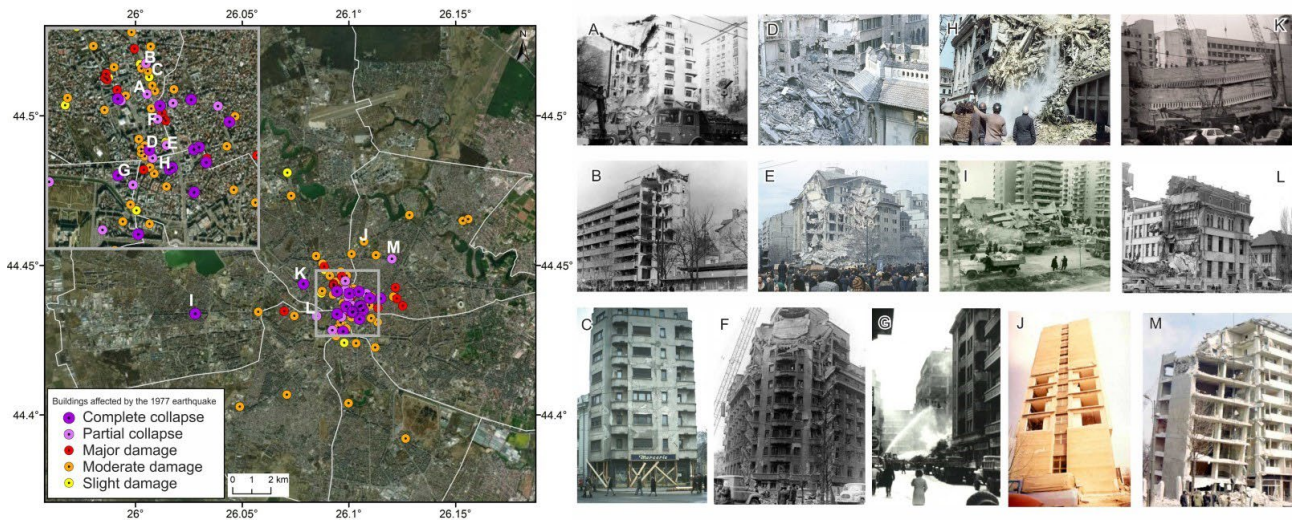


Figure 6.4 Map of buildings in Bucharest affected by the 1977 earthquake and photo examples. A web-GIS map is available [here](#) (INFP, 2024).

Vulnerability analysis

The impacts outlined in the preceding section are not solely the result of the earthquake but also stem from vulnerabilities of a physical, social, and even political nature. These vulnerabilities persisted over time and are still relevant today, holding significant implications for the effects of a future earthquake similar to the one in 1977.

Among the physical vulnerabilities, the absence of seismic design specific to the buildings constructed during the interwar period stands out as a crucial factor that contributed to the collapse or damage of the buildings in Bucharest. In Romania, seismic design regulations first appeared in 1941 and 1945, driven by the destruction caused by the 1940 earthquake. These regulations were not able to produce real changes in the security of the building stock in Bucharest, considering the damage caused by the Second World War and the economic depression that followed. The first compulsory design code was issued in 1963 (and it was revised in 1970), but it did not account for the particularities of the Vrancea intermediate-depth earthquakes. Such details were unknown at that time, due to the lack of full seismic recordings of earthquakes. It was only after two decades, that scientists learned that the earthquakes that affect Bucharest and originate in Vrancea present long predominant periods (in part due to local site effects), which is highly detrimental for high-rise buildings lacking an adapted design.

Another physical vulnerability refers to the types of buildings existing in Bucharest at the time of the earthquake (and even today): load-bearing masonry buildings with a low-level profile and wooden boards (constructed before 1940), and multi-storey buildings (with up to 10 storeys) having reinforced concrete structures (built after 1953) (Lupan 1982). In 1977, these configurations proved particularly vulnerable to the Vrancea earthquake, as many of the buildings constructed between the two World Wars having the above-mentioned structural design were severely damaged. Nowadays, the legacy of several of these historical buildings persists and continues to represent a source of danger for their inhabitants and nearby buildings.

A special type of vulnerability is related to the fact that the described physical vulnerabilities were inherited from the past and that their influence was witnessed during the 1940 earthquake, yet no significant efforts for seismic risk reduction were deployed to prevent similar consequences. The 1940 earthquake resulted in the collapse of one high-rise reinforced concrete building (the Carlton Hotel, Figure 5) and many more high-rise buildings were severely damaged. These buildings were not subsequently retrofitted (Beles, 1941), which contributed to their collapse in 1977 (examples include the Belvedere, Casata, and Wilson buildings). In technical terms, this is explained by Pantea and Constantin (2013) as “The number and variety of the elements exposed to the seismic action of the March 4, 1977, earthquake also emphasized the remanent effect caused by the overloading of the resistance structures from previous earthquakes, and especially from that of the 1940 Vrancea earthquake, which thus increased their vulnerability.”. In part, the diluted retrofitting efforts following the 1940 earthquake can be attributed to the conditions during the Second World War (Pantea and Constantin, 2013), when such initiatives were deemed pointless by the looming threat of bombings.

A noteworthy social vulnerability relates to the overcrowding of the available habitable spaces due to a substantial demographic increase stemming from the development of industry during the beginning of the communist era. Prioritising economic growth over safety and comfort, the socialist regime accommodated a large number of people in new residential buildings raised following questionable construction practices. This focus on economic advancement led to the neglect of retrofitting and rehabilitation of existing buildings, setting up the premises for the disaster caused by the 1977 earthquake that acted upon the physical vulnerability. This translated into a larger number of earthquake victims, as stated by Georgescu and Pomonis (2012): “The number of casualties increased in 1977 vs. 1940 because of existing pre-1940 high-rise and pre-1977 high-rise low ductility reinforced concrete buildings. Ratios of injured to killed in overall casualties was close to 2 in 1940 and over 7 in 1977”. All of the vulnerabilities specific to the moment of the 1977 earthquake stem from historical neglect and inadequate adaptation measures, directly correlating with the present-day high level of physical vulnerability of the building stock in Bucharest and also with the low level of knowledge, awareness, and preparedness (regarding seismic risk) among the population (Armaş, 2006, 2008; PARATUS Report D6.3, 2024). The situation is particularly alarming for the areas where high building vulnerability overlaps high social vulnerability, such as the city centre (Armaş et al., 2017). This ongoing nature of vulnerabilities results from failures to implement sufficient and effective mitigation measures following the hazardous event under analysis, as elaborated in the following section.



Figure 6.5 Carlton building in central Bucharest: before and after the 1940 earthquake. The building had been finished only 4 years before the earthquake

Recovery analysis

In terms of immediate response, many first responders and people promptly took action. Initially, central coordination was hesitant, mainly due to the absence from the country of the Romanian communist ruler, Nicolae Ceaușescu; which complicated the appointment of clear commands. In a few hours, military forces were mobilized to aid in search and rescue efforts, which represented a priority. Police forces also worked side-by-side with citizens and military personnel during this phase. The shortage of emergency intervention resources emerged as a prominent vulnerability, which was amended by requesting and supplementing the number of specialized first responders and even rescue-trained dogs from nearby counties. Another urgent task was to extinguish the fires started at certain collapsed buildings (e.g., Belvedere, Galati 33 buildings).

In the recovery period, several hospitals had problems with electricity, water, or heat supply, especially during the night of the earthquake, as noted by Buhoiu (1977) and shown in the videos of the aftermath. Medical supplies became scarce and people were called in to donate blood, prompting a positive response from the population. This was particularly important, given the large number of people found under debris (over 10,000, as reported by Pantea and Constantin, 2013).

Nicolae Ceaușescu, who was in Nigeria at the time of the earthquake, returned to Romania the morning after the event. Upon his arrival, he went straight to the most affected areas in Bucharest to assess the situation and convey the message that saving lives was a top priority for the moment. Also, on the 5th of March 1977, the State of necessity was issued through Decree no. 58/1977. In addition to search and rescue operations, significant resources and efforts were invested in the restoration of communication networks, and the functionality of the industrial sector. The World Bank report (1978) notes that interministerial and inter-agency central commission coordinated these first response efforts deployed in the most affected areas of Bucharest on short term (during the first week). Later on, the responsibility was decentralized and assigned to the chairman of the People's Council in each district and to the mayor of Bucharest, while the individual construction enterprises were put in charge of debris clearance (World Bank, 1978).

After 10-12 days since the event (which was not followed by significant magnitude after-shocks), search and rescue operations were halted, and attention shifted to the reparation and evaluation of vulnerable buildings. The context of the massive destruction caused by the earthquake was viewed as an opportunity to take another direction in urban development by communist authorities, at significant costs and disruption to habitation. Evaluation and retrofitting works were conducted at a large scale in Bucharest during the first six months, but Nicolae Ceausescu ordered an abrupt stop of serious interventions aimed at reducing seismic risk. This resulted in the perpetuation of the vulnerable state of numerous buildings, which is reflected in the post-communist technical assessments of the building stock in the capital city and the list of buildings with high seismic risk. In the long term, throughout the 1980s, a large part of central Bucharest was demolished to make room for the construction of a new city center and the emblem of communist power, namely the immense People's House building (currently known as the House of Parliament).

To support recovery, financial aid was requested from the international community, which was granted by both western and eastern countries. In various sources (Hodor, 2017), it is noted that the financial support was not entirely used for the post-earthquake recovery. An additional funding source was the "Omenia" fund, supported by the population, who was called in to donate for recovery efforts in the first 10 months

following the earthquake. This measure was met with disapproval by Romanians, adding to the list of criticized measures implemented during the communist period.

These recovery efforts paint a picture of conventional measures taken to restore the structure and functionality of the urban system following a major earthquake, lacking integration of adaptations aimed at enhancing future preparedness. The approach to hazard management heavily relies on reactive measures and follows the singular direction of reconstruction, which is performed not only overlooking, but bluntly discarding community needs. This results in the perpetuation of both physical and social vulnerabilities over time, which sets grim perspectives for the potential impact of earthquakes on present-day Bucharest, calling for urgent attention and more consistent mitigation efforts.

The earthquake of 1977 represents one of the most impactful hazards that affected Romania in modern times, and it is still remembered by the people as one of the most frightening natural events in their lives. When it comes to building resilience, the disruption produced by the earthquake translated into advancements in seismic design regulations, but more substantial and effective risk management measures (e.g., progression seismology as a scientific discipline and at the institutional level alongside the development of seismic network, improvement of the legal framework, investments in technology, bolstering first response, investments in educational and awareness-raising programmes) have only begun to be implemented since 2010-2020, at more than four decades since the event. This means that the decision-makers and other stakeholders in Bucharest and across the country still work on building resilience, which proved to be a time-consuming endeavor.

In the aftermath of the earthquake, the seismic design codes were thoroughly revised starting in 1978 and then in 1981, 1991, 1992, 2006, and 2013. These revisions relied on new scientific results in the field of seismology, acquired due to technological advancements: the full accelerogram obtained during the earthquake, and later on, more consistent seismic datasets from the less damaging 1986 and 1990 Vrancea earthquakes (MW 7.1, respectively 6.9 MW). The investments in research focusing on the construction sector also supported the development of seismic design codes that are increasingly capable of enhancing the resilience of buildings and infrastructure to withstand earthquakes.

Other technological improvements were made in the seismic network across Romania, which is nowadays administered by the National Institute of Earth Physics (INFP). The Romanian Seismic Network is one of the largest in Europe, with more than 170 locations and modern seismic equipment. The INFP is also a regional EIDA node for seismic data, and its products (e.g., Rapid Earthquake Early Warning, ShakeMaps, rapid loss estimation maps, felt reports) can significantly contribute to improved reaction and preparedness, and support policymaking.

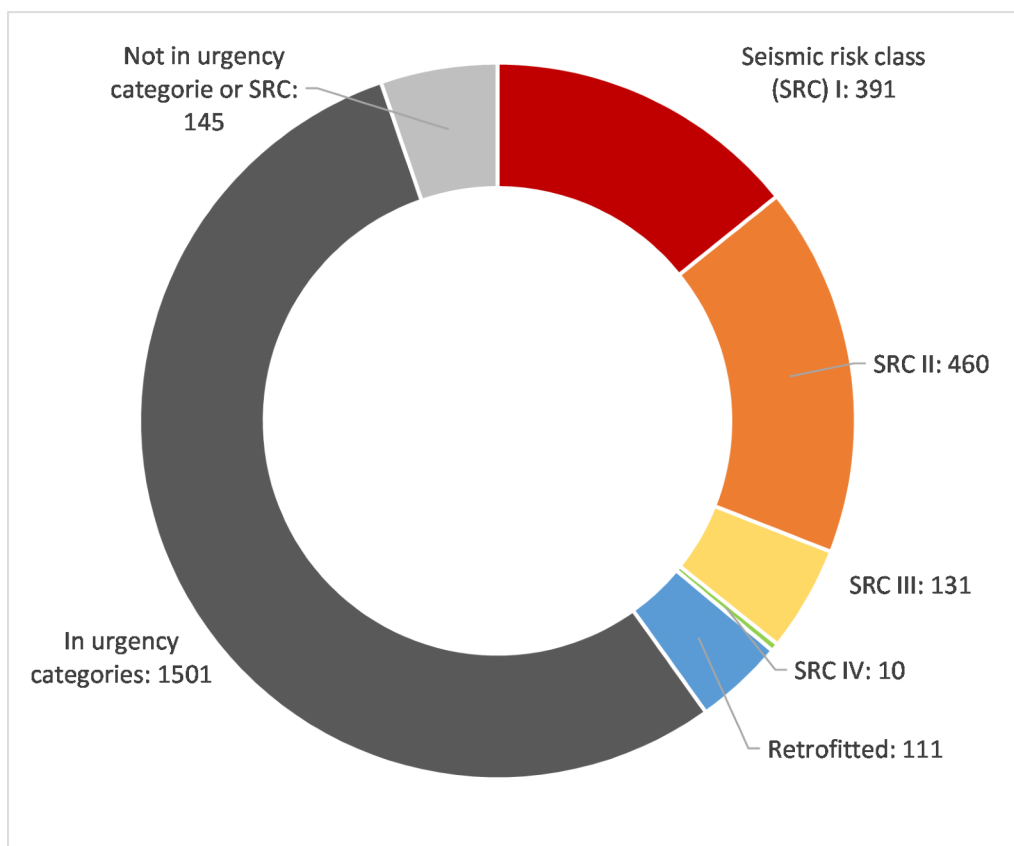


Figure 6.6 Number of buildings in Bucharest individually evaluated and classified in Seismic Risk Classes or Urgency Categories (previous regulations)

Following the transition from the communist to the democratic regime, the legal framework that has been regulating seismic risk reduction in Romania was difficult to follow (PARATUS Report D6.3, 2024) and did not produce the desired results. For example, many buildings were technically evaluated and classified per urgency or seismic risk class, but very few were actually retrofitted. This ineffectiveness can be traced back to the cumbersome provisions that coordinated the access to the (limited) funding allocated to retrofitting, but also to the lenient sanctions applied when citizens or even authorities failed to comply with the law. According to official data (Municipal Administration for the retrofitting of buildings with seismic risk, 2024), there are about 400 buildings in Bucharest that were assigned the first seismic risk class (most vulnerable). Nevertheless, there are many more buildings that have not been technically evaluated and represent major hidden sources of danger. As highlighted by the Ro-Risk Project (2017), the seismic risk of Bucharest is of a very high level, meaning that the numbers pertaining to the buildings that might be significantly affected by an earthquake, potential casualties, and economic losses are also very large. The Plan for Analysis and Coverage of Risks for Bucharest (PAAR, 2022) provides an estimate of 23,000 buildings with severe damage, 1,000 buildings with partial or complete collapse, 95,000 people trapped in affected buildings (out of which 54% in high-rise buildings), and 6,500 deaths for a night-time Vrancea earthquake scenario. For a day-time earthquake, a reduction of 54% of the affected people is estimated.

Since 2022, the legal framework regulating seismic risk reduction has been decluttered, and the new normative acts facilitated its comprehension and application. By Law no. 212/2022, the retrofitting efforts target the buildings constructed before 1963 (which represents an expansion of the initial aim). This normative act sets tasks and deadlines for the managers of educational and public institutions to contract technical evaluations of the buildings that host the institutions in question, as well as action points for local authorities of both urban and rural settlements. It also established a National Programme to consolidate the buildings with high seismic risk, which is more focused and better regulated compared to previous versions, also ensuring improved financial support through Government Ordinance no. 6/2023 and Law no. 243/2023.

Other regulations of technical or legislative nature contribute to the overall progress, with promising prospects:

- 2019: revision of the code for seismic evaluation of existing buildings (P100-3)
- 2021: National Conception for Post-Earthquake Intervention
- 2022: Law 212 from regarding measures for seismic risk reduction of buildings, with important amendments in 2023 regarding how many apartment owners are needed for the building to enter retrofitting and if businesses can take place in seismic risk class I buildings
- 2022: National Strategy for Seismic Risk Reduction
- 2022: Rules for the rapid visual inspection of buildings -> accelerated procedure for hospitals and schools
- 2023: Regulation regarding an emergency determined by an earthquake (Ministry of Development + Ministry of Internal Affairs)
- 2024: new seismic design code with different return period (475 years, corresponding to Eurocode 8) (P100-1)



Figure 6.7 The Seismic Risk of Bucharest web-GIS map, which shows the footprint of buildings with high seismic risk levels and areas which might become difficult to reach in case of vulnerable building collapse (source: [INFP, 2024](#))

Another path to building resilience follows the investments in first response capabilities. These take the form of purchasing new equipment, particularly valuable in emergency interventions pertaining to multi-hazard situations that are becoming more and more frequent. This is complemented by the setting of international cooperation mechanisms that lay the groundwork for substantial assistance – which Romanian teams of first responders also provided in various events such as the 2023 Turkey earthquake, gaining practical experience.

Another concerning vulnerability that began to be addressed in recent years, frequently exemplified based on the outcomes of the 1977 earthquake, is the low level of knowledge, awareness, and preparedness of the population when it comes to earthquakes and seismic risk (Armaş, 2006; PARATUS Report D6.3, 2024). One overarching proxy for this situation is the low insurance coverage in Romania. Although compulsory insurance for natural disasters was enforced in 2008, only 1 out of 5 homes aligned with this preparedness measure at the national level, and for Bucharest the percentage of insured households out of the total is 38.9% (PAID, 2024). Nevertheless, both authorities and NGOs are more and more engaged in instructing and preparing people to cope with earthquakes and their impacts, with an ever-increasing list (Figure 6.8): the Mobile Earthquake Exhibition of INFP, the earthquake simulator at Destiny Park in Bucharest, the “I don’t shake during an earthquake” campaign developed by the Inspectorate for Emergency Situations. Despite these efforts, the overall level of population preparedness and resilience is still low, although many acknowledge that they are afraid of an earthquake and its effects.

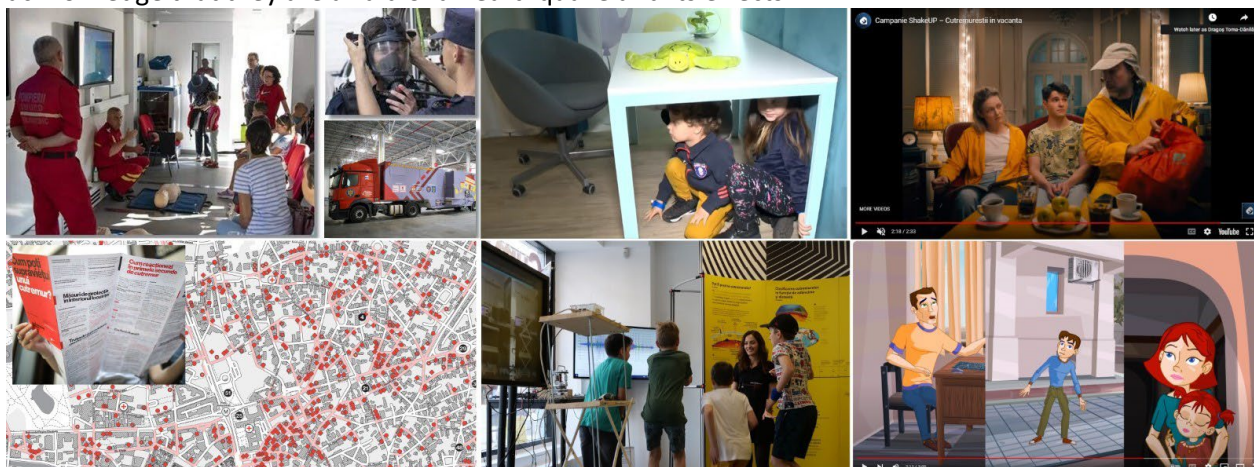


Figure 6.8 Examples of recent earthquake preparedness campaigns and products: a) earthquake, fire and first aid mobile center of the Inspectorate for Emergency Situations; b) map of vulnerable buildings individually evaluated in Bucharest and brochure regarding earthquake preparedness, made by NGOs in the Seismic District Project; c) the earthquake simulator at Destiny Park in Bucharest; d) the Mobile Earthquake Exhibition of INFP, with non-formal activities; e) the earthquake preparedness video of the Shake Up campaign; f) earthquake preparedness from the “I don’t shake during an earthquake” campaign of the Inspectorate for Emergency Situations

6.2 Impact Chain (incl. improvement of previous IC)

The Forensic Analysis and the construction of the Impact Chain are two core elements of the PARATUS Project that mutually reinforce each other’s development. The Forensic Analysis and the construction of the Impact Chain are two core elements of the PARATUS Project that mutually reinforce each other’s development.



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Together, these methods provide a comprehensive view of the 1977 Vrancea earthquake (i.e., hazard), its effects in Bucharest (i.e., impacts), as well as an in-depth understanding of the more subtle factors that contributed to this disaster (i.e., vulnerabilities) and the specific Disaster Risk Management approach (i.e., adaptation options).

Due to thorough initial documentation, no additional elements needed to be included in the Impact Chain after completing the Forensic Analysis. Nevertheless, the analysis aided in the correction of several connections established among the elements of the Impact Chain. To conduct the Forensic Analysis, we extended the pool of studied sources, adding more scientific papers about the earthquake itself and its aftermath, as well as about the current physical and socio-economic vulnerabilities rooted in the communist past. This supplementary documentation resulted in an update of the source types and references used to build the Impact Chain. Moreover, the descriptions of both elements and connections in the chain were filled in with details extracted from the Forensic Analysis.

These improvements made to the Impact Chain prove that the Forensic Analysis benefited the overall inquiry into the impact of the 1977 Vrancea earthquake in the capital of Romania. Therefore, the two methods worked in synergy, streamlining the organisation and the visual coherence of the information. The Forensic Analysis and Impact Chain are complementary in nature, each enhancing the other's effectiveness in facilitating decision-making grounded in science.

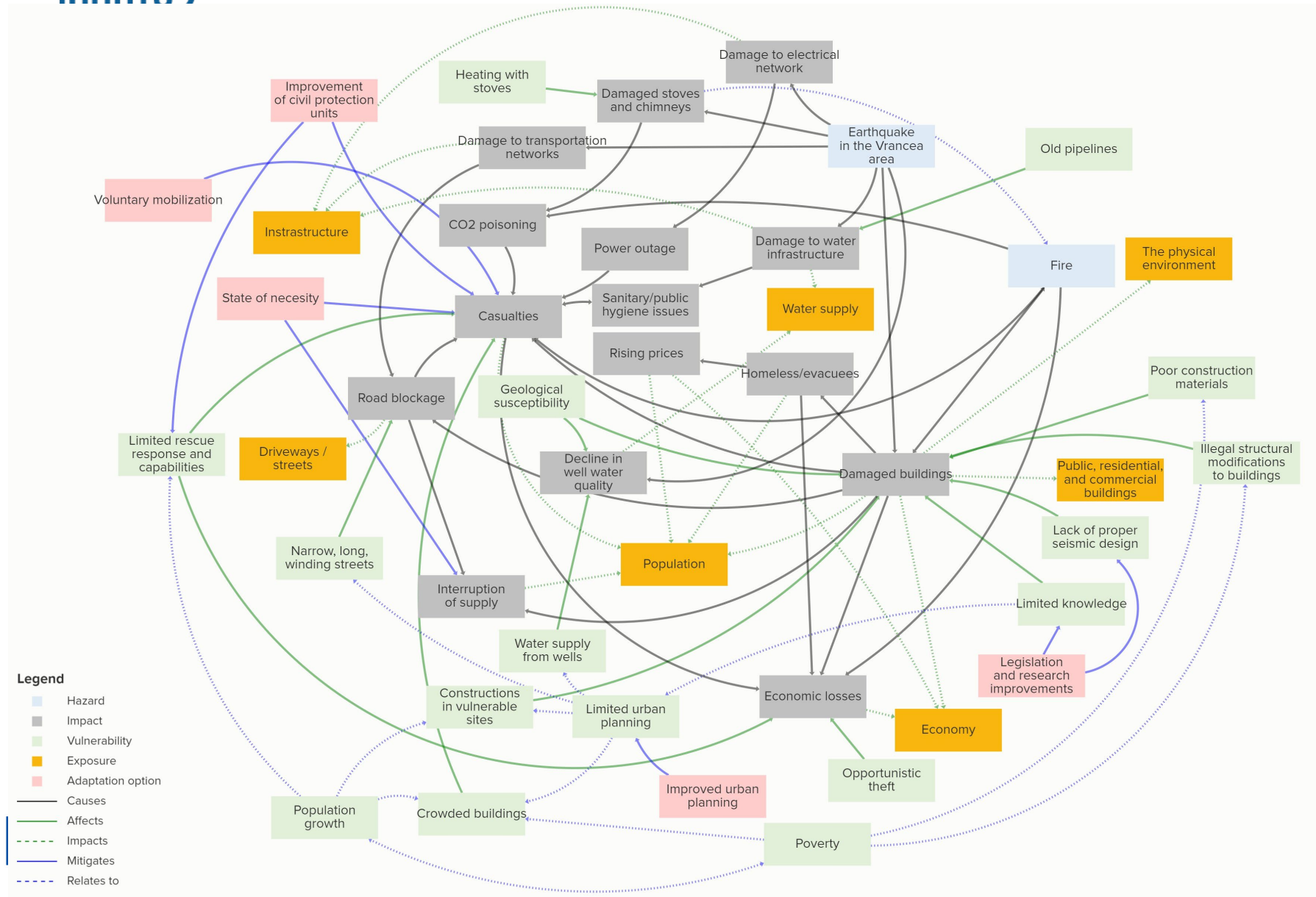


Figure 6.9 Improved IC for the 1977 Vrancea earthquake impact on Bucharest, based on the results of the Forensic Analysis. The Impact Chain content can be explored interactively through the [Impact Chain Wiki](#).

7 Landslides observatory

7.1 Forensic Analysis

The scope of this Forensic Analysis is dealing with *Landslide Observatory Lower Austria*, from now on referred to as LOLA. This setting is somewhat unique as we are dealing with a set of three different study sites in Lower Austria which are analyzed under the umbrella of LOLA, particularly investigating long-term slow-moving landslide processes. This means that we will bring together experiences and knowledge from the different sites, not necessarily analyzing one particular event. Due to the nature of slow moving landslides catastrophic events are rare (one exception is Hofermühle 2013) and partly not well documented. The focus here is on the process understanding and the analysis of impacts which are rather small but happen continuously since many decades. Hence, low magnitude, high frequency events can in the long run be of high importance for these study sites.

Hazard analysis

The main hazard which will be focused on is landslides. Landslides represent one of the most important natural hazards worldwide. They can be triggered by different factors and can have wide-ranging negative impacts on humans and their assets in different sectors and the landscape (Glade & Crozier 2005).

The geographical scope of the Forensic Analysis is Austria, in particular the state of Lower Austria. This region covers a total area of approximately 19.000 km², in north-eastern Austria (*Figure 7.1a*). The three landslide observatories under investigation introduced are namely Hofermühle, Gresten and Brandstatt (*Figure 7.1b-d*). These sites are comparable in terms of natural setting (geological and climatic conditions), land use and anthropogenic influences, such as drainage systems. However, they show distinct site-specific differences in the number of landslide subsystems, spatial extent and dynamics (Marr et al. 2023).



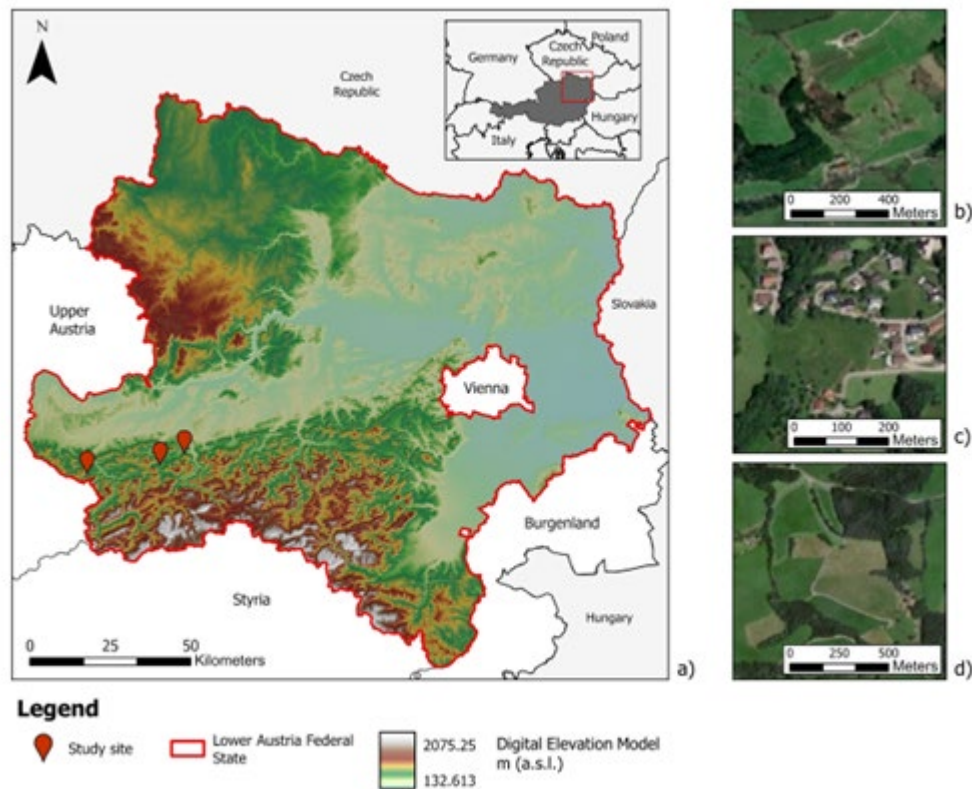


Figure 7.1 Location of the landslide observatories and areas of investigation in Lower Austria. (a) Location of the Lower Austria federal state, in north-eastern Austria. Relief shading in is based on the Austrian 10 m DEM [43]; (b)-(d) Location of the (b) Hofermühle, (c) Gresten), and (d) Brandstatt observatory, respectively. Satellite images of the landslide sites provided in the ArcGIS Pro 3.0.0 software using World Imagery (Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community), Marr et al. 2023.

The sites are located in a complex geological setting which represents the most important predisposing factor driving the landslides occurrence and activity in the region (Petschko et al. 2013, Stumvoll et al. 2019, Thenius 1974). Most of the complex, hydrologically triggered slope instabilities described in the previous studies in Lower Austria are predominantly located in the Flysch Zone, the Klippen Zone and the Austroalpine Northern Calcareous Alps. Due to the high content of clay minerals and the corresponding weathering products, the geo-mechanical behaviour of these lithological units prompts this area to landslide processes (Petschko et al 2013, Stumvoll et al. 2019). Actually, of the 1100 landslides registered in Lower Austria from 1965 until 2006, 62% were reported in the Flysch Zone (42%) and Klippen Zone (20%) (Gottschling 2006).

Climate conditions are driving both the weathering and the triggering mechanisms of slope instabilities affecting the Flysch Zone and Klippen Zone lithologies in the study area. Here, the main triggering factors of landslides activity include long lasting heavy rainfall and rapid snow melting (Schweigl & Hervás 2003). The study area is located in the NE Alpine foreland and it is characterized by a warm temperature and humid climate. Long-term precipitation time series are available from the Histalp project (www.zamg.ac.at/histalp) in order to assess patterns and trends within the European Alps. However, since the snow height has not been continuously monitored over time, insights from the contribution snow-melting from the past cannot

be proved, but its influence is reported (Schweigl & Hervás 2003). The mean annual precipitation rate is approximately 1197 mm/yr (period 1896-2021; data obtained from Histalp project). Although the annual precipitation recorded an alternation across the average value in the recent years, the analysis of rainfall time series exhibits a trend of increased precipitation in the 10-yr average value, especially after 2019 (Figure Figure 7.2a). Monthly mean precipitation amounts are also reported (Figure 7.2b), in which summer (June to August, 413 mm) is the dominant precipitation season and an increasing trend from March to July is evident. Notable changes have not been found in the analysis of the spring season (March to May) time series, where a fluctuation between the dry and wet seasons occurred (Figure 7.2c). The most interesting and evident changes are shown in the summer season time series (Figure 7.2d), in which dry periods have become dominant since the late eighties. However, an increasing trend in the precipitation amounts was recorded in the period 2002-2009, showing a summer highest sum of 706 mm in 2009.

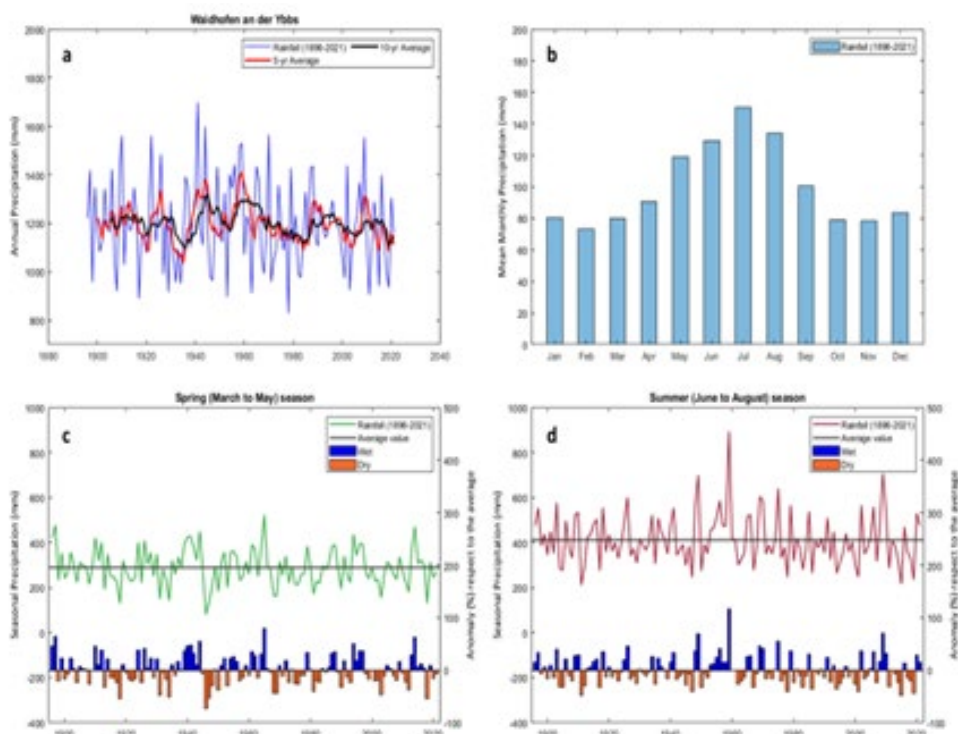


Figure 7.2 Precipitation time series from Waidhofen an der Ybbs meteorological station (Period visualized: 1896-2021, data obtained from Histalp project). (a) Annual precipitation rate is reported, as well as the 5-yr and 10-yr average value; (b) Monthly mean precipitation amounts; (c) Seasonal time series are reported respectively for the spring; (d) summer season and rainfall anomalies respect to the average.

Among the different landslides occurring in Lower Austria, understanding the dynamics of slow-moving landslide is of particular interest (Marr et al. 2023). Complexity and non-uniform spatial as well as temporal kinematics of slow-movements preclude the use of short-term measures to assess landslide processes (Lacroix et al. 2020, Petley et al. 2017). For this reason, it is important to integrate available historical data with long-term, multi-parameter monitoring approaches in order to assess and mitigate the potential landslide hazard (Li et al. 2021, Moradie et al. 2021).

The temporal scope of this contribution is described in the following. Due to the reported historical data and the continuous socio-economic impacts, the three sites in Lower Austria were selected for the implementation of long-term monitoring systems. The installations within the landslide monitoring sites have been initiated in 2014 by the Geomorphological Systems and Risk Research (ENGAGE) working group of the Department of Geography and Regional Research at the University of Vienna (project information: www.noeslide.at). In the initiation phase, this work has been accompanied by the Geological Survey of Lower Austria. The selection of the specific locations for the different instruments is based on previous knowledge of landslide dynamics. The gathered information varies in spatio-temporal resolution, from point measurements with 5-minute intervals, e.g. automatic inclinometers, to areal data obtained on a monthly basis, e.g. terrestrial laser scanning or UAV flights. There are a large variety of surface and subsurface methodological approaches at the different landslide observatories. Beside basic installations which are present at every site (e.g. meteorological station), site specific techniques have been implemented in the respective locations.

The operational framework consists of information by scientific publications, official reports by state authorities, perspectives of stakeholders and experts as well as media coverage.

Short and long term impact analysis

According to Cruden and Varnes (1996) and Dikau et al. (1996) landslides are defined as the movement of rock, debris or earth down a slope. Only in the case that humans and/or anthropogenic structures are negatively affected the event will be considered as a hazard (Varnes 1984). Landslides are dynamic systems that commonly occur on hillslopes and mountainous areas worldwide and are an important agent in landscape evolution (Dai et al. 2002; Glade et al. 2001). These natural phenomena cover a wide range of mechanisms and processes, on different scales, both in space and time (Glade & Crozier 2005). As a result, understanding the evolution over time of slope instabilities represents a difficult task since a combination of different controlling factors could exist. Three important factors have been identified to be critical in the kinematic transition from a stable to an actively unstable slope: (1) preconditioning, (2) preparatory and (3) triggering factors (Glade & Crozier 2005). These factors are dynamic, and the inter-dependencies of natural processes and human activities have influences on the occurrence of landslides (Van Den Eckhaut et al. 2010). Assessing the driving mechanisms that are causing the instability is useful to deepen hazard analysis and determine adaptation and mitigation strategies to lower the vulnerability of the elements at risk.

Here, we focus on slow-moving landslides, gradually moving downslope centimetres to decimeters per year. Therefore, catastrophic failures rarely occur; rather, continuous moving has a steady impact. Slow-moving landslides play an important role in both theoretical slope evolution and practical landslide hazard and risk research (Stumvoll et al. 2021). Slow-moving landslides, in comparison to rapid landslides, present a unique opportunity for natural disaster prevention by setting in place suitable monitoring systems and modelling the mechanics of their movement (Li et al. 2021). Furthermore, landslides with relatively low moving rates offer the possibility to study the involved processes in depth over a longer period with different phases of activity. This helps to correlate movements to specific potential triggering factors, such as precipitation events.

The short-term impacts within the LOLA comprise damages to the road in Brandstatt due to the downward movement of the slope. This can lead to short-term closure of the road until its repair. However, the repair can take up to several days and local residents, as well as service trucks, such as for the collection of milk,



have to use another road. Another short-term impact is the inaccessibility of farmland for agricultural machines, which prevents the farmer from cutting the grass for cattle food production purposes. In case of cattle being on the affected slope, this might lead to a danger to individual cattle due to the uneven ground with possible injuries.

The first response to visible slope deformation will be the quick reconstruction of destroyed elements to keep roads accessible, which can take between hours and days.

Long-term impacts, such as when a whole road is destroyed, agricultural land is disturbed, or the land is generally impacted, can lead to important economic factors.

Vulnerability analysis

Since the focus is on long-term monitoring of slow-moving landslides, with some events in the past such as the Hofermühle landslide in 2013, the following will shed more light on the vulnerabilities associated with slow-moving landslides concerning the LOLA, but also with slope processes.

With regard to physical vulnerabilities, roads, especially aging infrastructure, such as poorly maintained roads are susceptible to erosion and landslide activity and can increase landslide activity. The roads in Brandstatt for example have to be renewed at least one per year as some active areas move several centimeters per year. As this road is being used daily also by heavy trucks (for dairy products) it is a vital physical but also economical vulnerability. This is seen in other areas, where most sliding activity originates along forest pathways (Glade & Crozier 2005). Buildings located at or on slow-moving landslides can be severely damaged or even rendered uninhabitable, as in some cases there is a risk that a slow-moving slide can transform into a rapid landslide (Ref Tirol?). However, these buildings can also weaken the slope itself. The Salcher landslide is located in and surrounded by residential areas where some houses can be described as vulnerable.

Since most landslides occur on agricultural lands, these can be considered as practices that increase the vulnerability to landslides. On the other hand, if landslides and agricultural areas are damaged, this will affect the economic stability of the area.

Usually, the population in the studied side is not under direct threat and may only need to evacuate houses if these areas are damaged in their structural element and not safe. Only in the unlikely case of a deep seated, rapid mobilization of one of the landslides of the LOLA buildings with persons, cars on roads or the roads it itself could be directly threatened.

Looking at environmental vulnerabilities, steep slopes exacerbated by deforestation and improper land management could create the perfect environment for movement. If the slope is close to rivers or other bodies of water, this can increase the risk of landslides.

Socio-cultural vulnerabilities include the displacement of people and the need to change land management practices. These, however, have not been a concern in the studied area. Institutional vulnerabilities may include weak enforcement of land use regulations and inadequate disaster preparedness and response mechanisms. Therefore, risk drivers are unplanned expansion of agricultural activities, deforestation, and land conversion for residential and commercial purposes, which alter natural landscapes and increase vulnerability to slope activation. The underlying causes are primarily natural processes of slope equilibrium,

but are often accelerated by human intervention, such as drainage systems that alter natural hydrological processes, and extensive land use practices such as deforestation and urbanization that disrupt ecosystems and increase the frequency and intensity of these natural slope movement processes.

Recovery analysis

As no severe damages have been reported from the LOLA site, recovery and adaptation mechanisms are mostly concentrated on two pillars. (1) Direct action and rebuilding of damaged infrastructure and (2) intensive monitoring of all three sites.

In the aftermath of the debris flow at Hofermühle in 2013 a dam was build (costs about 1. Mio. Euro) to protect one house located in the path of potential future debris flows (Figure 7.3). Additionally, drainage pipes were build into the slope, further altering the stability and possibly generating new uncertain vulnerabilities for future activations in the gully to the west of the slow moving slide (Figure 7.4).

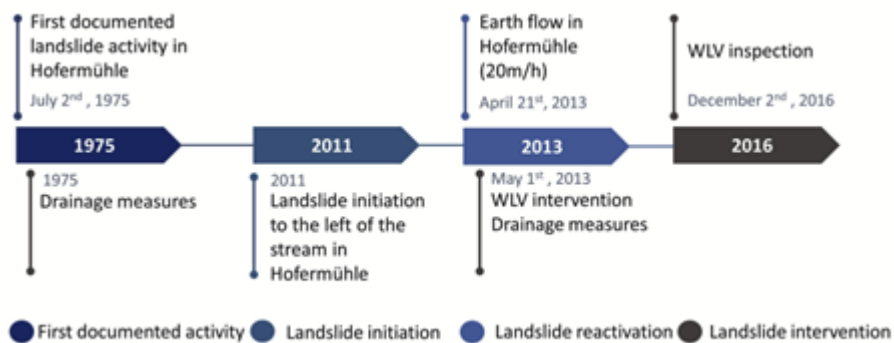


Figure 7.3 Historical information of the landslide activity in Hofermühle, one of the three study sites of the LOLA (Marr et al. 2023)

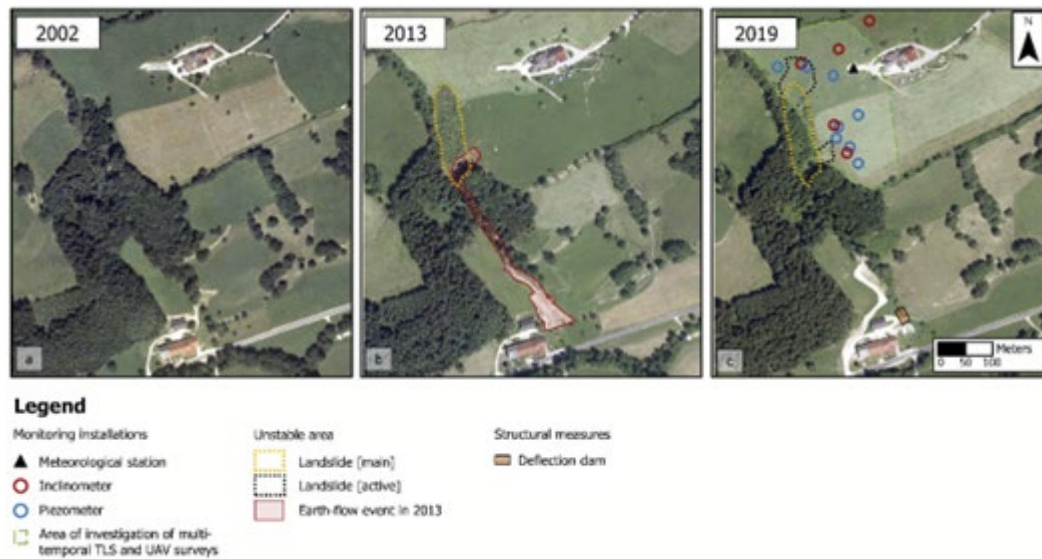


Figure 7.4 Digital orthophoto from (a) 2002, (b) 2013 and (c) 2019 of the Hofermühle landslide. The area affected during the earth-flow event in 2013 is also represented in (b). Main areas of investigations are indicated in (c), as well as simplified morphological features of the landslide activity. Monitoring installations and structural measures to mitigate a possible landslide are visible in (c). Orthophotos are provided by the Federal State Government of Lower Austria (Noel 2002; Noel 2013; Noel 2019) (Marr et al. 2023).

Next to structural implementations the long-term measurement of the slopes in Lower Austria was started, looking at three sites that showed minor movement. Within the NoeSLIDE (<https://www.noeslide.at/index.php/de/>), Core Facility eSurflab (<https://esurflab.at/>) and the MoNEW Project (<https://www.eurac.edu/de/institutes-centers/center-for-climate-change-and-transformation/projects/moneu>), inclinometers measuring the movement rate, TLS laser scanning campaigns, UAV measurements and Geophysical measurements were used to retrieve detailed data on movement processes and triggering factors. To reduce the risk of major slides this monitoring can help finding suitable adaptation measures and it is planned to develop this setting towards an early warning system. In addition, the population, as well as administrative parties, are involved in the project and get regular updates on the behavior of the landslides.

Building resilience for future events

Building resilience for future events requires a multifaceted approach that addresses both immediate needs and long-term strategies. In response to recent events, efforts have been made to improve the recognition of slow-moving processes and landslides as hazards, garnering more national and federal attention and funding for investigations. However, challenges persist, particularly in mitigating physical vulnerabilities such as rebuilding infrastructure in high-risk areas and uncovering historical evidence like the locations of drainage pipes. To reduce future risks and increase resilience, ongoing initiatives focus on comprehensive assessments, proactive measures, and filling crucial knowledge gaps to ensure a more robust understanding of hazards and enhance preparedness for potential future incidents.



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7.2 Impact Chain (incl. improvement of previous IC)

Refining the Impact Chain for the Learning Case Study LOLA using the Forensic Analysis toolset was insightful, though it did not result in major changes to the original Impact Chain. Since LOLA investigates slow-moving landslides rather than singular large disaster events, this case study serves to understand the interaction between processes and impacts.

In the initial draft (D1.1), connections were adjusted, and the vulnerability of vegetation was removed. Instead, farming practices were included as a vulnerability, given their significant contribution to increasing slope susceptibility to movement. However, it's important to note that vegetation, as a general term, is both affected as an exposed asset and serves as an adaptation to enhance slope stability.

The Forensic Analysis highlighted two main components in adaptation measures crucial for these sites. First, short-term structural and technical solutions, such as implementing new drainages and building dams. Second, long-term monitoring to better understand the triggering processes in time and space, moving towards an early warning system capable of capturing thresholds and likelihood of movement. However, due to the complexity of gravitational mass movement, especially after initial sliding, it is not feasible on a local scale to predict when a slope will transition from a stable state to an active stable and unstable state.

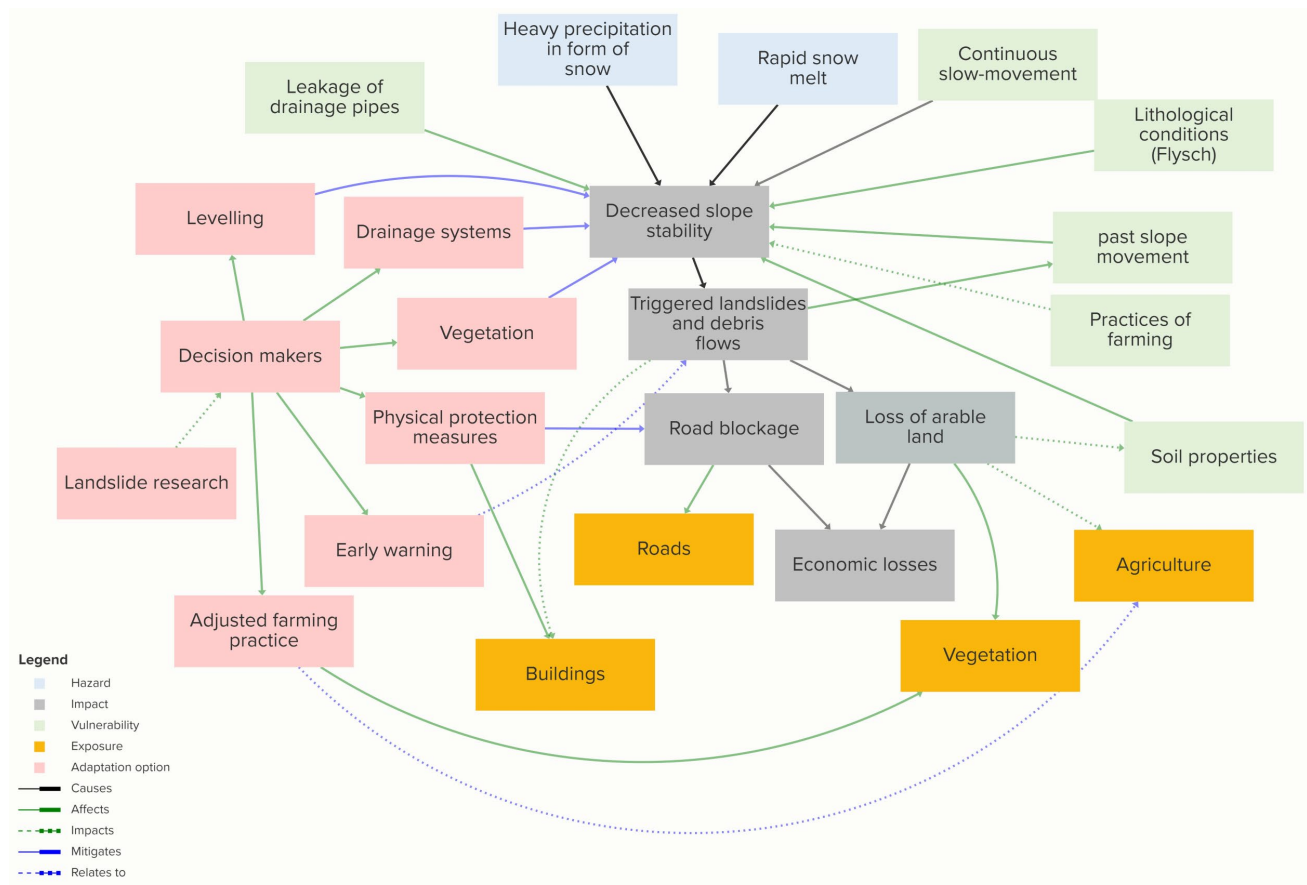


Figure 7.5 Updated Impact Chains for Landslide Observatory Lower Austria. The Impact Chain content can be explored interactively through the [Impact Chain Wiki](#).

8 Vaia windstorm, 2018

8.1 Forensic Analysis

Vaia is the name of the Mediterranean cyclone that developed rapidly over the Tyrrhenian Sea in the end of October 2018, attributed by the Free University of Berlin. However, the name is nowadays used to identify not only the cyclone itself, but also all the hydrological and meteorological events that occurred during those days such as exceptional windstorms, landslides, floods but also waves and storm surges (Giovannini et al., 2021). Vaia Windstorm has affected four out of the seven administrative units situated in the Italian Alpine area, namely Autonomous Province of Bolzano, Autonomous Province of Trento, Veneto and Friuli-Venezia Giulia and more than 500 municipalities (ref.). The storm also transboundary impacts Tirol on the Austrian side.

Due to the data disaggregation and complexity of data collection in multiple administrative areas, we will focus our analysis on the Autonomous Provinces of Bolzano and Trento. Furthermore, this choice is justified by the extensive number of projects run by Eurac Research organization focusing on these two affected provinces.

The triggering event lasted four days from October 27th to 30th October 2023, therefore, for the purpose of the analysis, short term impacts are those occurring as a direct consequence of wind and heavy precipitation such a windthrow and the subsequent road blockage and communication interruption (within hours or weeks). On the other hand, long-term impacts will also include more systemic consequences as well as specific impacts occurring in the following months and years (up to 2023). The goal of this Forensic Analysis is to merge existing data and available information to develop a detailed analysis of the event, from its surge to the recovery phase. Further than understanding the development of the event, the scope of the Forensic Analysis is also to analyse how pre-existing vulnerabilities have influenced the occurrence of impacts. Thus, our analysis will also focus on vulnerabilities of the study area prior to the event. The main sources adopted for the analysis consist of other European project results, scientific papers, technical reports, and PhD theses.

Hazard analysis

The period before the Vaia event was characterized by stable weather. During September and the first weeks of October 2018, precipitation inputs were low; this was also evident from the lower-than-average river flows. At the end of October, the synoptic situation changed dramatically over Europe: a descent of air masses of polar origin to lower latitudes (crossing Great Britain and France) was favored by the presence of two anticyclones centered one over the Atlantic and the other over Eastern Europe. The presence of high pressure in the East also resulted in a "blocking" situation whereby the cold air remained almost stationary, drawing strong southerly winds containing very humid air masses for several days. Under such southerly stau conditions, the southern slope of the Alps was therefore affected by intense and heavy precipitation (Munari et al., 2018).

The hazard event was widely and correctly predicted by the national and regional meteorological services. Alert, emergency and first response phases were managed similarly in both provinces. On 26 October 2018, the Departments of Civil Protection in both provinces assessed a moderate hydrogeological criticality (orange level) for the period from noon on 27/10 to noon on 30/10, and a state of Civil Protection 'Alfa' (attention) was declared. On the 28/10, due to the expected increase in precipitation, the hydrogeological criticality



passed from the moderate (orange) level to high (red) for the period from midnight on 28/10 to midnight on 30/10, and the Civil Protection 'Alfa' (attention) level was confirmed over the entire provincial territory. This was communicated to all concerned stakeholders according to the provisions of the alert system. On 29/10, the state of Civil Protection "Charly" (alarm) was declared throughout the provincial territories. The level of alert dropped to the ordinary level (yellow) only in the late afternoon of 1/11 to cease on 2/11, when the entire provincial territory returned to the state of Civil Protection "Zero" (Provincia Autonoma di Bolzano, 2018).

In particular, the hazard event was structured in two main phases:

- the first phase, between Saturday 27 and Sunday 28 October, was characterized by moist south- and south-westerly winds and heavy rain in the northern Apennines and throughout the Alps, from upper Piedmont to Carnia. The intense southerly winds drove rainfall of unusual intensity up to Comelico (Veneto) and Alto Adige, on the border with Austria. In particular, extraordinary precipitations were recorded in Vipiteno (95 mm) on Sunday 27, and above all in Sappada (299 mm) (Cat Berro, Acordon, and Castellano 2018). The rainfall balance of this first phase shows an average precipitation of about 100 l/m² over the 48-hour period in the province of Bolzano, with higher concentrations between Val Ridanna and Val Sarentino and in the Sexten Dolomites (Provincia Autonoma di Bolzano, 2018; Pollinger et al. 2018).
- After an overnight interruption, the second phase started in the morning of Monday 29 October and was characterized by the strengthening of sirocco winds and by the development of convective storm cells. Unlike the first event, this second phase of precipitation had a markedly convective character and was, therefore, accompanied by outbursts and thunderstorms. A thunderstorm front formed to the south, which, although weakened to the north, recorded almost 500 lightning strikes in South Tyrol. There, during this second phase, the south-easterly current released the heaviest rainfall in the Ortles, Tessa and Dolomites areas (Pollinger et al. 2018)

Overall, the precipitation event was exceptional, not only in terms of quantity but also in terms of its extension over the Eastern Alps. In South Tyrol, at all stations, more than 100 l/m² were measured, with values between 180 and 200 l/m² over a large part of the province. The peak was recorded at the easternmost station in the province, at Prati di Croda Rossa (1910 m), with 363 l/m². Considering also 30 October, the station reached almost 400 l/m². In many weather stations, the 72-hour rainfall record was reached (Pollinger et al. 2018; Consiglio della Provincia Autonoma di Trento, 2019)

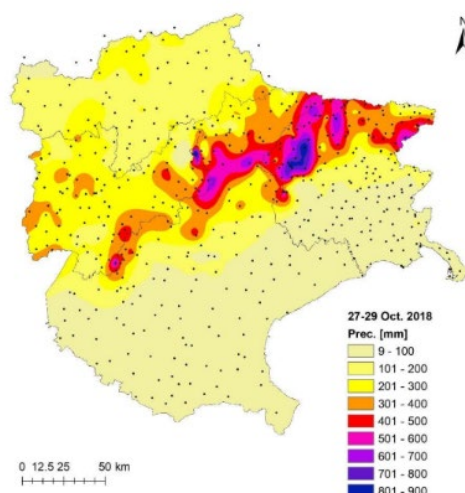


Figure 8.1 Accumulation of rainfall in the regions affected by Vaia (source: Borga, 2019)

As for the precipitation, also the wind was exceptional, both in terms of the intensity of the phenomenon and its effects on the ground. During the entire event, the wind aloft from the southern sectors assumed a strong to stormy character, peaking with the passage of a cold front on the evening of 29 October. The violent gusts that occurred that evening were caused by the exceptional area of low pressure associated with a cold front. The most intense wind gusts were recorded between 1500 and 2000m altitude. In South Tyrol, the highest speed was 188 km/h, recorded at the Zaunkofel weather station (2475 m), between Trafoi and Solda. Also noteworthy were the gusts of 120 km/h measured at the relatively low station of Nova Ponente (1470 m) (Pollinger et al. 2018).

Short and long term impacts analysis

In Trentino Alto Adige there were four main sources of direct damages, directly connected to the nature of the event:

- I) Extreme intense wind gusts
- II) Debris flow due to landslides and mudslides
- III) Overflowing of rivers and streams and bank erosions
- IV) Erosions in riverbeds, deposits and accumulations

Extreme wind gusts affected primarily mountain forests, destroying 19.800 hectares of forest, while debris flow and overflowing of rivers strongly affected road and water infrastructure.

The event had consequences in 93 out of 116 municipalities of the Province of Bolzano. These municipalities correspond to 93% of the provincial surface area and 83% of the provincial population. The estimated direct damage in the Province of Bolzano amounts to a total of 159.076.826 €, of which 41 % consists in public damage, 58 % in private damage and 1 % in damage to productive assets. The most important cost items (87 % of the total direct damage) relate to damage caused to the forest stock from windthrow. This damage has been estimated at €138.000.000 (e.g. landscape/environmental heritage, forest trail network and forest business restoration) (Provincia Autonoma di Bolzano, 2018).

For what concerns the Province of Trento, the preliminary estimation of damages and losses amounted at 184 millions of €, this number was later rectified based on more accurate data and indemnity request presented. The overall amount of damages amounted to 360 millions of € (Consiglio della Provincia Autonoma di Trento, 2019). The most important cost items 179.400.000 millions of € were allocated to reconstruction and restoration of public and private infrastructure damaged, as well as the damage suffered by economic and productive activities cultural and landscape assets and the building heritage. The second most relevant costs items, 91.000.000 millions of €, were related to structural interventions to residual risk reduction in the affected areas.

Forestry:

Storm Vaia primarily damaged dense and mature spruce forests (*Picea abies*), creating vast areas where trees were either snapped or uprooted by the strong winds. In particular, the storm caused the crash of about 15

million cubic meters of wood: more than 5 million in the Veneto region and in Trentino, more than 2 million in the Bolzano province, and in the Friuli Venezia Giulia region (Stefani and Pompei 2023).

Table 8.1 Areas affected by Vaia windstorm and volume of windthrown wood per Autonomous Province
Source (Provincia Autonoma di Bolzano, 2020; Provincia Autonoma di Trento 2022)

	Affected area (ha)	Wood volume affected by Vaia m3
Autonomous province of Trento	19.800	4.098.722
Autonomous province of Bolzano	5918	1.536.344

In the Autonomous Province of Bolzano, windthrow was reported in 92 municipalities, with a quantity of wood equivalent to that which can be harvested from the forest under sustainable management in two years; for some areas, the loss is considerably greater. For example, in the Latemar area, the loss is equivalent to approximately 16 years; in the areas of Fontanefredde and Nova Levante (East part of South Tyrol) respectively the 12 and 9% of the forest area was affected by the windthrow. The damage affected about 2.000 forest owners in total, including privates, municipalities, and collectives (Servizio Foreste e Fauna – Agenzia Provinciale delle Foreste Demaniali Provincia Autonoma di Trento 2020).

In the Autonomous Province of Trento, the damage was concentrated in a relatively small portion of territory (Figure 8.2). The majority areas were affected by a forest loss ranging between 50% and 100%, this loss had tremendous repercussion in the economy of the forest sector, destroying a quantity of wood equivalent to the one that would have been harvested in nine years. This huge injection of wood saturated the timber market, causing a drop in wood price of 69% in Trentino and 33% in Alto Adige (Udali et al. 2021).

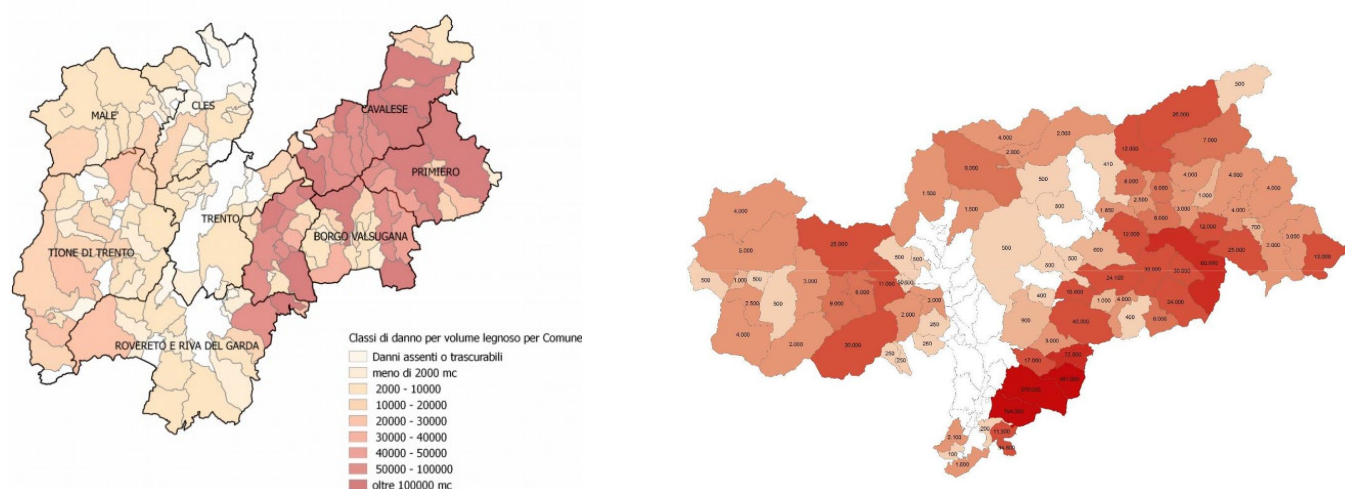


Figure 8.2 Distribution of windthrown wood in Trentino (wood mass in cubic meters) source: Servizio Foreste e Fauna Provincia Autonoma di Trento, 2022

Figure 8.3 Distribution windthrown wood in Alto Adige (wood mass in cubic meters) source: Servizio Foreste Provincia Autonoma di Bolzano, 2020

The forest damage had a significant impact on the fulfilment of the **protective function** of the forest. In the mountainous territory of the Province of Bolzano, the protective function of forests is of fundamental importance for any human activity. If we consider the protective function of the forest with reference only to avalanche, rockfall and water regulation phenomena, as much as 58 % of the forest (approx. 195.000 ha) performs a predominant protective function. If one limits the protective action of the forest to forest stands that directly protect settlements, transport routes and other infrastructures, as much as 24 % of the forest area is considered to have a predominantly heteroprotective function . In total, 2.650 ha (1.3%) of protective forest were affected by windthrown .

In the Autonomous province of Trento it was verified a similar situation, 25% of forest windthrown had an important direct protective function against avalanches and rockfalls. Furthermore, it provided a key indirect protective and regulating function to mitigate hydrological phenomena (erosion and water regulation). Table 8.2 shows the areas affected by windthrown identifying the specific protective function they provided.

In both Autonomous provinces vast areas affected by the windthrown involved slopes with steepness between 30° and 55°strongly prone both to avalanches and rockfalls. Due to an important loss of forest coverage, these areas became new potential avalanche, landslide and rockfalls areas; this led to updated "hazard maps" of the Province of Trento and Province of Bolzano in order to include new risk-prone areas.

Table 8.2 . Windthrown forest area affected specifying protective function

Forest protective function	Affected areas (ha)
Protective function against avalanches	900
Protective function against rockfalls	1.500
Hydrological regulating function (antierosion)	3.860

To temporarily mitigate this loss of protective function, in some cases, it was decided to leave damaged wood on the ground to still maintain a certain degree of protective function against avalanches or rockfalls. Nonetheless, this choice could have strong repercussions on several other aspects of forest ecosystems and on the wood sector's economy.

One of the most relevant secondary impacts connected to the Vaia windstorm has been the strong proliferation of bark beetles. In the long term, the weakened or damaged trees provided a suitable breeding ground for the **bark beetle** (*Ips typographus*), leading to an increase in beetle populations. This population surge typically peaked in the third growing season after the storm, a pattern observed in previous storm

events. As the windthrown trees became infested, dried out, or were removed, the beetle population began to spread to neighboring forest stands. The epidemic beetle attacks primarily affected standing spruce trees along the edges of the previously windthrown areas. Trees along newly formed forest edges are vulnerable to sudden changes in microclimatic conditions and other stressors like direct sunlight and wind damage, making them highly susceptible to beetle attacks. In such cases, the mortality caused by *Ips typographus* beetles following a storm-induced disturbance can surpass the damage inflicted by the storm itself (Deganutti et al. 2024). The bark beetle affected large areas outside the windthrow areas, extending the modification in hydrologic, hydraulic and avalanche hazards. In Autonomous Province of Trento the hectares damaged by bark beetles between 2019 and 2021 amounted at 5.031,27 ha (equal to 594.829 m3) overcoming the hectares damaged by the storm itself (Servizio Foreste Provincia Autonoma di Trento 2022).

Tourism and landscape:

The forest damage caused by windthrow also led to damage to the **landscape heritage**, which affected three quarters of the areas affected by windthrow in the Province of Bolzano. Also, in the province of Trento, the damages to the aesthetic and recreational value of the forest have been extremely relevant. The latest data collection estimates that 30% of the damaged forest belongs to a protected area, belonging to the natural park or to Natura 2000 areas. While the direct impacts and their respective costs have been investigated more in depth, the indirect impacts have received limited investigation efforts. Natural capital and especially forested areas constitute touristic attractions in Trentino-Alto Adige. In the region, tourism contributes significantly to regional economic output and the area is renowned for its natural beauty, exemplified by the inclusion of the Dolomites in the UNESCO World Heritage list. A study analyzed the impact of Vaia on tourist flows, finding a significant decrease in stays for the three years following the event, especially concentrated in the summer months. The municipalities where forests were more strongly affected by Vaia have indeed experienced a substantial decrease in summer stays. The impact on the tourism sector seems to be greater in those municipalities where natural amenities prevail over cultural amenities such as museums, castles and other attractions (Bernardi, Cascarano, and Modena 2023). Regarding hiking tourism, the estimated number of partially or totally interrupted trails was over 2,000 kilometers (out of a total of total of 6,000 km of paths in Trentino), with a total of 814 paths. Further than damages to landscape and to trail paths, the tourism industry in the Province of Trento has suffered several damages to hotels and accommodation facilities. The impossibility of restoring the facilities in time for the summer season had direct repercussions on the job market.

Winter tourism, on the other hand, was less affected, as the impact of the storm was less visible when concealed by winter snow. Winter tourism prioritizes activities like skiing, less impacted by forest conditions. Additionally, ski infrastructure and lifts were unaffected by the Vaia storm, ensuring their continued operation. Consequently, the demand for winter tourism remained unaffected by this event (Bernardi, Cascarano, and Modena 2023).

The situation was different in Trento Province, where several types of ski infrastructure were damaged by falling logs and also by the interruption of the management of the sites in preparation for the winter season. Damages and losses amounted up to 800.000 €, only partially covered by insurance policies.

Population and private buildings:



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The direct effects on the population were mainly limited to some evacuations (San Lorenzo di Sebato and Bressanone), while in some centres (Chiusa and San Candido) the inhabitants of the ground floors were asked to move to the upper floors for the duration of the event. In some areas, the White Cross set up assistance points for the affected population and intervention forces (Sterzing, Innichen, Brixen, Klausen and Bruneck). A similar situation occurred in the Autonomous Province as well, where the main direct impacts on the population were damage to houses, where roofs were blown off by the wind, and damage to cars. The greatest damage was concentrated in val di Fiemme, val di Fassa, Primiero, in Alta and Bassa Valsugana, in Valle di Sole and in Alto Garda and Ledro. While damages caused by flood were mostly located in Primiero, Valle di Fiemme, Valle di Sole and Dimaro. Initial official estimates indicate that damage to private movable and immovable property (homes outbuildings, furniture and equipment, vehicles, landed property in urban or adjacent areas) are quantifiable at approximately € 9 million, of which € 8.5 million for first homes and 172,000 € for vehicles. Evacuation of residents was issued only in only in one settlement (Dimaro) because the house were destroyed by debris flow .

Unfortunately in the Autonomous Province of Trento, five casualties were recorded, two of them directly caused by the windstorms and the rest happened during forest operations aiming at cleaning the forest area affected .

In the Province of Bolzano, considerable damage to **private homes also occurred, mainly caused by** the Drava River flooding in the municipality of San Candido, as well as spot landslides in the municipalities of Sesto, Naturno, Bressanone, Chiusa, Perca and Varna caused. A total of 94 houses were affected. The amount of direct damage to private dwellings was estimated by the Technical Office for Housing at €1,285,000 .

Transport infrastructure:

Flooding, debris flows, erosive phenomena and landslides provoked quite significant impacts on the transportation infrastructure. Road infrastructures at the state, provincial and municipal levels, a motorway section (A22), and the Pustertal railway were affected. In the Brenner area, for example, the railway, state road and motorway were interrupted at the same time .

In Alto Adige, as well as in Trentino, the main critical issues occurred due to the closure of various **provincial and state roads**, mainly due to landslides and tree crashes. The amount of direct damage to the road network was estimated by the Roads Department of the provincial administration of Bolzano at € 1,420,000. The state roads that were most affected were the SS620 Lavazè Pass, the SS241 Val d'Ega - Carezza Pass, the SS244 Val Badia, the SS51 Dobbiaco - Cortina and the SS52 Carnica. In Trentino damages to the road networks amounted to 30.6 millions of €, 2 of them were dedicated exclusively to restore cycle paths. Among damages to road infrastructure, it is relevant to mention damages to the forest roads. Those damages amounted at 546 km, the restoration costed 1.074.801 €.

Damage was recorded also for **municipal infrastructure**, mainly concerning municipal and inter-municipal roads and bicycle paths along streams, with a total direct damage of 9.232.595 € .

The **A22 motorway** was also affected. Emergency interventions were needed at the section of the A22 in Brenner and Fortezza, where the Zirago and Bianco torrents flooded the motorway carriageways with solid material, resulting in a direct cost of €124,300.00. Moreover the Brenner motorway company estimated a €

17,500 damage to the motorway network, mainly for the repair of the telecommunications and electrical infrastructure .

The main critical situations on the **railway network** were on the Val Pusteria railway line between San Candido and the state border, where flooding and landslides disrupted the line for three days from 29 to 31 October 2018 .

Public utilities:

The **electricity distribution network** suffered extensive damage, in particular due to the crashing of tall trees on pylons and spans on medium and high voltage bare conductor overhead lines. Several hydroelectric reservoirs triggered emergency procedures, but no damage was reported. The main energy provider of the provinces reported a power outage for approximately 20,000 people in Bolzano area and a disconnection for more than 50.000 users in Trento area (ufficio stampa). In Bolzano province 39 municipalities were partially or completely affected. The amount of direct damage to the power grid was estimated by the reference distributor for the Autonomous Province of Bolzano (Edyna) at € 1,800,000.

Water utility infrastructure was also affected. In particular, as a result of the serious damage to the **main aqueduct**, the village of Anterivo was left without drinking water and had to activate a temporary supply service by means of tankers. Moreover, several sections of the main **sewer** laid along the Gadera stream in Val Badia were damaged by erosion.

Damage to **hydraulic defence works** also widely occurred, with 4,650,000 € for interventions especially for consolidation works, flood walls, restoration of riverbed sections, protection dikes, which account for approximately 9 % of the total direct damage .

Economic activities:

In the Autonomous Province of Trento damages to production activities were concentrated in the Primiero Valleys, in the Fiemme Valley, and in the Sole Valley and can be estimated at € 7.6 million. In the Autonomous Province of Bolzano was affected by direct damage to economic, industrial and commercial activities (€ 947.117), where in particular in the Municipality of San Candido, the flooding caused by the Drava river caused considerable damage to four commercial and tourist buildings. .

Agricultural activities:

Damage concerned in particular mudslides and landslides in meadows, failure of retaining walls and damage to individual agricultural buildings. The amount of direct damage to agricultural activities was estimated by the Agricultural Department of the provincial administration of Bolzano at € 976,762. In Province of Trento damages in agriculture and farming sector overcome 7 million euro. They were mainly concentrated in Valsugana, Primiero and Valle di Non. Significant damage to fish farms were recorded in Levico and Dro. Damages in the agricultural and farming sector were relatively contained as the main culture were already harvested and have affected mainly small fruit sector

First response



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Civil Protection and Fire brigades were immediately activated as soon as the alert level reached the highest level. In the night between 29th and 29th of October, only in the Trento area, were involved in more than 3000 interventions. From the Civil Protection side there were more than 4000 volunteers managing multiple aid requests and different types of interventions.

The State of Emergency was declared with the resolution of the Council of Ministers on 8 November 2018 in the territories affected by the storm (i.e. Lombardy, Autonomous Province of Trento, Autonomous Province of Bolzano, Veneto and Friuli Venezia Giulia) (DPCM, 2018). The state of emergency, initially intended to be valid for 12 months was then extended for another 12 months (Resolution of the Council of Ministers on 21 November 2019).

With the 558 ordinance the Head of Civil Protection defined the modalities of the interventions aimed at overcoming the emergency. The decision-making authority was transferred to the Deputy Commissioners of the affected areas, that in Trentino- Alto Adige corresponded to the Presidents of two Autonomous Provinces. The Deputy Commissioners were required to present a plan of interventions (relief and assistance to the population and interventions to restore public services and infrastructure) within 20 days from the publication of the Ordinance.

The Autonomous Province of Trento established an ad hoc institutional body to evaluate the damages and losses caused by Vaia storm and identify adequate recovery measures. This institutional body called "Commissione speciale di studio sui danni causati dalla perturbazione meteorologica eccezionale che ha colpito il trentino alla fine del mese di ottobre 2018 e sulle conseguenti misure di intervento" was in charge for almost one year, from December 2018 until October 2019, in the first phase of the response phase.

It has three main goals:

- collecting data, information to evaluate the extent of the event.
- identify the programme of actions to restore the affected areas.
- monitor the use of resources made available for recovery and reconstruction.

On the basis of the initial and preliminary damages quantification, the State allocated financial resources to the damaged regions to cope with the initial challenges. In this first the autonomous Province of Trento received more than 11.5 million € to answer to population and private sector needs (DPM 558, DPCM 2019). The European Solidarity Fund as well allocated specific funds to restore and manage damages done by the windstorm. The Autonomous Province of Trento received 15million of € that have been mainly used to restore damaged forests and trails paths .

The governmental resources have been coupled with provincial resources. On the overall, the Special Committee allocated 143 millions of € to spent between 2016 and 2021 to cope with damages and losses caused by Vaia windstorm .

In the Autonomous Province of Bolzano, on 9 November 2018, the provincial council issued a memorandum addressed to all the municipalities for the coordination of the necessary emergency measures, covering the following points :

- Identification of the worst affected areas, in need of emergency measures.



- Organization of meetings by Mayors between affected landowners, provincial offices and other institutions.
- Establishment of a central provincial coordinating office for timber and for provincial reference offices for different types of damage (e.g. to dwellings, to forests and their infrastructures, to agriculture and to watercourses)
- Evaluation of the establishment of a rotation fund for investments and timber purchase.

Moreover, on 10 November 2018, the Council allocated from the provincial budget reserve €2,030,000 in favor of the Civil Protection Agency and €600,000 in favor of the Forestry Department for the implementation of emergency measures .

Vulnerability analysis

Physical dimension

Both in Trentino and Alto-Adige several critical infrastructures proved to be not resilient in case of a disruptive event. Railways and road networks, as well as power grid infrastructure are often not redundant, and this led to a complete service disruption in case of damage. Moreover, linear infrastructures are mostly located above ground leading to an increased vulnerability to extreme events. Similarly, while hydraulic protection measures were in place and proved to work well no structural protection measures was in place for wind. For what concerns electricity and power grid infrastructures, the lack of redundancy was not mitigated by an adequate availability of emergency power generators or power backup systems. This led to a full isolation of entire settlements and villages up to entrance roads were not free by windthrown logs and debris flow.

Another important physical vulnerability is linked to the maintenance of forest roads. The storm has highlighted the need for frequent and capillary maintenance of primary and secondary forest roads to facilitate access to damaged forest patches and to fasten wood removal.

Environmental dimension

Both Trentino and Alto Adige regions are characterized by steep slopes, the majority of them overcome 30% of steepness. This geomorphological feature leads to a high susceptibility to gravitational mass movements as well as to avalanches.

From the forest perspective, the huge quantity of windthrown wood highlighted the lack of accurate multi-purpose forest management that properly balanced productive purposes with biodiversity and regulation services. In the areas affected by the storm, both in Trentino and Alto- Adige, forests are characterized by a strong spruce monoculture and even-aged trees. These characteristics denote that forest management was mainly concentrated in productive purposes and overlooked the creation of a risk resistance forests. The presence of monoculture, the species chosen and the lack of age diversification led to a domino effect in which there were no trees able to withstand the wind force, causing the destruction of huge patches of forests .

These two elements were identified and recognized as great sources of vulnerability by forest owners and forest managers of the provinces, this recognition led to the modification of provincial forest management plans to increase future forest resilience .

Economic dimension



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A relevant aspect that worsened the economic losses related to forest damages was the absence of any type of insurance for forest stands. The lack of insurance meant that the majority of the economic damage of the forest loss was covered only with ex-public aid. The lack of insurance coverage means that forest owners are totally dependent on the availability of ad hoc public funding to cover emergencies. This does not provide a structured measure for tackling damages due to climate change and extreme events .

Another relevant vulnerability linked to the economic dimension was the lack of a solid and well-structured forest value chain. Despite both Autonomous Provinces identified themselves as sufficient and adequately prepared to manage the consequences of the windstorm, it was clear that forest value chains in both provinces were not adequately structured to manage such an enormous amount of wood. The absence of a coordinated and integrated forest value chain that includes multiple industrial activities and stakeholders led to the clearance of timber to wood-processing companies outside the region. In the last decades, the forest value chain has been gradually depleted in terms of resources, machinery and workforce, and it was not able to take full advantage of the enormous quantity of raw material that Vaia has provided. The lack of resources was coupled with the lack of expertise in managing huge quantities of salvaged wood; this situation resulted in the preference for selling wood lots to foreign companies instead of transforming the raw material internally. This resulted in a missed opportunity for creating value added in the forest value chain of affected territories (Mountain Wilderness 2022)

Institutional dimension

Several institutional vulnerabilities were highlighted in multiple institutional documents produced after the storm. One of the most striking issues is that none in Trentino or In Alto-Adige wind was addressed as a hazard in civil protection and contingency plans. On one hand, this was due to the fact that windstorm were not identified as a common /likely hazard in the Alpine areas. On the other hand, this denotes a lack of nowcasting and monitoring tools that could alert in case of strong wind gusts and produce automatic warnings for civil protection and meteorological services (Santini et al. 2022). As a result of the fact that no contingency or hazard plan existed, there were also no procedures in place for firefighters and civil protection. Thus, a general contingency plan for emergencies was adopted.

Vaia Windstorm also highlighted the need for several improvements in the application of civil protection plans as well in awareness rising, both at the institutional and population levels. Concerning civil protection plans, it was evident the need for updating the risk and hazard scenarios considered, also including future climate changes as a relevant variable. Updates in scenarios are tied to an update in awareness raising campaigns both at institutional and civil society levels and to an increase in periodical testing of risk plans as well as response actions .

Looking at risk-related institutional communication, institutions highlighted the difficulties of reaching a large number of non-residents in the areas, such as tourists or second house owners. This lack stressed the need to improve the institutional risk communication plan including communication to non-residents. Furthermore, both institutions and residents highlighted the need to increase the frequency of awareness campaigns as well as training on how to be prepared and how to behave in different hazardous situations (Romagnoli et al., 2022).

In the aftermath of the storm, it was clear a strong lack of coordination and cooperation among the different regions and areas affected. The response and recovery activities, as well as the identification of the different measures to be implemented in potential cross-regional sectors (such as critical infrastructures, forest management, forest value chain, etc.), was characterized by a strong institutional fragmentation that prevented from maximizing resources available and mainly led to duplication in activities across regions and



provinces. This lack of coordination, further leading to an inefficient use of resources, prevented knowledge transfer among institutions and stakeholders. This situation also affected Trentino-Alto Adige where the collaboration among the two provinces in the response and recovery phases was almost absent (Abruscato et al. 2019; Santini et al. 2022).

Social and cultural dimension

In literature, institutional reports or media articles there was not a specific focus of attention to vulnerabilities related to social and cultural aspects.

Recovery analysis

As happened in the first response, also in the recovery phase the State allocates financial resources. Governmental resources have three main focuses (DPCM, 2018):

- Realize structural measures to reduce hydraulic and Hydrological risk. To develop these measures, the Province of Trento received more than 133 million of € from 2019 to 2021.
- Restoration of interrupted public services. The sum allocated to this aspect amounted to 80 million euros for Trento province.
- Reduction of residual risk. The finances allocated to this aspect amounted to 6 million €.

In both Autonomous Provinces, recovery actions were at first focused on restoring main public services, such as energy and water supply and functionality of transportation infrastructure. At the same time, strong efforts were put in place to i) clean forests from windthrown, ii) support the forest-timber value chain, iii) repair and improve protective and risk reduction measures. The main recovery actions consisted of the following:

- **Restoring power supply**

By the evening of 29 October 2018 about 20,000 users were temporarily cut off from the power supply. On Tuesday 30 October, power was gradually restored on a provisional basis, reducing the number of disconnected users to around 4,000. In addition to the problem of numerous damaged or destroyed medium-voltage lines, a major problem was the lack of power supply to S. Valburga (restored 31.10.2018 late in the evening) and Corvara (restored 4.11.2018) from the high-voltage lines

- **Restoring the functionality of transport infrastructure**

In all, 124 projects were implemented in 70 municipalities with an investment of € 3.5 million. By the end of February 2020, 94% of these projects had already been completed. More than 900 cableways were also built to transport the crash timber. Of these installations, 869 had already been dismantled by April 2020 (Ripartizione Foreste Provincia Autonoma di Bolzano, 2020)

- **Private and public financial assistance**

With the Governmental Decree of National Emergency (DPCM , 2018), a few preliminary measures of financial aid were activated to support affected households and private sector companies. Along the 2 years after the eruption 1 427 request for damage compensation were activated for a total amount of 22.8 million €. Further, several institutional fund-raising campaigns promoted by the Province were activated and coordinated by an ad-hoc technical body. In total, more than 204 million of € were collected . Furthermore, with a specific financial agreement with banks, a special protocol, valid for 2 years (until 2020), was activated.



This financial protocol included: i) suspension of loan repayments; ii) activation of specific financing lines; iii) Support and free advice for financial services and aid request .

- **Restoring forest road infrastructures**

Immediately after the event, the forestry inspectorates of Bolzano Province worked in the first instance to restore the forest roads compromised, in order to make the affected areas accessible and safely reachable and create the conditions for the removal of the damaged wood (Pollinger et al. 2018). The same happened in the Autonomous Province of Trento where 2.474 km of forest roads (almost 1/3 of overall forest roads) were destroyed strongly hindering the cleaning of slopes and salvage logs operations. In several cases, further than restoring it was needed the full construction of new forest infrastructures such as roads, logging tracks and yards. The overall costs of improvements of forest roads and infrastructures amounted at 15 millions € .

- **Clean-up/clearing of areas affected by windthrow:**

In the Bolzano Province the wood clearing work began in the first month after the weather event. By the end of November 2020, approximately two years after the event, around 80 % of the impacted areas were cleared. This consists of 1.63 million gross cubic meters of wood, which corresponds to the wood removal of almost 2.5 years for the whole Province of Bolzano and to the same mass it normally uses over a period of nine years. This considerable quantity of wood was cleared so quickly thanks to the emergency measures aimed at restoring the forest road network, thanks to the commitment of all stakeholders in the area, owners, and forestry companies, and finally, also thanks to the favourable environmental conditions that prevailed after the event. The wood removal was faster in affected areas with larger dimensions (e.g. larger than 100ha). To ensure competency in processing wood, one of the most dangerous work activities in the forest, thirty-four training courses were held at the Latemar Forestry School before November 2020, involving more than 170 participants.

Similarly, in the Autonomous Province of Trento, wood removal and forest cleaning started immediately after the storm. Within the first two years after the storm 1.255 forestry sites were opened, and this allowed to harvest almost 79% of windthrown logs. Considering the high degree of risk and dangerousness it was needed to implement specific safety measures for the employees involved in salvage logging activities. For that reason, from 2019 until 2021, 89 training course activities on safety issues and harvesting specific techniques were activated that involved 831 qualified forest professionals.

- **Timber harvesting and sale**

Timely timber harvesting had a twofold objective: i) avoid bark beetles' outbreaks, ii) harvest and sell wood before a sharp decline in quality and a full market saturation. The windstorm has blown down 4 million m3 of wood, which corresponds to the quantity of wood removed in 9 years. The quantity of timber to be managed strongly overcame the management capacity of the forest-timber value chain in Trentino. Thus, it was needed to restructure and boost several sectors of the forest- value chain. Several private and public investments were made to support stakeholders of the forest sectors, from forest owners to harvesting companies and sawmills. By the end of 2021, 76% of the harvested wood was sold (AA. VV., 2022).

- **Repairing prevention infrastructure and protective measures (e.g. in particular hydraulic prevention infrastructure)**



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From 2019 onwards the Provincial Government put strong emphasis on improving hydraulic infrastructures. Fifteen millions of € were dedicated to restoring river bed functionality and reconstruction of river embankments to reduce the residual risk. Several other interventions focused on risk reduction have been realized such as: axle guard nets and avalanche barriers. On the overall 130 million of € were spent to realize risk mitigation measures. In some cases, risk mitigation measures were realized to mitigate the loss of protective forests, in particular with respect to settlements and road infrastructure.

- **Restoration of forest to fulfill multiple ecosystem services**

This includes landscaping and restoration of the protection forest but also interventions with technical works, such as rockfall and avalanche nets. The areas to be prioritized (in total 2000ha in South Tyrol) were selected in agreement with forest owners. In order to maintain and restore the stability of the soil and its fertility, the provincial forestry service plant nurseries reacted promptly to obtain seedlings to replace trees that had been felled by the wind and to help revitalize the forests. By the end of February 2020, one third of the 161 projects initiated in 41 municipalities to restore the protective function of the forests had been completed. 7.4 million € had been invested.

In Trentino, the prioritization of forest restoration projects was driven by the identification of different ecosystem services and functions provided by the forest. Table 8.3 summarizes surfaces that were prioritized for restoration due to their key ecosystem functions.

Table 8.3 Hectares of forest with prioritized ecosystem functions

source Servizio Foreste e Fauna – Agenzia Provinciale delle Foreste Demaniali Provincia Autonoma di Trento 2020

Prioritized forest ecosystem services	Hectares
direct protection against rockfalls	1.565
direct protection against avalanches	2.254
hydrological restoration	549
several damaged ideographic basins and riparian forests	6.908
protected forest habitats in natural 2000 areas	2.266

Building resilience for future events

Besides being a tremendous disruptive event, VAIA windstorm was recognized as unique opportunity to study the forest resistance and resilience to windstorms from different points of view. Both in Trentino and Alto-Adige forestry departments started close collaborations with universities, research centers, and institutions for multiple aspects of forest management and forest monitoring. Some of the topics addressed are the following:

- Study of the hydrological behavior of destroyed forest areas (erosion, absorption, loss of nutrients following rainfall), by comparing between areas still wooded and cleared areas (without regeneration, with natural regeneration and with artificial regeneration).
- Analysis of the influence of wild animal damage on forest renewal.



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- Different approaches to forest regeneration (managed or natural renovation).
- Long term monitoring of multiple variables (e.g. CO2 absorption, pioneer species coming after the storm).
- Long term forest management strategies.

Further than fostering institutional collaborations, both provinces increased cooperation with private and public (such as collective properties) forest owners. Institutions provided not only learning opportunities (i.e. Specific trainings in forest management practices) but also opportunities of exchange relatively to preferred forest management techniques and shared decision on how to maintain and monitor forests.

The aftermath of Vaia windstorm has been crucial for spur Forest Department to revise forest management approaches and planting options and plan preventive management options to increase resilience and resistance of forest to changing climatic conditions (Corona et al. 2018). Furthermore, new methods have been delineated to monitor bark beetle spreading and try to limit the evolution of the outbreak.

The unique impacts of storm Vaia offered a great opportunity to inform citizens about the real status of the region's forests and provide a lot of crucial knowledge on the forest sector in Italy. In Trentino the aftermath of Vaia and its devastating consequences opened the dialogue between citizens, civil society and public institutions on how to commonly manage forest, raising awareness and interests in forest and landscape management. To this purpose 28 organizations gathered together and signed a letter of intents called "Green deal for forests of the dolomites" in which forest is identified as a common good, that requires the involvement of all societal actors to create forests resilient to climate change and that for an holistic and sustainable development of the region including environmental, social and economic aspects(Un green deal per le foreste dolomitiche n.d.).

In line with this general letter of intents, the Autonomous Province of Trento launched a fundraising campaign that involved both private individuals and municipalities. The project was composed by two main activities to : i) collecting funds to restore the forest patches, ii) promote virtuous ideas and behaviors to reach environmental sustainability (Un green deal per le foreste dolomitiche n.d.). On the hills of this institutional and civic society proactivity, several private and collective actions have been promoted to boost the raise of the forest sector and help the restoration of forest.

Among the others it is worthy highlighting the project of PEFC to promote the purchase of damaged timber at national level to mitigate the economic and social drawbacks of the storm and avoid outsource of raw material (Negro et al., 2021).

The consequence of Vaia has led to a strong change in the landscape, this has consequences not only from the aesthetic point of view, but also strongly modify risk susceptibility of certain areas. For that reason, new defense measures have been implemented in areas prone to debris flow, rock falling and avalanches. Similarly, several already existing defense measures have been reinforced and improved after storm. On the overall in both provinces, Vaia windstorm pointed out the need of updating territorial risks and vulnerability maps and of reviewing territorial planning and management. The update of risk maps will take into account that risks related to natural hazards may change due to changes in climate and that affect new areas that were not considered prone to risk . In Trentino, the analysis of territorial planning and development, combined with the recognition of potential changes in risk patterns has also led to reconsider the suitability of electricity and telephone infrastructures. This led to the decision to burying cables and installations in areas at risk, in order to preserve them from possible future damage and thus ensure continuity of service

After Vaia, multiple departments and institutional actors in both provinces felt the need to capitalize lessons learned, reconsider the impact of climate change, and consequently define new risk management strategies for extreme weather events in the context of adaptation to climate change impacts. After the first phase of emergency management, several rounds of consultation between the province and key stakeholders were activated. During these consultations, participants gave suggestions on how to improve and facilitate procedures and emergency actions of special corps, as civil protection or mountain rescue, in emergency situations

Beyond suggestions and improvements of first aid procedures, several efforts have been done improve climate mitigation and adaptation policies. Both provinces delineated a “Climate change Adaptation Plan”, that identifies different actions, guidelines and measures to be implemented in order to limit CO2 emissions and contrast the negative impacts of climate change. The experience of Vaia highlighted the need to foster cross-regional cooperation to tackle climate changes consequences and implement mitigation actions. This rise of awareness led to the participation of both Autonomous Provinces and the respective Civil protection agencies in an Interreg project “X-RISK-CC” focused on transboundary cooperation, knowledge exchange and creati. on of local strategies to manage extreme events in the context of climate change .

8.2 Impact Chain

Vaia windstorm represents a Learning Case Study. Being a Learning Case Study, the analysis of the event was done only through desk-based research, using multiple sources of information.

The Forensic Analysis allowed to disentangle multiple aspects related to the development of the hazard and to the overall consequences derived from a compound-hazards situation. Furthermore, digging deep into socio-cultural and institutional conditions, this analysis allows to determine the social component of risk and define how the human component (in our case mainly related to institutional and economic factors) and the specificities of the context influenced the final impacts of the hazard and the affected communities.

The information gathered with the Forensic Analysis constituted the basis for developing the Impact Chain. The structure of the Forensic Analysis allowed us to clearly identify the major sectors affected, the main direct and indirect impacts, and to disentangle the multiple sources of vulnerability that exacerbated the overall impacts of the Vaia windstorm.

All the information gained through the Forensic Analysis has been distilled in the Impact Chain. The Impact Chain methodology allowed us to draw the interaction among the different elements composing risk (i.e. hazard, vulnerability, exposed systems) and to support the connections with multiple pieces of evidence. The Impact Chain resulting from the elaboration of the information gives a sounded and well-supported analysis that visualizes:

- i) the interactions among cascading hazards
- ii) the main sectors affected by the storm
- iii) how the impacts in one sector spillover into other sectors
- iv) the influence of vulnerabilities in specific hazards impacts
- v) the interaction between direct and indirect hazards impacts



The Impact Chain highlighted how the windstorm impacts were not limited to the environmental and ecological dimension, but strongly spilled over into social dimensions such as economic, institutional, and cultural. Furthermore, it was possible to clearly highlight the strong protective and risk mitigation function of forest stands and stress how a change in forest structure affects the risk dynamics, leading to a gap in risk protection measures and to a reformulation of risk susceptibility of multiple areas. In figure XXX are depicted most relevant impacts as well as exposed systems and vulnerabilities and reciprocal interconnection that were retrieved from Forensic Analysis.

The Impact Chain highlighted the interconnections existing among different forest environmental dimension, determining how a change in forest structure and composition lead to changes in biological components (i.e. forest biodiversity, regeneration dynamics) that in turn is likely to affect bark beetles colonization. At the environmental and ecological levels major impacts have been identified in forest structure and composition, in ecosystem service provisioning, at geomorphological and hydrological level and in forest biotic components (i.e. spread of bark beetles and other bark-boring insects). Nonetheless those impacts need to be analysed considering the pre-existing vulnerabilities characterizing the forest conditions. Indeed, those previous vulnerabilities have led to an exacerbation of the impacts caused by strong wind gusts.

At the economic level, major impacts were represented on one hand by economic losses caused by extensive damages to road and transportation infrastructure and on the other hand by direct impacts to wood-forest value chains and tourism attractions. Concerning those last aspects, it is relevant to highlight the role of pre-existing vulnerabilities of the forest-timber value chain and of the forest market in the affected areas. Impacts were connected to specific exposed systems, which appear to be mostly represented by infrastructure systems, ecological systems and economic systems (i.e. forest-value chain and tourism).

The Impact Chain makes explicit the connection among multiple risk elements. Nonetheless, it also highlights the paucity of information, at least for what concerns reports and academic articles, regarding the influence of the socio-cultural components in risk management and on the overall analysis of impacts, vulnerabilities and exposed systems connected to the Vaia Windstorm. The consequences of the storm at socio-economic and institutional levels seem to be restricted to the forest-timber sector and to institutional forest management.

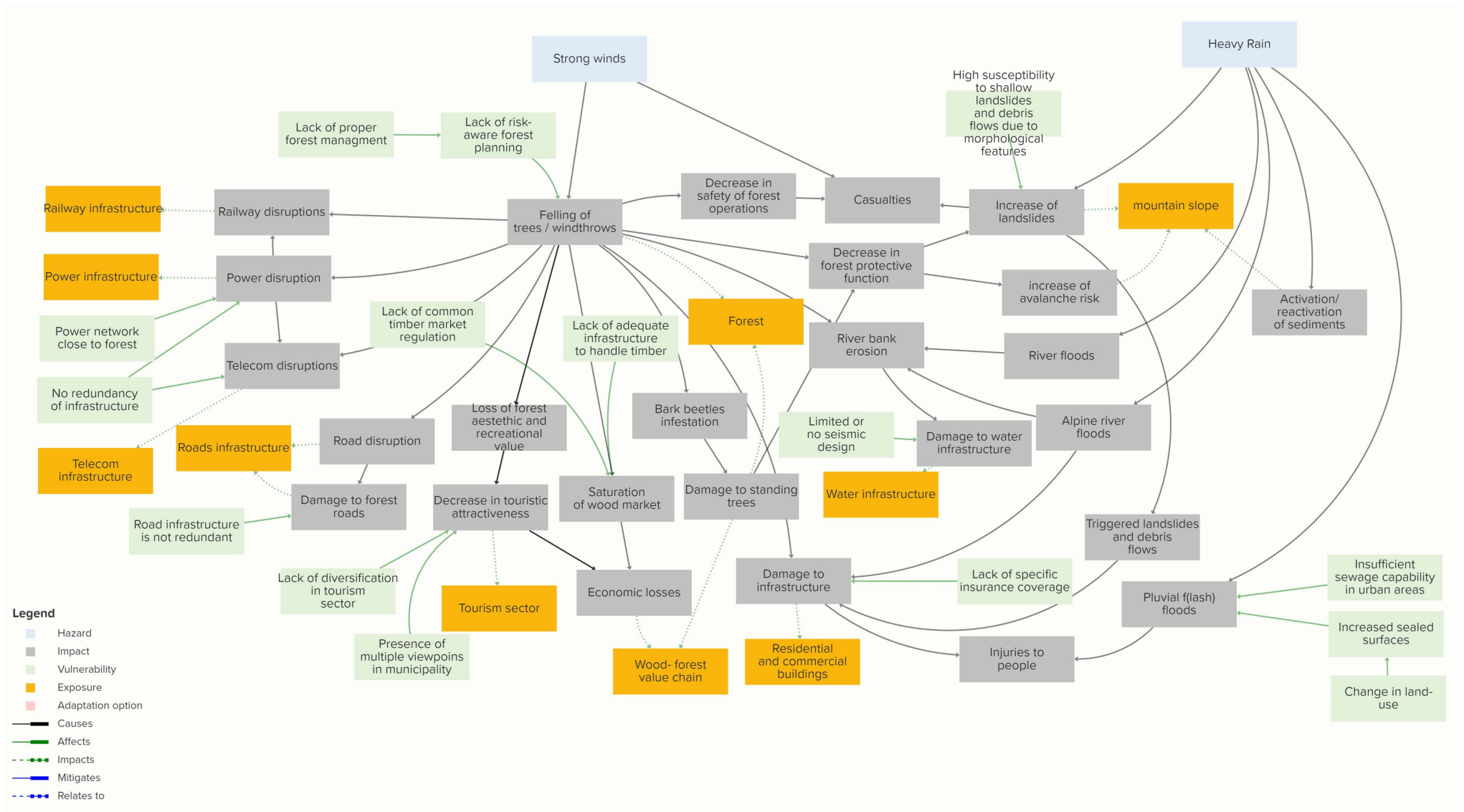


Figure 8.2 Impact Chain of Vaia windstorm. The Impact Chain content can be explored interactively through the [Impact Chain Wiki](#).

9 Gloria storm, 2020

9.1 Forensic Analysis

This section presents a Forensic Analysis of the Gloria storm that struck Catalonia in January 2020, specifically focusing on its effects on the Tordera River basin. The analysis will adopt a forensic approach, depping in the events before, during, and after the storm, along with the reasons behind them. It will examine both fluvial (riverine) and coastal hazards triggered by the storm within the Tordera River basin, with a particular emphasis on the municipalities of Malgrat de Mar, located downstream, and Tordera, situated upstream. The temporal scope of this analysis encompasses both short and long-term effects of the storm. Short-term implications pertain to immediate consequences observed during and shortly after the event, such as flooding and infrastructure damage. Long-term considerations extend to the lasting impacts on communities, ecosystems, and infrastructure. To achieve this analysis integrates data from scientific papers, news articles, and expert insights. By synthesizing information from diverse sources, this document aims to provide a holistic understanding of the Gloria storm's impact, contributing to future preparedness and mitigation efforts against similar natural disasters.

The Tordera River basin, spanning 898 square kilometers, is located in northeastern Catalonia. The river, 55 kilometers in length, originates from the slopes of Montseny and the Guillerics, with its main tributaries being the Santa Coloma and Arbúcies Rivers (Rovira & Batalla, 2006). Additionally, the watershed is directly connected to the Mediterranean Sea through a small delta. Historically and to this day, the Tordera river has served as a crucial geographical reference axis for population centers and socio-economic activities in the region.

Characterized by globally sub-humid Mediterranean climate conditions with maritime influences, the region experiences a period of summer drought and marked seasonality of rainfall, concentrated in spring and autumn, often leading to intense storm episodes and precipitation (Pascual et al., 2015). These events can result in sudden river surges known locally as "torderades". The Tordera is considered as a rain-fed river, with its flow regime significantly influenced by parameters such as rainfall.

The current population of the basin is primarily settled in the urban areas of the Tordera terraces and alluvial floodains (notably Sant Celoni and Tordera), and especially in coastal towns near the deltaic mouth (Blanes, Lloret de Mar, Pineda de Mar, and Malgrat de Mar). In these coastal municipalities, population density (ranges between 15,000 and 20,000 inhabitants per square kilometer) contrasts with headwater municipalities like Montseny or Fogars de Montclús (around 100 inhabitants per square kilometer).

Over 80% of the catchment area is covered by forest. In its middle course, the Tordera runs longitudinally between the Montnegre and Montseny massifs, where significant road and rail infrastructure converge with a notable industrial axis (textiles and chemicals). The basin plays a crucial role in the connection between North and South Catalonia. At its mouth, agricultural activities from the delta blend with a prominent tourist zone (Pascual et al., 2015).

Transformations in the alluvial plain area, increased industrial land use, and the development of road infrastructure have confined the river to a narrow and heavily modified strip. This convergence of social, economic, and environmental elements makes the Tordera basin a territory of exceptional singularity.



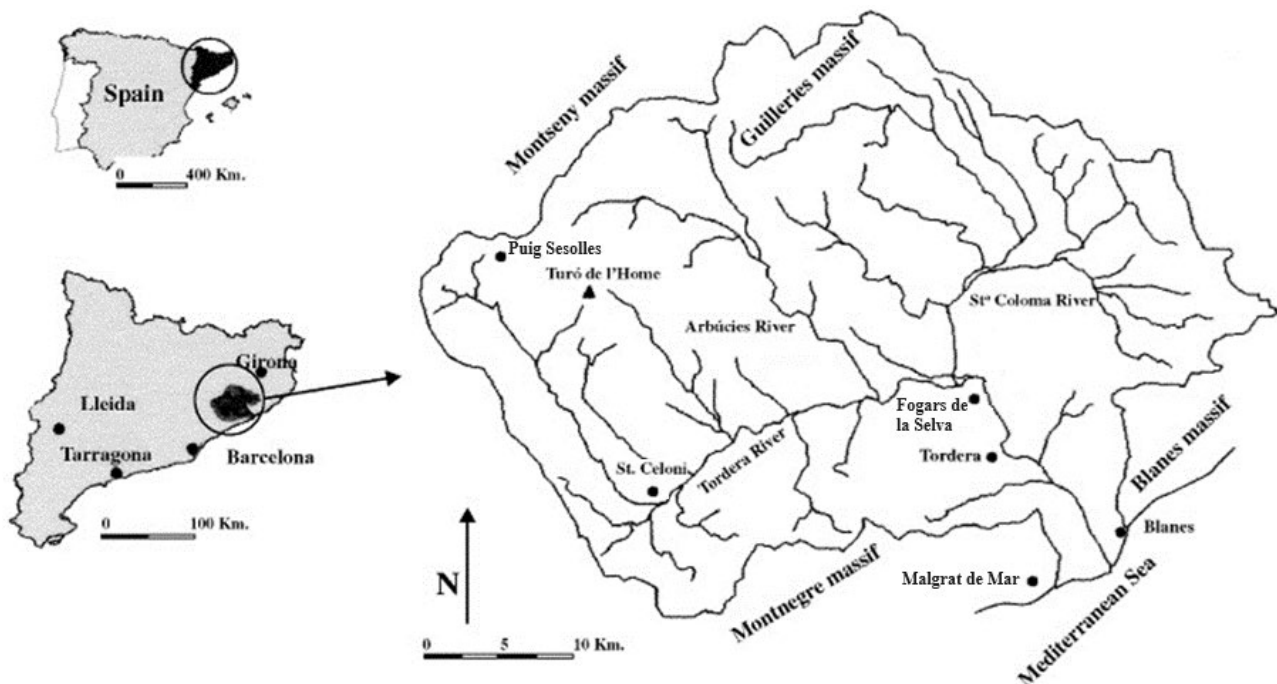


Figure 9.1 Location of the Tordera basin (Adapted from Rovira & Batalla, 2006).

Hazard analysis

In the Tordera basin, Gloria storm lasted from January 19th to 24th, 2020, with strong winds starting on the 18th and 19th (Figure 2, a) and b)). Rainfall began gently on Monday the 20th, significantly increasing on Tuesday the 21st, reaching a cumulation peak precipitation of approximately 204.4 mm in the upper basin (Puig Sesolles) and around 80 mm downstream (Fogars de la Selva) (SMC, 2020). Wednesday the 22nd was the morning with the most rain; the heavy intensity and accumulation caused rainfall accumulation of about 300 mm in the upper basin area and 150 mm down basin. Rainfall gradually decreased until Thursday the 23rd. Overall, the highest rainfall records were in the headwater's areas of the Tordera.

The extended rainfall episode caused several peaks in precipitation that led to surges in river flow in Catalonia. For instance, at the headwaters of the Tordera River in Sant Celoni, the river experienced three peaks in fluvial discharge linked to the rainfall. In chronological order, the river reached 150 m³/s, peaked at around 260 m³/s, and also had a surge that grew to 90m³/s (ACA, 2020). It's worth noting that the annual average flow of the Tordera in Sant Celoni is slightly less than 1 m³/s (Figure 2, c)). In the downstream section of the main channel of the Tordera, in Fogars de la Selva, the flow gauge station also recorded three peaks in fluvial discharge during the Gloria storm. In a temporal sequence, the river rose to 260 m³/s, exceeded 730 m³/s, and peaked at 200 m³/s (Figure 2, d)) (ACA, 2020). It's important to recall that the annual average flow of the Tordera in Fogars de la Selva is slightly less than 6 m³/s. The intensification of river runoff was not only due to the amount of rainfall that fell but also the moisture that had already accumulated in the soil of the headwater area during the preceding months (Moixó, 2020).

Regarding coastal conditions, the strong winds during the storm generated extreme waves. At the Tordera delta, this event was exceptional in terms of its probability of occurrence, as it marked the highest simulated wave height in this area. For example, at the SIMAR point located at the Tordera delta, a maximum significant wave height of 5.91 m was estimated, corresponding to a return period of 115 years (Puertos del Estado, 2020). Another notable feature of the storm included its prolonged duration (approximately about 50 hours).

The Gloria storm of January 2020 in the Tordera basin exemplified the cascading and compounding hazards inherent in extreme weather events.

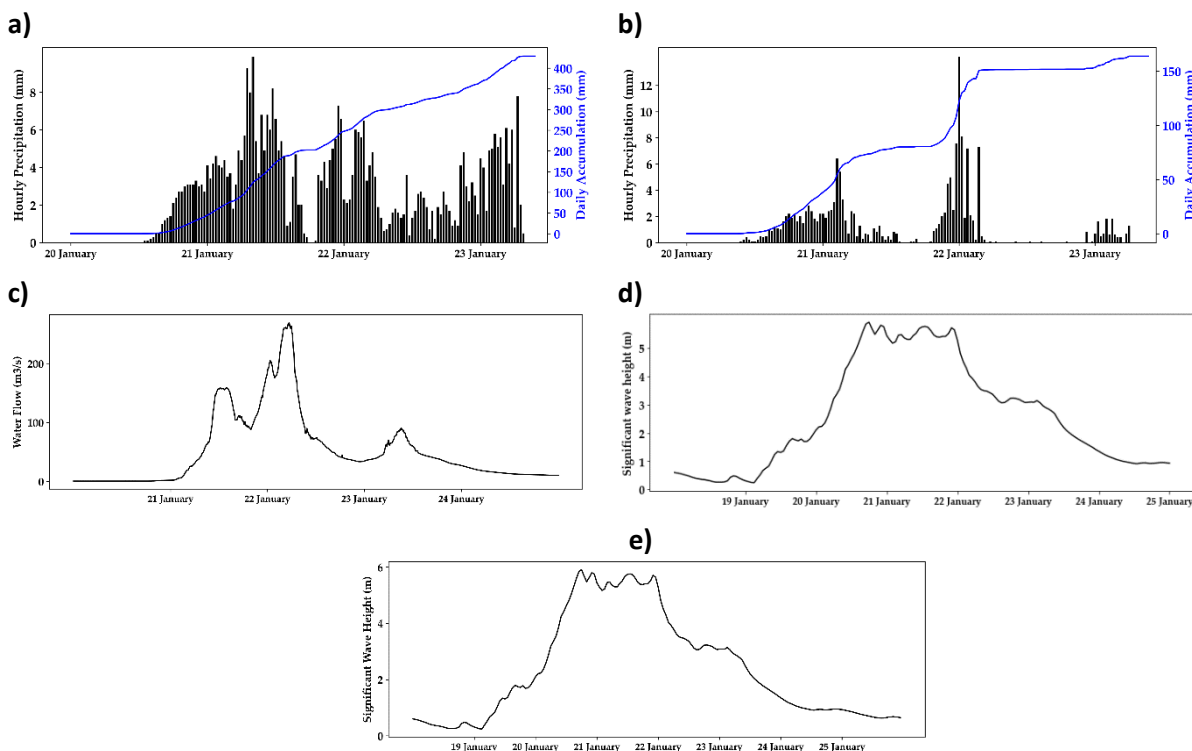


Figure 9.2 Multi-hazard Gloria storm event. a) Hourly precipitation and daily precipitation accumulation in Puig Sesolles (SMC, 2020); b) Hourly precipitation and daily precipitation accumulation in Fogars de la Selva (SMC, 2020); c) Tordera discharge at Sant Celoni gauge station (ACA, 2020); d) Tordera discharge at Fogars de la Selva gauge station (ACA, 2020); e) Maximum wave height at SIMAR grid node 2118140 (Puertos del Estado, 2020).

Short and long term impacts analysis

Short-term impacts

In the Tordera basin, damages can be categorized into two types: those upstream caused mainly by river effects, and those downstream, primarily by the combination of river and coastal effects. Specifically, in the deltaic zone, municipalities suffered significant economic damages due to the merging of these effects. In general, the effects associated with river dynamics have arisen due to flooding, erosion of riverbank margins, and the accumulation of sediments and floating objects (Figure 9.3a and b) (González et al., 2020).

These have resulted in various damages to both infrastructure and the surrounding terrain, including bridge collapses, disruptions to railway and road networks, flooding of streets and buildings, inundation of crop fields, and uprooting of trees caused by the force of water, among other effects (Figure 9.3, c and d) (González et al., 2020).

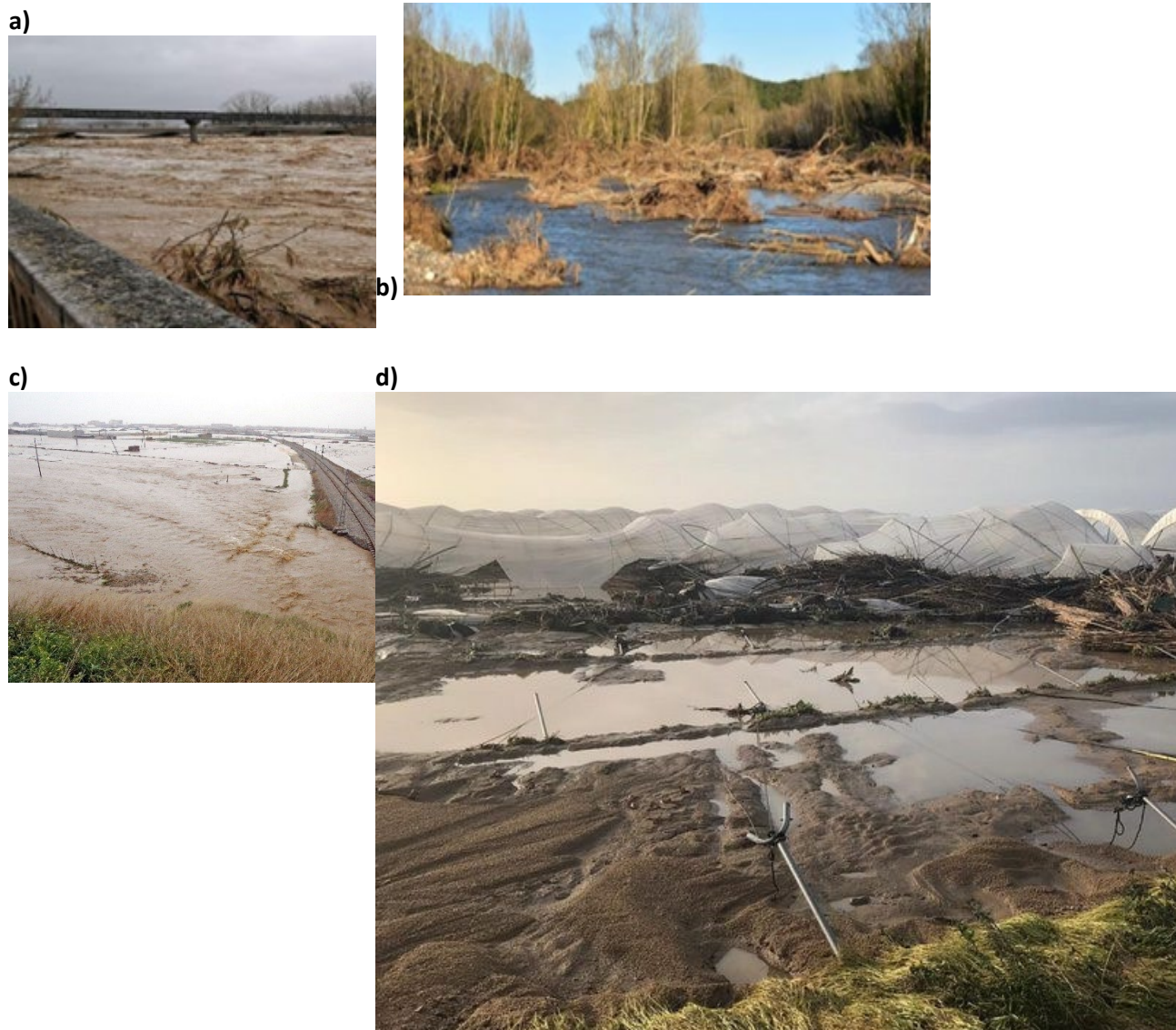


Figure 9.3 Gloria storm river dynamics and damages. a) Fluvial water discharge and sediment movement; b) Accumulation of floating objects (Caellacom, 2020); c) Affected railway line (Capgròs, 2022); d) Flooded crop fields (El punt Avui, 2020).

The coastal geomorphological effects following the Gloria storm include variations in the coastline, with erosion in some areas and accumulation in others, marine flooding involving storm surge and high wave heights (Jiménez Quintana, 2020). Infrastructure damages are extensive, ranging from near-coastal areas

such as damaged coastal promenades, urban furniture, and beach services (Figure 9.4a and b) (Moixó, 2020; Santasusagna Riu & Tort Donada, 2020)

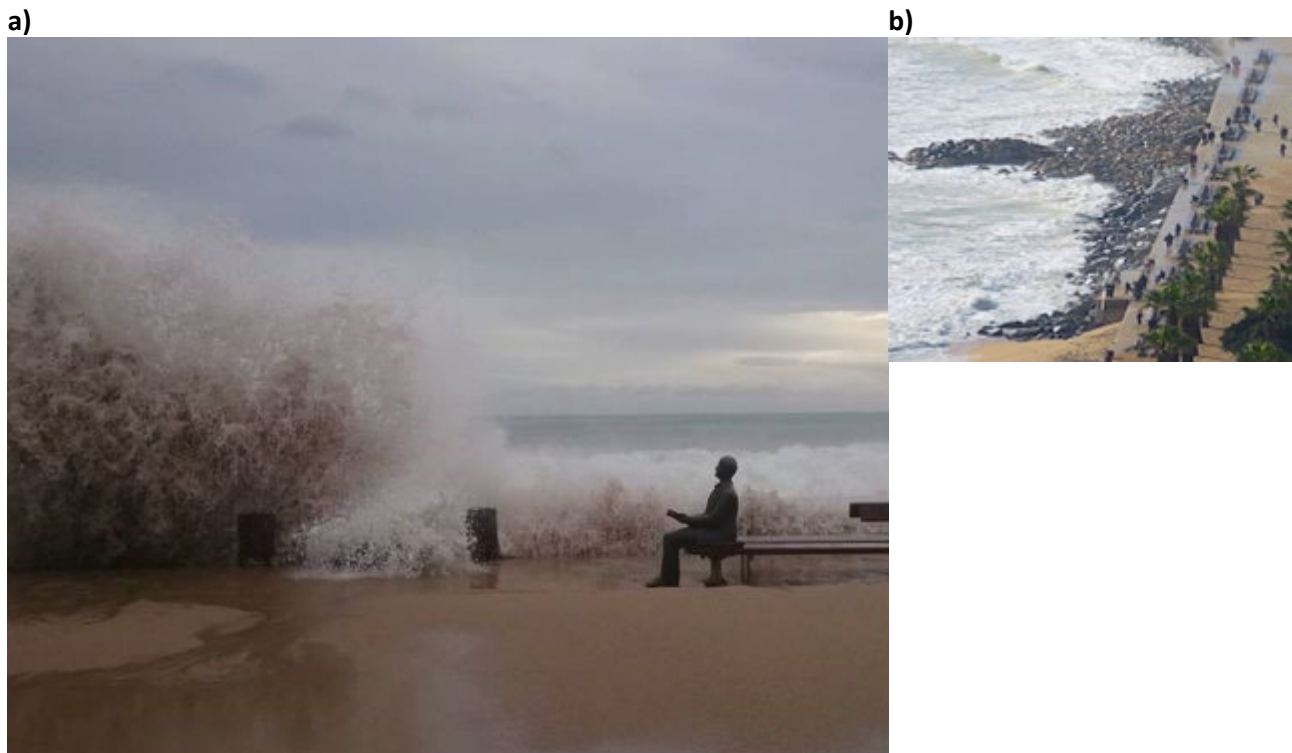


Figure 9.4 Gloria storm coastal dynamics and damages. a) Extreme coastal waves in Blanes (ACN, 2016); b) Affected seafront promenade (Blanesaldia, 2020).

Long-term impacts

Due to the lack of available literature specifically addressing the long-term impacts of the Gloria Storm in the Tordera river basin, we can extrapolate potential long-term consequences based on the observed short-term impacts and insights from experts familiar with the region. The long-term impacts expected are mainly related to the environmental degradation.

When considering the fluvial dynamics effects of the Gloria storm:

- The erosion of riverbank margins can result in:
 - Loss of vegetation, alterations in water flow patterns, and habitat destruction. This disruption to local ecosystems may significantly affect biodiversity and the provision of ecosystem services in the area (Prat et al., 2020).
 - Loss of natural protective structures.
- Inundation of agricultural lands may prompt shifts in soil properties, changes in soil management strategies and in agricultural practices.

When considering coastal dynamics effects of the Gloria storm:

- Erosion and sediment accumulation along certain coastline segments:
 - Disruption of the natural balance of coastal ecosystems. This alteration may lead to habitat loss and changes in sediment dynamics over time.

- Increased vulnerability of coastal infrastructures could have lasting economic consequences, particularly for regions dependent on tourism. Disruption of essential coastal amenities exacerbates the situation, further impacting the economic viability of coastal communities.

First response

Civil protection plans are planning tools that establish the operation and organization of human and material resources to improve response to emergencies or serious risks. In Catalonia, special civil protection plans refer to specific risks, the nature of which requires technical and scientific methods to assess and address them. To address emergencies due to floods, or wind-related risks, Civil Protection relies on the special plans INUNCAT (Protecció Civil de Catalunya, 2017b), and VENTCAT (Protecció Civil de Catalunya, 2017a), respectively.

These plans must quantify and locate the danger and effects throughout the territory of Catalonia on various vulnerable elements with the aim of minimizing risk, ensuring the safety of individuals, and protecting property, essential services, infrastructure, and the environment. Additionally, they establish warnings, organization, and procedures for action by the services of the Government of Catalonia, other public administrations, and also relevant private entities involved in emergency management.

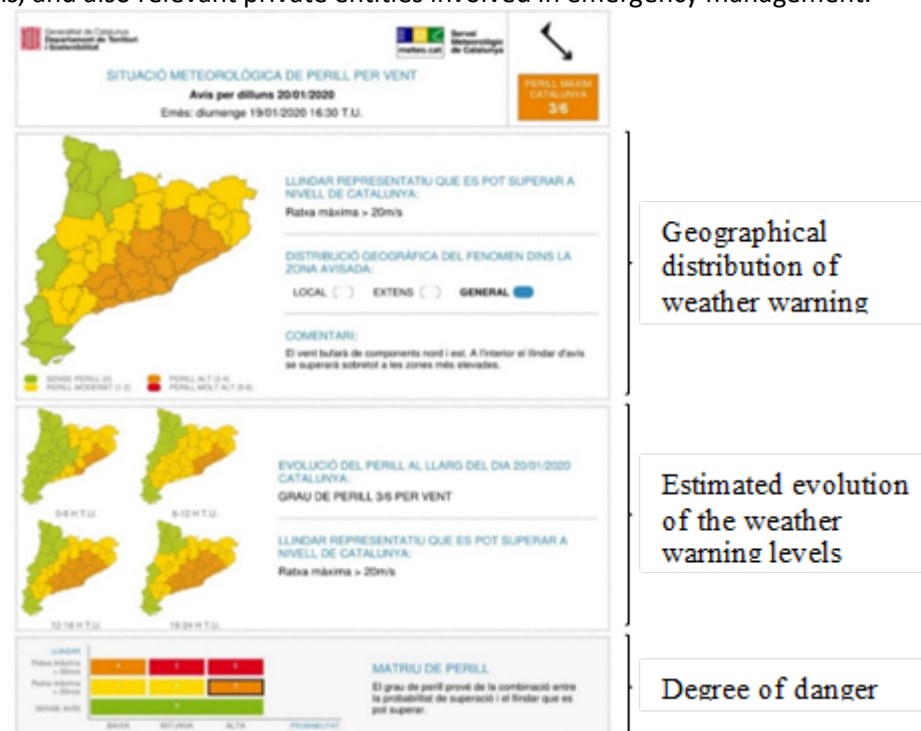


Figure 9.5 Meteorological Service of Catalonia rainfall forecast and degree of danger estimation for wind-related risk on the 20 January 2020. Source : (SMC, 2020)

The criteria for implementing the preventive phases of the special plans and the activation criteria are established based on different variables, which are primarily: the type of weather warning (degree of danger)

issued by the Meteorological Service of Catalonia (SMC) and the associated anticipation of the prediction (Figure 9.5) (Protecció Civil de Catalunya, 2017b). Based on these factors, three warning levels can be established: pre-alert, alert, or emergency.

In January 2020, Catalonia faced adverse weather conditions due to the Gloria Storm, leading Civil Protection to activate emergency plans for wind, snowfall, and both coastal and river floods. The specific plans were adapted to the different weather conditions (Figure 9.6):

- On January 18, 2020, the Civil Protection of the Generalitat issued a series of alerts for Catalonia in anticipation of adverse weather conditions (Generalitat de Catalunya, 2020a). The Special Emergency Plan, VENTCAT, was activated on alert due to the impending risk of strong winds starting from January 19. Simultaneously, the INUNCAT emergency plan was also put on pre-alert due to expected heavy seas along the Catalan coast. Citizens were advised to take extreme precautions while traveling, exercise caution during outdoor activities, and avoid coastal areas for safety. They are encouraged to stay informed by monitoring weather forecasts.
- On January 19, 2020, the Civil Protection of the Generalitat maintained the alert level for the Special Emergency Plan due to the risk of wind in Catalonia (VENTCAT) (Generalitat de Catalunya, 2020b). Additionally, the Generalitat's Civil Protection placed the INUNCAT emergency plan on alert that morning due to the predictions of high waves on January 19, especially on January 20, along the entire Catalan coast. Besides the heavy seas, a significant rainfall episode was forecasted starting from the night of January 20 to 21. Thus, INUNCAT alert level encompasses both heavy precipitation and coastal conditions. From the afternoon of January 21, an increase in river flow was expected, along with the possibility of sudden river and stream flooding. The Tordera basin was particularly highlighted as being at high risk.
- On January 22, 2020, as part of monitoring the effects and evolution of the Gloria storm, the INUNCAT Plan was elevated to emergency phase due to the arrival of a new rainfall front (Generalitat de Catalunya, 2020c). The Meteorological Service of Catalonia emphasized that these precipitations were hitting a territory that already accumulated a lot of water and had already begun to experience river overflow. Concerning the Tordera River, it was one of the rivers worrying authorities because it had already exceeded its emergency threshold, leading to preventive evacuations. The Operational Coordination Center CECAT contacted municipalities to anticipate the closure of access to riverbeds, fords, level crossings, and points. Also, recommendation to avoid mobility to carefully plan to prevent risky situations.
- On January 26, 2020, the Civil Protection of the Generalitat declared the alert phase of the Special Emergency Plan for Floods in Catalonia (INUNCAT) concluded, as river flows returned to their usual state and were no longer posing a threat according to updates from the Catalan Water Agency (Generalitat de Catalunya, 2020). Despite this improvement, Civil Protection advised the public to exercise caution in areas affected by the storm until normal conditions were fully restored, particularly by respecting the signage placed by authorities in identified danger zones.

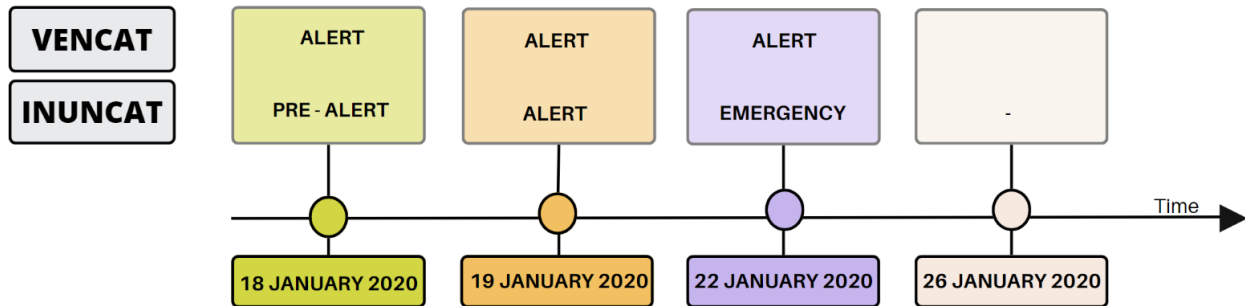


Figure 9.6 First response Gloria storm evolution

Vulnerability analysis

The municipalities in the Tordera River basin show two very different conditions in terms of exposure and vulnerability, depending on whether they are upstream or downstream. Therefore, we have chosen two municipalities for characterization: Tordera, located upstream, and Malgrat de Mar, located downstream of the Tordera river. These choices are also influenced by the effects of the Gloria storm.

Regarding the institutional dimension, the Tordera river basin is divided among three comarques and two provinces. Additionally, the areas within the basin are geographically quite distinct from each other, yet it must be remembered that they are all connected by the river as a unifying link. Therefore, for local administrations, this presents a rather complex situation.

- **Malgrat de Mar**

Over the past 40 years, the municipality has experienced rapid growth, with a steadily increasing population. In 1958, the population was about 5,500, and by 2006, it had risen to 17,531. Since 2008, the population has surpassed 18,000 and has remained stable in the subsequent years (INE, 2024).

Tourism is the primary economic driver of the municipality. Malgrat de Mar is equipped with hotels, campsites, and shops to cater to visitors' needs. Over the years, the number of campsites and hotels has significantly increased, with the number of accommodations doubling in the 1990s (Figure 8) (IDESCAT, 2022). Tourism has flourished along the coastline and the delta region (Figure 9.7), becoming so prominent that during the third quarter of the year, Malgrat de Mar accommodates a demand that is 155.44% of its population.

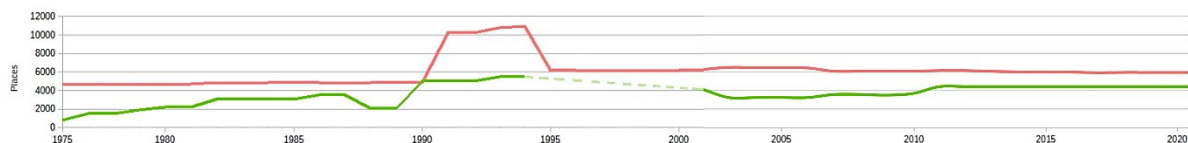


Figure 9.7 Malgrat de Mar campings (green) and hotel (red) available places evolution from 1975 to 2020.

Source : (IDESCAT, 2022).

Agriculture and industry are also significant economic activities (Figure 9.7). Nonetheless, these sectors have been losing momentum in recent years. For instance, the utilized agricultural area has decreased over the years, from 319 hectares in 1982 to 264 hectares in 2009, and 203 hectares in 2020 (IDESCAT, 2024).

Geographically, the structure of the municipality of Malgrat de Mar is organized with a compact population center in the middle, surrounded by agricultural land to the east and protected non-developable land to the west. Malgrat de Mar is strategically located midway between the cities of Barcelona and Girona along the Mediterranean coast. Thus, the municipality has major transportation routes, such as National II (which runs from Madrid to the French border, passing through Barcelona and serving as the main axis of the Maresme region, running parallel to the Mediterranean), highways, roads, a railway line (connecting Barcelona with Baix Llobregat and Maresme, running parallel to the coast), and another railway line (Ajuntament Malgrat de Mar, 2005). The town and the beach are physically separated by the railway line (Figure 9.8).

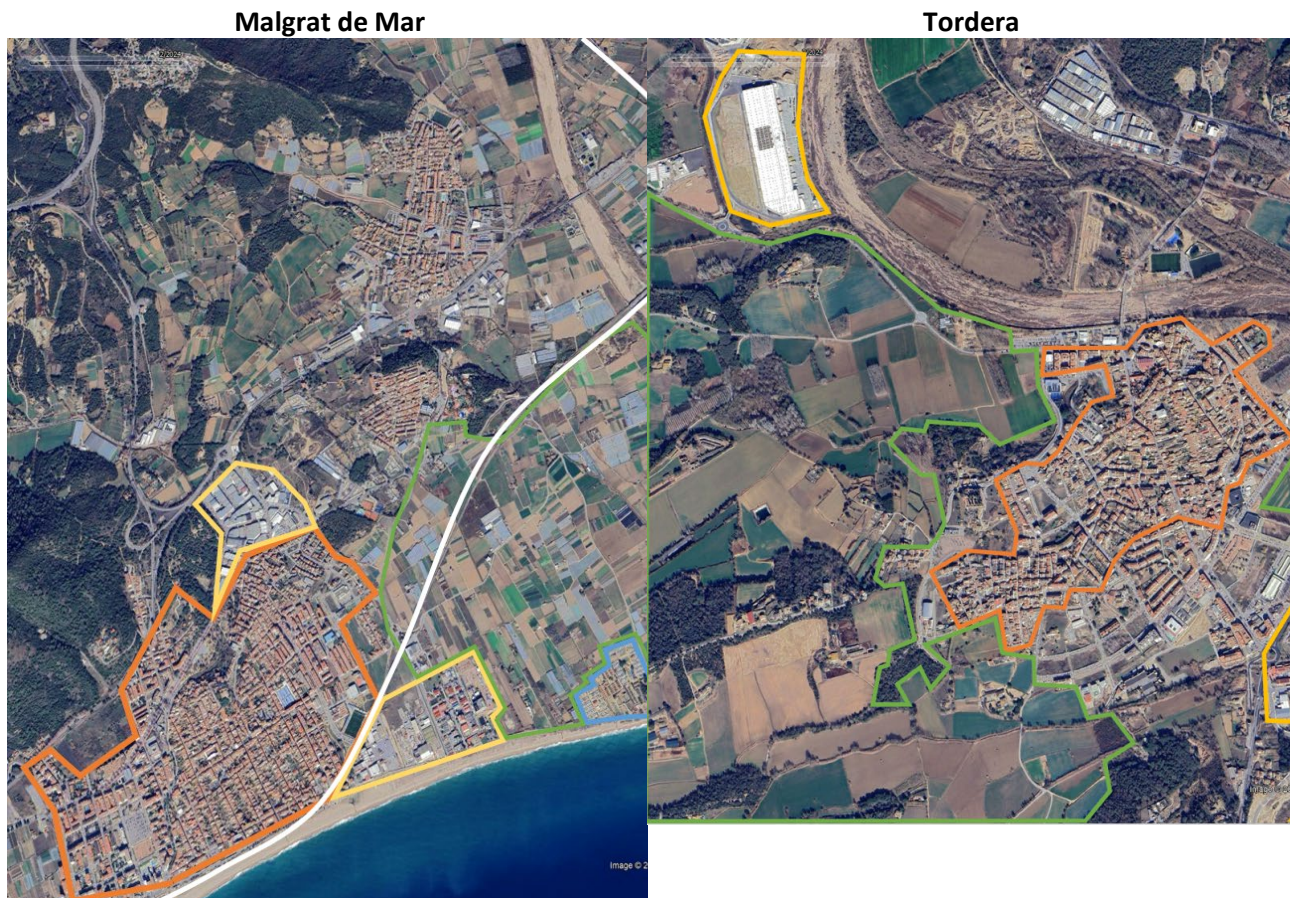


Figure 9.8 Malgrat de Mar and Tordera aerial photography and delimitation of the urban center (orange), industrial zones (yellow), agricultural zone (green), camping area (blue) and train line (white).

- **Tordera**

The municipality of Tordera comprises a historic nucleus that originated right next to the Tordera River, along with a collection of neighborhoods and numerous scattered urbanizations throughout its territory. Currently, Tordera continues to experience demographic and economic expansion.

Around 2007, Tordera was trending towards demographic growth and underwent significant transformations in various aspects (Figure 9.9) (INE, 2024). However, this growth has sparked some controversy, as the urban

expansion encroaches upon the floodplain of the Tordera River. Currently, and especially in recent years, an increasing number of people from the Barcelona metropolitan area have been opting to relocate to Tordera for more accessible employment and housing conditions.

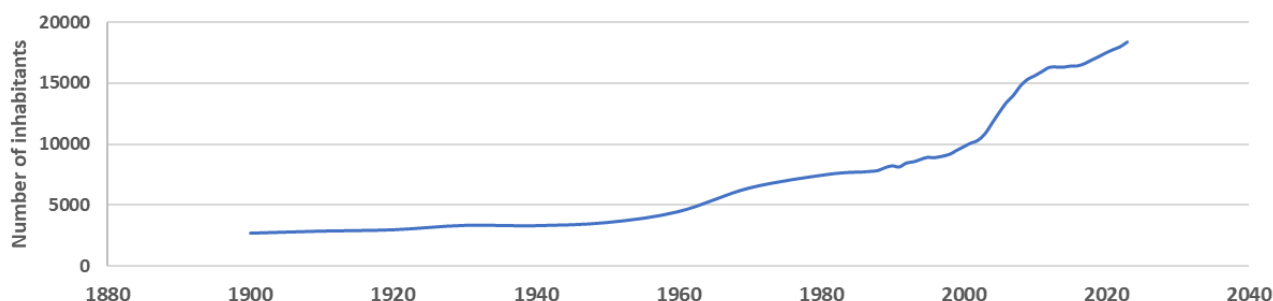


Figure 9.9 Tordera population evolution since 1900 to 2020. Source : (INE, 2024)

Since no historical data is readily available on the evolution of the number of industries in the Tordera municipality, comparing two land use maps can provide an overview. A map from 1990 shows a modest industrial zone occupying the eastern part of the municipality, by 2018, this area had undergone significant growth, quadrupling in size (Figure 9.10).



Figure 9.10. Tordera aerial photography and delimitation of the urban center (orange), industrial zones (yellow), agricultural zone (green) and highway line (white).

The city is connected by numerous roads and highways. In terms of its location relative to the national road, it serves as a highly frequented point along this road due to its connections with Barcelona, Girona, and Mataró, among others (Figure 11).

Recovery analysis

To address the recovery phase after the Gloria storm in the Tordera river basin, we focus primarily on the direct damages caused by Storm Gloria. We consider direct damages as the cost of repairing and rebuilding.



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For this reason, we gathered the most comprehensive data to address all these direct costs incurred in the municipalities of Malgrat de Mar and Tordera (Tables 1 and 2), along with their corresponding descriptions. This database contains information exclusively from public entities, and all the specified direct costs are actual investments, not estimates.

Each damage considered in this work is described with the most probable hazard that caused it, the exposed element, and the cost for repairing and rebuilding. The elements at risk have been classified as follows:

- Natural environment: Includes ecosystems, wildlife habitats, and natural features.
- Transportation networks: Infrastructure such as roads, railways, bridges, and airports that facilitate the movement of people and goods.
- Industrial Use: Manufacturing facilities, factories, and warehouses where production processes take place.
- Commercial Use: buildings and spaces utilized for business activities.
- Residential Use: Housing developments, apartment complexes, and individual homes where people reside.
- Vehicles: Automobiles, trucks, and other modes of transportation.
- Essential facilities: Critical infrastructure necessary for maintaining public health, safety, and welfare, such as hospitals, emergency shelters, and government buildings.
- Utility System: Infrastructure providing essential services like water, electricity, gas, and telecommunications.
- Non-Essential Facilities: Buildings and structures not crucial for immediate public needs.

- **Malgrat de Mar**

The Gloria storm inflicted significant damage on Malgrat de Mar, with estimated total direct costs of repairing and rebuilding reaching approximately 25.5 million euros (Table 9.1). The impacts were broadly categorized into fluvial (river-related) and coastal damages, each contributing to different aspects of the overall loss. The total amount for fluvial damages accounted for 95% of the costs and the remaining 5% of the total amount of the direct costs incurred in Malgrat de Mar.

Table 9.1 Direct damage costs of repairing and rebuilding the effects of Storm Gloria in Malgrat de Mar municipality. + : Aggregation of different sources

Hazard	EAR	Cost	Source
Fluvial	Natural Environment	170.979	ACA
Fluvial	Transportation Networks - <i>Railway</i>	10.412.121	Adif
Fluvial	Transportation Networks - <i>Bridge</i>	4.589.286	Departament de Territori
Coastal	Transportation Networks - <i>Railway</i>	946.504	Adif
Coastal	Transportation Networks - <i>Urban Road</i>	76.346	+
Coastal	Transportation Networks - <i>Minor Road</i>	59.750	+
Fluvial	Industrial Use	468.908	Consorcio Seguros
Coastal	Commercial Use	4.539.108	Consorcio Seguros
Fluvial	Residential Use	3.806.345	Consorcio Seguros
Fluvial	Vehicles	298.857	Consorcio Seguros
Fluvial	Essential Facilities	11.700	ACA
Fluvial	Utility System	74.675	+

Coastal	Non Essential Facilities	23.004	+
Coastal	Content_Furniture	57.892	+
	TOTAL	25.535.480	

Fluvial damages primarily affected infrastructure and the natural environment, with substantial costs associated with transportation networks and essential facilities. The costliest damage was to transportation bridges, with a combined total of nearly 15 million euros, including 10,412,121 euros from Adif, and 4,589,286 euros from the territory department of the Catalan council. Adif is a public corporate entity affiliated with the Ministry of Transport and Sustainable Mobility, responsible for the railway network. The Tordera River, lacking any reservoirs, was unable to manage the substantial surge in water levels brought on by the Gloria storm (Figure 2, c) and d)). This led to one of the most striking scenes of the storm in Catalonia: the destruction of two bridges. One was the coastal railway bridge that connects Blanes to Malgrat, and the other was a local road bridge that links the two towns (Figure 9.11).

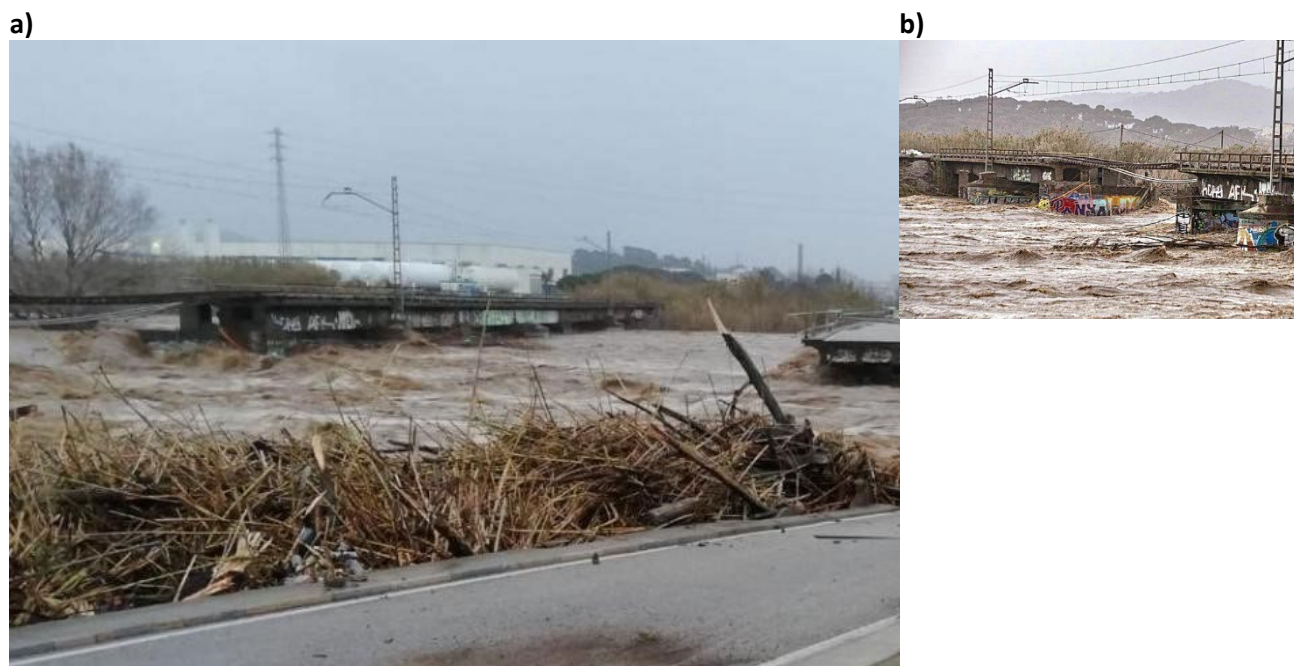


Figure 9.11 Gloria storm fluvial damages on transportation networks. a) road bridge (La Vanguardia, 2020); b) railway bridge (Diari de Girona, 2021).

Commercial use areas faced damages amounting to 4,539,108 euros, while residential use areas incurred costs of 3,806,345 euros, both covered by *Consorcio de Seguros*. *Consorcio de Seguros* is a Spanish public corporate entity operating in the insurance sector. Since the insurance consortium employs a broad hazard classification for potential damages, this study has identified the most likely hazard based on location and expert opinions from the area. As the consortium operates as an insurer, we are unable to obtain more detailed information regarding these types of damages.

The natural environment incurred impacts totaling 170,979 euros, overseen by the Catalan water Agency (ACA). These costs encompass the restoration and cleaning of riverbanks (Figure 3 b)).

Additionally, non-essential municipal buildings incurred 23,004 euros in damages, while minor and urban roads totaled around 135,000 euros. This figure provides an estimate of the damages sustained by the primary municipal center situated near the coastline, encompassing seafront promenades and urban furniture (refer to Figure 4b and Figure 8).

Due to the large amount of sediment carried by the river, a sandbar formed in front of the deltaic zone (González et al., 2020). After Gloria, over time, this shifted, resulting in the municipality of Malgrat de Mar, located south of this delta, not incurring costs related to beach sand erosion and the need for replenishment (Figure 9.12).

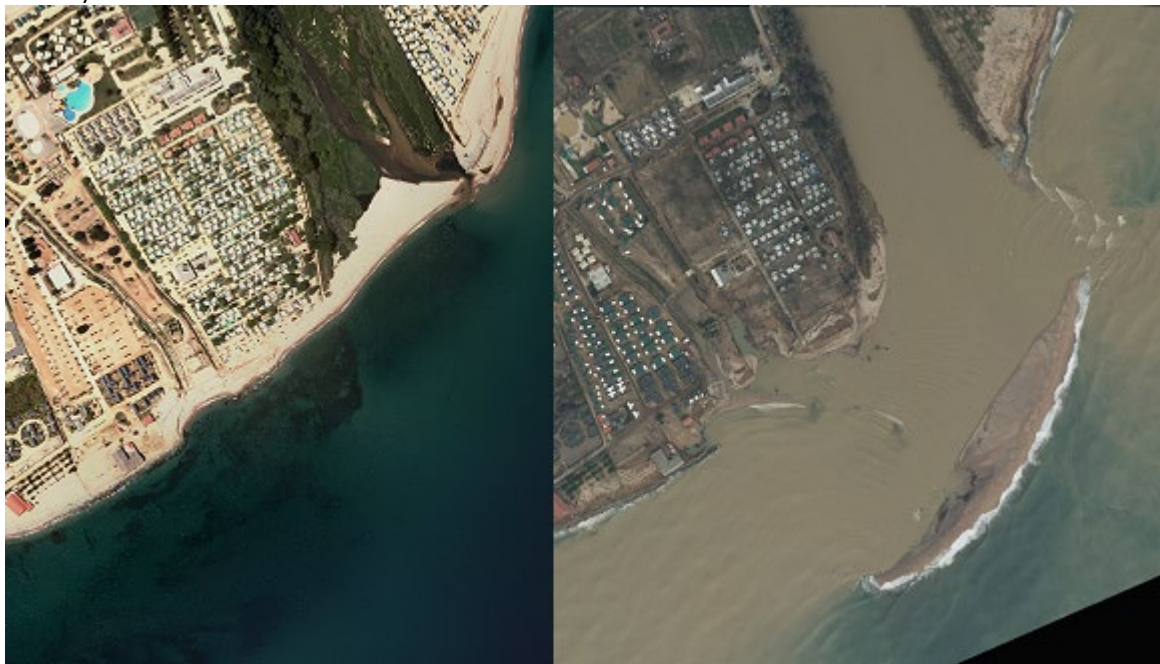


Figure 9.12 Comparison of the Tordera delta before (left) and after (right) Storm Gloria. In the post-storm image, sediment-laden water can be seen flowing into the sea, along with the emergence of a sand island just in front of the river mouth (Blog CREAM, 2020).

Overall, fluvial damages, primarily due to flooding, caused extensive infrastructure damage, particularly to bridges, and affected industrial and residential areas. In contrast, coastal damages were mainly related to transportation networks and municipal facilities due to beach erosion and retreat.

- **Tordera**

The Gloria storm hit the municipality of Tordera, with the total expenses for repair and reconstruction nearing 3 million euros (Table 9.2). These expenses include a range of damages, with the overall losses incurred primarily associated with river-related impacts.

Table 9.2 Direct damage costs of repairing and rebuilding the effects of Storm Gloria in Tordera municipality.
+ : Aggregation of different sources

Hazard	EAR	Cost	Source	Date
Fluvial	Natural Environment	297.500	ACA	
Fluvial	Transportation Networks - <i>Bridge</i>	42.108	+	
Fluvial	Essential Facilities	54.260	ACA	
Fluvial	Transportation Networks - <i>Major Road</i>	146.038	+	
Fluvial	Transportation Networks - <i>Minor Road</i>	407.585	+	
Fluvial	Industrial Use	122.600	Consorcio Seguros	
Fluvial	Commercial Use	648.780	Consorcio Seguros	
Fluvial	Residential Use	710.469	Consorcio Seguros	
Fluvial	Vehicles	46.123	Consorcio Seguros	
Fluvial	Utility System	404.008	+	
Fluvial	Content Furniture	7.998	+	
	TOTAL	2.887.469		

When comparing the two municipalities, Malgrat de Mar's damages stem from both the combination of coastal and fluvial effects, while Tordera municipality's are solely from the river. The total cost of damages differs significantly between the two municipalities, with Malgrat de Mar reaching nearly 30 million euros and Tordera at 3 million euros.

- The impact of the river was significant. Upstream of the Tordera river (Tordera municipality), the costs of repairing riverbanks amount to nearly 300,000 euros, remaining substantial at the river mouth, where a sandbar was formed (see Figure 12).
- Despite being a municipality with a favorable geographic location and serving as an important communication hub provincially, transportation networks were not well-protected. During Gloria, these networks suffered severe damages, resulting in high reconstruction costs. The disruption to transportation not only incurred immediate costs but also led to long-term consequences as traffic had to be rerouted, impacting businesses and communities along the affected routes. These costs were significant at both municipalities, both in Malgrat de Mar and Tordera. In fact, there have been aids at the national, provincial, and municipal levels to restore this type of damage.
- Between the two municipalities, there is a difference in the direct reconstruction costs of residential infrastructure. As mentioned earlier, Malgrat de Mar currently has a higher population, which would explain why the costs are higher. However, in Tordera municipality, the costs are also substantial, and the population is on the rise, increasing further. This observation is also consistent with the direct cost of vehicles and affected businesses by Storm Gloria, which are higher in Malgrat de Mar.
- Malgrat de Mar boasts a well-serviced coastline with amenities and municipal furniture, as tourism is one of the main drivers in the municipality. This explains why the costs are higher than in Tordera municipality, where such offerings are more limited.

- In the Tordera municipality, the prioritization of water control structures and the reconstruction of utility systems were crucial aspects of the recovery efforts. However, no information has been published regarding these specific measures.

It's important to emphasize that Storm Gloria had significant implications for Catalonia, prompting various levels of public administration (national, provincial, and municipal) to take action to address the damages. In smaller meteorological events, such extensive aid efforts are not typically mobilized. Additionally, it's worth noting that due to the varying importance of certain exposed elements within the territory, it is easier to find information and descriptions of the impacts. Utility systems, essential facilities, and other vulnerable elements are often underrepresented in loss databases or publications in reports or newspapers.

A significant effort has been made to gather the most comprehensive data to address all the direct costs of the damages incurred in these two municipalities, Malgrat de Mar and Tordera, along with their corresponding descriptions. We consider that these data accurately represent and depict what occurred during Storm Gloria in the territory. However, it's possible that damages were underestimated, and there may be inaccuracy in the classification of the hazards that caused these damages.

We have limited information on when the aid was disbursed. Aid at the provincial level (Generalitat de Catalunya) became available shortly after Storm Gloria, but due to the nature of public tenders, contracts weren't awarded until six months later, delaying the start of the works. These aids primarily targeted major projects. Furthermore, the Catalan Water Agency promptly initiated riverbank clean-up efforts just one month after the storm. However, restoration work in other affected areas required budgeting before execution, leading to varying timelines based on the scale of the projects. Generally, by the six-month mark following the storm and with the onset of summer, most smaller-scale projects had been completed, while larger projects were still underway. Nonetheless, restoration efforts for less critical elements took longer to finalize.

Building resilience for future events

The Tordera is a river with a distinctly torrential character due to its climate, topography, and the size of its basin, featuring significant mountain ranges just a few kilometers from the coast and a rainfall pattern marked by seasonality. Major floods of the Tordera, known as "Torderades", such as the one caused by Storm Gloria on January 2020, are regular, relatively frequent, and well-documented throughout history. Therefore, episodes of significant precipitation like Gloria and the subsequent "Torderades" are not extraordinary phenomena but recurring and predictable events. While it is impossible to know exactly when they will occur, it is certain that they will continue to happen in the future.

One example showing that this territory and its floods are well-studied are the two projects carried out by CREAM in this same area (ISACC and REDAPTA). These projects aim to conduct a comprehensive study of the basin to develop strategies for adapting the Tordera river basin region to the effects of climate change (ISACC *TorDelta*). These projects seek to align and harmonize the socioeconomic and environmental interests of the area.

As a result of Storm Gloria and based on previous studies, the direct damage caused was not due to the climate or the river's flooding but to poor management and excessive occupation within the river space. For



a long time, there has been a call to relocate the complexes situated along the coastline, in the mouth area, and on the alluvial plains of the Tordera river. This is not only about protecting nature but also about ensuring safety. However, progress has been stalled due to difficulties and differences among the various administrations involved (Pavón Gamero & Panareda, 2020). Nevertheless, following Storm Gloria, a scientific and technical committee convened to propose integrated solutions for future “Torderades” (NatMonT, 2020). These solutions can be summarized as follows:

- **Territorial Reorganization:**
 - **Recovery and Protection of Natural River Outlets:** The current occupation of the coast (e.g., campsites) prevents water from flowing out and poses a safety risk to the population. Additionally, there has been a noted decline in the area's biodiversity.
 - **Relocation of Structures Near Riverbanks:** This includes widening the main riverbeds and tributaries.
 - **Relocation of Coastal Structures:** Moving structures away from the coastal fringe.
 - **Expansion of Protected Natural Areas:** Increasing the boundaries of protected natural spaces.

“Unfortunately”, the actions taken after Gloria were exclusively focused on repairing and rebuilding the damage due to the emergency and the need to repair the damage, which were justified and unavoidable. However, territorial management of the basin cannot end with reconstruction and economic support tasks (Pavón Gamero & Panareda, 2020). While these interventions are necessary, they are not sufficient. More comprehensive, medium-term measures are needed that consider the natural dynamics. In some cases, this will require rethinking aspects of the socio-economic exploitation model in the basin, particularly along its coastal front.

There is currently no detailed information available regarding the evolution or implementation of the proposed territorial reorganization. A year after the Gloria storm, the rebuilding efforts by the Catalan Water Agency (ACA) and local municipalities have mostly focused on repairing or expanding damaged structures. These interventions were often made without proper technical and scientific knowledge on flood damage mitigation, which contributed significantly to the damage during the storm. Despite evidence of their ineffectiveness, these costly efforts have failed to prevent future damage and have hindered essential priority actions identified after Gloria because they contradict the real needs and current protections for the river, including the area's hydraulic and ecological needs (NatMonT, 2021).

However, the municipalities of Malgrat de Mar and Blanes have collaborated to protect the natural space at the Tordera River's mouth, including requesting the Generalitat of Catalonia to declare the area a Partial Nature Reserve.

Economic and political pressures are very strong in the territory, and these floods have been occurring and studied for a long time. Despite the existing studies and the evaluations conducted after the Gloria storm, the solutions to extreme weather events remain the same: repair and rebuild. It seems difficult to reconcile the political and economic differences in the region to implement new territorial reorganizations that protect both the safety and interests of people and the environment.

10 Meta-analysis on Learning Cases

The following chapter summarizes the main findings from the Forensic Analysis conducted across the PARATUS project's case studies, including the Alps, the Caribbean, Turkey, and Romania. It follows the structure of the Forensic Analysis framework and aims to give a comprehensive overview of the similarities in disaster risk management across the studies. It also aims to identify the progress and gaps in building resilience. The summary table of these findings is in the Annex II (Table 13.1).

Hazard

The PARATUS Forensic Analysis approach examines various case studies related to different types of natural hazards, such as landslides in Austria, hurricanes in Sint Maarten, earthquakes in Kahramanmaraş (Turkey) and Vrancea (Romania), the Vaia storm in Bolzano and Trentino Provinces (Italy), and the volcanic eruption in Saint Vincent and the Grenadines. These case studies highlight the nature of hazard interaction, which occurs when multiple hazards compound in the event. Likewise, they pinpoint the role of compounding factors (e.g., the COVID-19 pandemic and dengue outbreak in Saint Vincent and the Grenadines), which can exacerbate the impacts and challenge disaster risk management.

The definition of hazard interaction is still under discussion among the experts. However, most of the definitions fall under similar classifications. This analysis shows the types of hazard interaction defined by Tilloy et al., (2019), namely, independence, triggering (cascading), compound hazards (association), change conditions, and mutual exclusion (negative dependence). Below is the summary of the interaction analysis in the frame of PARATUS case studies.

Table 10.1 Types of hazard interactions by Tilloy et al., (2019) identified in the case studies within the Forensic Analysis

Type of hazard Interaction	Case study	Interaction
Independence	Saint Vincent	Volcanic Eruption, COVID-19-19 and Dengue Outbreak
	Sint Maarten	Hurricane Irma and Maria - Dengue Outbreak
Triggering (cascading)	Vrancea (Romania)	Earthquakes lead to FIRES
	Sint Maarten	High wind velocities, accompanied by storm surges coupled with high and low incoming waves, provoked flooding of the lower coastal areas.
	Türkiye, Kahramanmaraş Earthquake	The long-term motion of Anatolian plate is facilitated by repeated earthquakes along the North and East Anatolian Faults.
	Province and Bolzano and Trento, Vaia Storm	The cyclone caused several hazard events, such as debris flow due to landslides and mudslides and riverbed erosion due to deposits and accumulations.

Compound hazard	Saint Vincent	Volcanic eruptions are compounding hazards due to an eruption that can lead to different hazards such as ash falls, PDCS and Lahars.
	Türkiye, Kahramanhama Earthquake	Fault rupture spanning over 300 km along the left-lateral East Anatolian Fault resulted in three major earthquakes in the south-east Anatolian region of Türkiye (Pazarlık, Elbistan, and Hatay-Yayladağı) and caused displacement of approximately 3-5 m on the fault.
	Vaia Storm	Mediterranean cyclone with hydrological and meteorological events that occurred during the cyclone (exceptional windstorms, landslides, floods, waves, and storm surges).
Change Condition	Landslide Observatories Lower Austria (LOLA)	Climate conditions such as long-lasting heavy rainfall and rapid snow melting drive both weathering and triggering mechanisms of slope instabilities, resulting in slow-moving landslides.
Mutual Exclusion	Saint Vincent	On a smaller scale, ashfall deposits might prevent the roofs from being damaged by the wind gusts of the hurricane.

Each case study, whether focusing on specific events (e.g., the 2023 Kahramanmaraş earthquakes, Hurricane Irma, and Maria in 2017) or providing a broader historical perspective (e.g., landslides in Lower Austria, earthquakes in Vrancea), shows how these hazards have caused significant damage and disruption to the affected regions, impacting infrastructure, buildings, and human lives. Hazard interactions are unique for specific events in a particular time and area. The analysis shown in Table 10.1. helps to understand the hazard interaction classifications and how the examples vary even if they have similar events.

Short-term Impacts

The short-term impacts, i.e. those immediately following the event, reported in the case studies, evidence a wide range of consequences due to the different hazards involved, their magnitude, and the specific context. Despite the heterogeneity of the events, some impacts were common across the case studies, shown in Table 10.2.

Table 10.2 Main impacts across the case studies, the x indicates if the impact was reported in the analysis.

Impact/Case study	Lower Austria-Landslides	Sint Maarten-Hurricane	Turkey - Earthquake	Romania – Earthquake	Saint Vincent-Volcanic Eruption	Vaia, North Italy-Windstorm
Damage to Housing and Buildings		X	X	X	X	X
Damage to Critical Infrastructure	X	X	X	X	X	X

Environmental Impacts		X			X	X
Health Impacts		X	X	X	X	
Impacts on Agriculture and Food Security		X			X	X

One of the most significant impacts observed across multiple cases is the **damage to housing and buildings**, often leading to the evacuation, displacement of the population, and disruption of livelihoods. The earthquakes in Kahramanmaraş, Turkey, in 2023 and Vrancea, Romania, in 1977 caused severe damage and collapse of residential and commercial structures, resulting in numerous casualties and injuries. Similarly, hurricanes Maria and Irma in Sint Maarten in 2017 and the volcanic eruption of La Soufrière in Saint Vincent in 2021 led to the destruction of thousands of homes and the evacuation of affected areas.

Every case study reported **damage to critical infrastructure**, including transportation networks, utility services, and healthcare facilities. This type of damage is crucial in the health sector since the damage to healthcare facilities and the limited capacity to provide medical care during emergencies worsened the health impacts, leading to loss of life, injuries, and even an increased risk of disease outbreaks.

The environmental impacts of natural hazards included **damage to forests, contamination of water sources, and impacts on biodiversity**. These events had far-reaching consequences for ecosystems, wildlife habitats, and the overall natural landscape, which can have long-term implications for environmental conservation and tourism.

The case studies of the Caribbean and Vaia storm highlighted the significant **impacts on agriculture and food security**, particularly in regions where these sectors are vital to the local economy and people's livelihoods. In these instances, agricultural lands, crops, and livestock were significantly damaged, leading to food shortages, increased prices, and threats to food security.

Finally, multiple cases reported **life losses and injuries**. For instance, the Kahramanmaraş earthquakes in Türkiye resulted in over 53,000 casualties and 100,000 injured, while the Vrancea earthquake in Romania claimed 1,424 lives and injured 7,598. This stresses the fact that medical care is enormously challenging during a disaster due to damaged health facilities and limited resources in affected areas. These cases underscore the critical need for **emergency preparedness and healthcare readiness**.

Long-Term Impacts

The long-term impacts of disasters varied notably across six case studies, influenced by the type, magnitude, exposure, and vulnerability associated with each natural hazard. Most case studies revealed extensive **long-term economic losses and livelihood disruptions**, especially in the agriculture and tourism sectors. Damage to critical infrastructure, including transportation, utilities, and housing, necessitated prolonged reconstruction efforts. **Environmental degradation** was prevalent in most cases, encompassing habitat destruction, water contamination, and loss of ecosystem services. Additionally, the analysis reported that

affected populations experienced **social impacts**, such as psychological displacement and the loss of community networks.

First Response and warning systems

Certain commonalities in the analysis regarding warning systems were identified, such as the challenges in **effectively disseminating warnings**, especially for vulnerable populations. The lack of integrated and comprehensive warning systems for multiple hazards is highlighted in the Caribbean case studies, while the Vaia Storm case emphasizes the need to amplify the warning system for another hazard, such as windstorms. The analysis also underscores the importance of **improving public awareness and education about disaster risks and preparedness**.

The first response differs from each case study and was especially relevant for earthquakes, volcanic eruptions and hurricanes. It is identified that there is a common protocol that includes the activation of emergency response teams, the evacuation and temporary shelter, the establishment of emergency operations centres and coordination mechanisms, and the provision of immediate relief aid. The **challenges in coordinating multiple responding agencies and organizations** were evident, particularly in the case of infrastructure damage. When the magnitude of the event exceeded the capacity of the local government, international aid organisations and foreign assistance became involved.

Pre-disaster conditions

Vulnerability

The main results found in the dimensions of vulnerability are described below and summarised in Figure 10.1

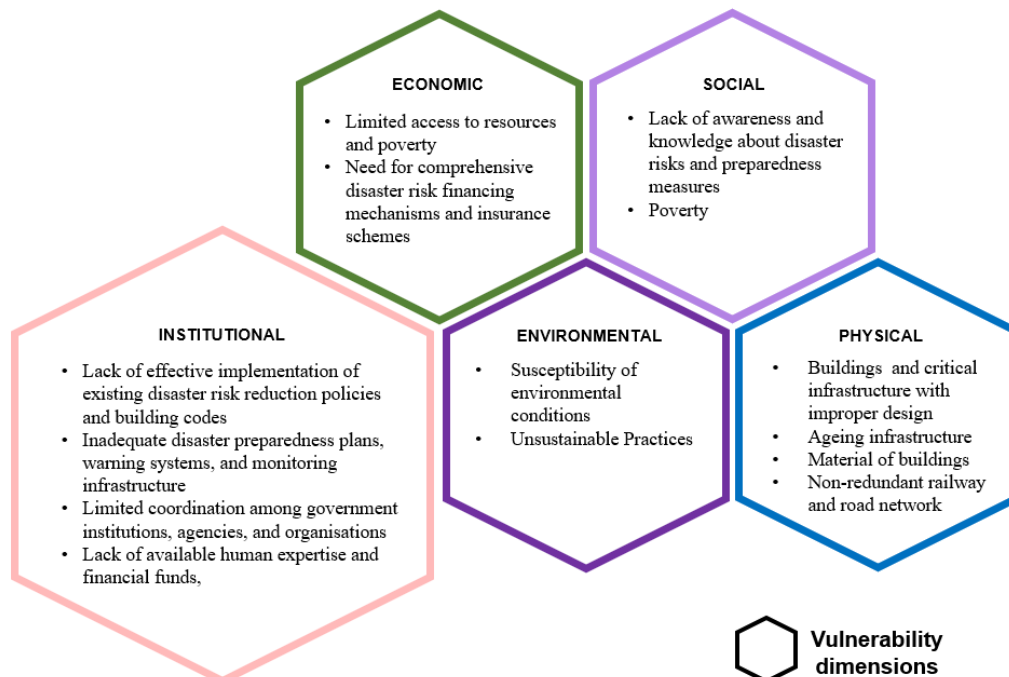


Figure 10.1. Main vulnerabilities identified across the case studies.

Physical dimension

The physical vulnerability was key in all case studies. Despite the Forensic Analysis covering different hazards, certain vulnerabilities are mentioned repeatedly. One example is the **ageing infrastructure**, which means that old infrastructure often lacks building codes to mitigate the impact of hazards, and its age makes it more vulnerable if there is inadequate maintenance. Connected with the ageing infrastructure, the non-redundant railway and road network made the area more prone to disruptions and cascading impacts.

Another relevant aspect of physical vulnerability is linked to the buildings' material and design; in the earthquake case studies, it was mentioned that **buildings with improper seismic design** were more prone to suffer collapse and damage. Likewise, in the case of hurricanes, buildings must be designed to withstand them. Moreover, **the material of the buildings** also played a fundamental role in the case of ashfall.

Environmental Dimension

The findings in this vulnerability dimension can be divided into two categories: the **susceptibility of environmental conditions** and the **unsustainable practices** that contribute to increasing vulnerability. In the first category, steep slopes and geomorphological features in mountain areas contribute to landslides and mass movements, as seen in the Alps and Saint Vincent case studies. In the second category, unsustainable such as deforestation, habitat destruction, and ecosystem degradation increase the environment's vulnerability to natural hazards. Moreover, unsustainable land use practices in terrestrial ecosystems can also contribute to increased vulnerability.

Institutional Dimension

Four common and main institutional vulnerabilities were identified across the case studies. The first is the **lack of effective implementation of existing disaster risk reduction policies, regulations, and building codes**, which was particularly relevant for the earthquake case studies, such as the construction amnesty in Turkey and the impact of intermediate-depth earthquakes on building codes in Romania. This vulnerability also goes in the direction of some case studies highlighting the need to enforce current land-use regulations.

The second is **inadequate disaster preparedness plans, warning systems, and monitoring infrastructure**. This is primarily important in the Caribbean case studies, where the lack of adequate warning systems and monitoring infrastructure hampers preparedness and response during the event.

The third is the **limited coordination and communication among government institutions, agencies, and organisations** during the emergency response and recovery efforts. For instance, in the case of Vaia Storm, there was a lack of coordination between the provinces of Bolzano and Trento.

The fourth institutional vulnerability presented in the case studies pertains to a **lack of available human expertise, financial funds, and specific equipment for disaster risk management**. In the case of Saint Vincent and the Grenadines, stakeholders participating in the interviews noted a substantial lack of resources, including human expertise, equipment, and training required for effective disaster management.

Social Dimension

This dimension addresses how factors such as poverty, language barriers, gender inequalities, age (elderly and children), disabilities, and lack of awareness influenced the ability to cope and recover in the case studies. In most cases (excluding the ones in the Alps), **limited access to resources and poverty increased the adverse impacts of the disaster events**. Marginalised groups, such as migrants, female-headed households, the elderly, and persons with disabilities, face disproportionate vulnerabilities due to societal challenges and limited access to information and decision-making processes.

Another key social vulnerability is the **lack of awareness and knowledge about disaster risks and preparedness measures**. For instance, in Vrancea Romania, the Forensic Analysis mentions the "low level of knowledge, awareness, and preparedness (regarding seismic risk) among the population" as an ongoing vulnerability that limits failures to implement effective mitigation measures. A lack of awareness about risks can result in not taking necessary precautions or not following early warnings. Insufficient knowledge of safety protocols and evacuation procedures can threaten lives in emergency situations. Without understanding mitigation strategies, households and communities may overlook opportunities to minimise vulnerability. Limited information about available resources, support services, and disaster management plans can inhibit access to assistance during and after a disaster.

Economic Dimension

This dimension also addresses the fact that **limited access to resources and poverty** increase the adverse impacts of disaster events, as mentioned in the social dimension. This vulnerability is also linked to the difficulty of transferring risk through financial mechanisms such as insurance. In the Caribbean cases, a need was identified **for comprehensive disaster risk financing mechanisms and insurance schemes** that can support the mobilisation of funds promptly for vulnerable populations during emergencies.

Underlying Risk Drivers and Root Causes

The underlying risk drivers and root causes commonalities identified across the case studies are described below.

A relevant driver identified across the analysis was the **demographic trends** and the special link with migration patterns. For instance, In the case of Sint Maarten, the population growth is related to the migration of workers (driven by the rising tourism economy). This represents a challenge due to having an irregular status and not speaking the language (for a considerable amount), increasing their vulnerability and difficulty in humanitarian aid in case of a disaster. Similarly, in the case of Turkey, the significant presence of Syrian refugees in the country during the event exacerbated their critical situation, leading to a humanitarian crisis. On the other hand, in the case of Saint Vincent, out-migration patterns represent a risk driver due to the loss of human capital and, at the same time, is a consequence of the lack of opportunities in the Islands.

The unplanned development arose as a significant driver in most case studies. In the case of earthquakes, this is strictly linked to neglecting the implementation of the building codes. In Turkey, the rapid urbanisation process leads to converting agricultural land into urban areas, a raised demand for housing and urban services, and increased city population density. So, even though the seismic codes have been improved since the mid-1990s, the amnesty of laws and regulations encouraged the construction of low-quality and



vulnerable buildings. Likewise, in the case of Romania – Vrancea 1977, the overcrowded space because of the demographic increase driven by the development of industry at the beginning of the communist era, in buildings with questionable construction practices, combined with not retrofitting and rehabilitation of existing buildings for seismic hazard, mean historical neglect of taken adequate measures for reducing vulnerability.

On the other hand, the Caribbean case studies shared similar characteristics related to their geographical location, which means high exposure, limited available land, and historical colonial history. In Sint Maarten, about 70% of the economy is based on tourism. Unplanned development is connected to the transition from agriculture to tourism. During this shift, building codes and spatial planning were not enforced, leading to neglect of permitting processes. In the case of Saint Vincent, the colonial heritage led to difficulties in accessing land and resources for the most vulnerable population and a lack of studying and employment opportunities.

Finally, it is remarkable that despite the particular context, there is a need for a paradigm shift **from reactive measures in disaster risk management to proactive preparedness** and for **connecting disaster risk management to development policies**.

Recovery

The recovery section is divided into implementation, strategies, and gaps.

Recovery Implementation

The recovery implementation across the case studies focused on restoring critical services and infrastructure and providing financial assistance. Despite the specific details varying, there are some notable similarities in the recovery approaches and mechanisms employed across these cases, which are listed below:

- I. **Immediate response and search and rescue operations.**
- II. **The restoration of critical infrastructure.** Returning operations in transportation, power, water, and communication networks were essential to restoring critical services.
- III. **Hazard monitoring and early warning systems.** They were emphasized to enhance preparedness and facilitate timely response.
- IV. **Financial assistance and funding mechanisms.** They were established for the governments using their own resources, international aid, or a combination of both. They were used to rebuild infrastructure, provide temporary housing and shelters, and support the affected population and their livelihoods.

Recovery strategies

A recovery strategy was developed in most cases, initially focusing on immediate response and service restoration. The strategy then shifts to a long-term view, incorporating disaster risk reduction measures,

environmental sustainability, economic regeneration, social equity principles, revised policies, and exploring funding mechanisms.

Across the Forensic Analysis case studies, particular strengths related to the recovery strategy were identified. For instance, Sint Maarten, Saint Vincent, and Lower Austria adopted **comprehensive recovery strategies** that addressed multiple aspects, including infrastructure rebuilding, livelihood support, environmental protection, and risk reduction measures. Likewise, the recovery plan for Sint Maarten **incorporated principles of good governance, poverty alleviation, equity, and sustainability**. In the particular case of Lower Austria, **innovative hazard monitoring programs** were established to study landslides and develop risk reduction measures. Moreover, Saint Vincent explicitly aimed to **integrate disaster risk management and climate change adaptation across policies, planning, and budgeting**. Other case studies, such as the Kahramanhamas Earthquake and Vaia Storm, focus on **the financial mechanisms** to accelerate recovery, i.e. facilitating disbursements of funds, such as mandatory insurance (DASK in Turkey) and assistance protocols with banks, such as the case in the aftermath of the Vaia storm.

Recovery gaps

Despite the strengths identified across the recovery strategies and the recovery implementation, gaps and limitations in the process remain. For instance, most cases **lacked specific details on tackling community engagement, capacity building, and addressing differential vulnerabilities**. This is important to ensure recovery needs among the population and ensure sustainable recovery. Considering a few exceptions, **the strategies have a relatively top-down approach and are centralised**; they potentially overlook local conditions and community-driven approaches. This aspect is relevant to canalise recovery efforts for specific needs and leveraging local knowledge and resources. Furthermore, there **was limited evidence on monitoring and evaluation frameworks** to assess the effectiveness of the strategies. While recovery implementation is progressing or “concluded” across the case studies, clear indicators are lacking that demonstrate the effectiveness and success of the recovery process. Finally, the recovery process primarily focuses on the economic aspect, but there is a **need to address the multidimensionality of recovery** as well. This can potentially be achieved by incorporating it into regulatory frameworks and plans across public and private organisations and scales.

Building Resilience

The forensic Analysis reports identified three main actions regarding building resilience, summarized in the following table.

Table 10.3 Summary of the main actions taken for building resilience.

Actions	Examples identified in the case studies
Updating policies and regulations	- In the Caribbean, post-Hurricane Maria and Irma recovery plans in Sint Maarten embraced "Building back better" principles, while Saint Vincent aimed to improve building codes for ashfalls. - Romania made significant advancements in seismic regulations, launching a legal framework in 2022.



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Enhancing Hazard Monitoring and Early Warning Systems

- Turkey is revising its 2018 seismic code after the Kahramanmaraş earthquakes.
- The Provinces of Bolzan and Trento in Italy recognized the need for new risk management strategies for extreme weather, such as the "Climate Change Adaptation Plan."

Improving Disaster Preparedness and Community Awareness

- Lower Austria increased funding for research, including the innovative LOLA landslide monitoring program.
- Romania improved its seismic networks and early warning systems.
- North Italy used the Vaia storm as an opportunity for forest research and long-term monitoring.
- In Sint Maarten and Romania, the government acknowledged the relevance of community awareness and included it in plans and campaigns.
- North Italy promoted cooperation between institutions and forest owners, offering training in forest management and facilitating exchanges and discussions.

Resilience Gaps

The forensic analyses also identified shortcomings in risk management or opportunities to increase resilience that had not been previously leveraged. The following resilience gaps, in bold type, summarise the main ones identified across the case studies.

Despite progress, **challenges persisted in mitigating physical vulnerabilities**, such as rebuilding infrastructure in high-hazard-prone areas, as seen in the Lower Austria case study. A similar example is the case of Turkey, where there is a significant concern regarding the buildings built before 2000, specifically in the city of Istanbul, due to their ability to withstand earthquakes, so there is a need for physical mitigation measures. Analogously, the case of the Vrancea Earthquakes in Romania highlighted the continuing improvement of retrofitting efforts for "risky buildings", specifically targeting the ones built before 1963.

Another aspect that still **needs improvement is the population's knowledge, awareness, and preparedness**. This aspect was particularly relevant for Romania and Caribbean case studies. Similarly, the Caribbean case studies showed **the need for better cooperation during the emergency response and recovery phase**.

Finally, increasing resilience requires **financial preparedness and risk transfer mechanisms and strategies**. Although improvements are being made, this aspect encompasses individuals, communities, and local and regional governments. This aspect was emphasised in the Romania case study when low insurance coverage was identified despite being compulsory. Comparably, in the case of Saint Vincent, the stakeholder interviews highlighted the lack of preparedness in terms of finances.



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Figure 10.2. Main resilience gaps identified across the case studies.

11 Outlook and next steps

The work conducted on the seven Learning Case Studies presented in this deliverable provides a first insight in the integration between the Forensic Analysis and the Impact Chains approach. The analysis of additional Learning Case Studies will follow, building up on the lessons gained from the work on the seven front runners. This activity regards both the compilation of the Forensic Analysis as well as the development of additional Impact Chains.

The final output of this work consists in a collection of Impact Chains, developed thanks to the inputs provided by participatory activities in Application Case Studies and by the Forensic Analysis in Learning Case Studies. These Impact Chains are collected in an online database under the form of an Impact Chain Wiki. The Wiki is available online on the [Disaster Risk Stakeholder Hub](https://www.cmine.eu/topics/35391/page/impact-chains-WIKI)¹ (see Figure 11.1), through KUMU, an online tool which allows to build and store Impact Chains, while assisting in managing this complexity. The aim of the Wiki is to store the knowledge related to the Impact Chains and to facilitate its consultation by project partners as well as by external stakeholders. Consequently, the Wiki does not only contain the visual representation of risk but also the features associated to the different elements, many resulting from the work on the Forensic Analysis.

¹ <https://www.cmine.eu/topics/35391/page/impact-chains-WIKI>

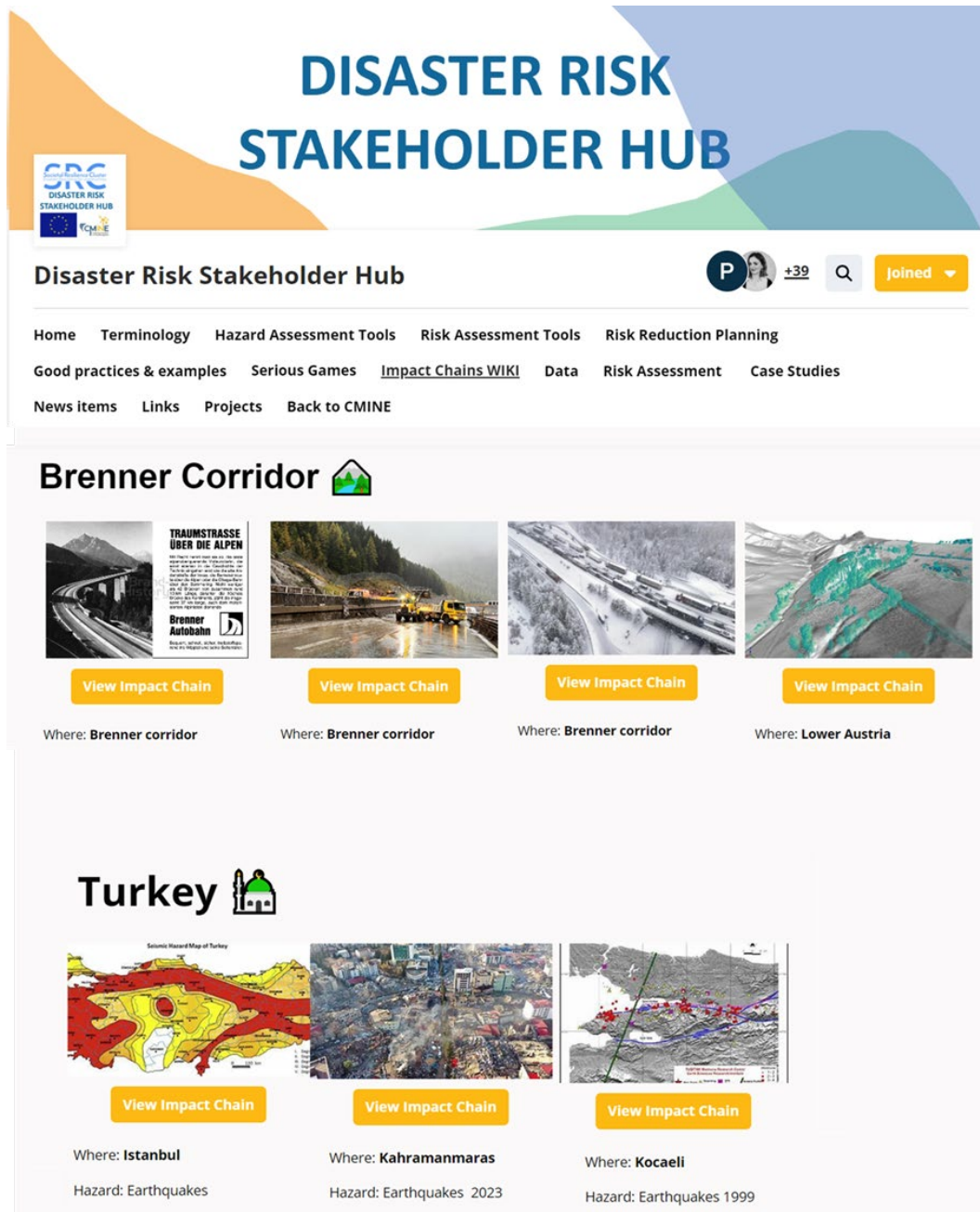


Figure 11.1 The Impact Chain Wiki accessible online from the Disaster Risk Stakeholder Hub (<https://www.cmine.eu/topics/35391/page/impact-chains-WIKI>).

Within PARATUS, the Impact Chains are being used for multiple purposes. Firstly, they serve as the backbone for data collection (WP2). With the development of Impact Chains in all four Application Case Studies, it became clear which components are important and which type of data are needed to provide a basis for quantitative and qualitative analysis.

Secondly, the vulnerabilities identified with the Forensic Analysis, which are part of the Impact Chains, can be used to identify adaptation options and for the development of serious games in WP3.



Finally, the Impact Chains guidelines which were originally developed and shared across the consortium will be updated, taking into account the experiences from PARATUS and other European projects where these are adopted.



12 Annex I

Table 12.1 Forensic Analysis framework characteristics and subdivisions

Hazard and impact analysis (what happened?) <i>when describing the aspects in this section address in the text their spatial distribution & time dimension e.g. where & when did these occur</i>	Hazard	Hazard analysis	Description of triggering hazard(s): e.g. Epicenter, time, scale, intensity, return period
			Description of cascading hazard(s), if any
		Large-scale (institutional) warning system- <i>both shortly before or during the event, depending on the type of hazard</i>	How: means of communication (e.g. sound, sms, bell, incl. language used)
			What: Message/information delivered
			Who: Institution responsible for/ who spread the warning
	Short-term impacts <i>They refer to the immediate consequences of a natural event, typically occurring in the days, weeks, and months immediately following the event. They can vary depending on the type of event and should be clarified in the initial scope</i>	Typology: description of short-term impacts by sectors	Physical assets
			Life/ Health
			Environment
			Functional/systemic e.g. transport/telecommunication interruption/loss of livelihoods
		Economic evaluation of the short-term impacts	Consider the economic losses related to the typology of impacts listed above
	First response <i>(during or shortly after the hazard occurrence)</i>	What & who - for each cell specify what has been done and who has done it e.g. local institutions vs international mechanisms	Evacuation
			Search & Rescue
			Other emergency services activated (e.g. shelters, water supply, energy generator, health)

	Long-term impacts. <i>These consequences originate from direct impacts and can persist for years or even decades after the disaster event.</i> <i>They can vary depending on the type of event and should be clarified in the initial scope</i>	Typology: description of long-term impacts by sectors	Physical assets
			Life/ Health e.g psychological impact
			Environment e.g deforestation, habitat destruction, water contamination, loss of ecosystem services
			Functional/systemic e.g. resettlement
		Economic evaluation of the long-term impacts	Consider the economic losses related to the typology of impacts listed above
Pre-disaster conditions (<i>why could it happen?</i>)	Vulnerability <i>be as specific as possible, mentioning aspects that could be potentially addressed in the future, be as evidence-based as possible</i>	Physical Dimension	e.g. lack of irrigation infrastructure, lack of road infrastructure, unprotected buildings and infrastructure, poor sewage system, insufficient maintenance of plants/pipelines, existing structural risk prevention measures
		Environmental Dimension	e.g. unfavourable soil conditions, crop highly susceptible to diseases, fragmented landscapes, lack of arable land and water, lack of biodiversity resources, habitat destruction

		Socio-cultural Dimension	e.g. limited skills and formal education, people with preexisting health conditions, age. employment status (formal /informal) (type of employment), marginalised groups of individuals, limited social networks, limited access to healthcare services, limited access to educational services, disregard of local knowledge, lack of engagement with local or indigenous communities, low risk awareness or low risk perception, mismatch of traditions and modern DRR-related technologies and policies.
		Economic Dimension	e.g. low access to credit, low access to risk insurance, low access to markets, low access to input
		Institutional Dimension	e.g. weak land tenure and access rights for women, inadequate climate information service, poor social protection, lack of disaster preparedness, lack of coordination between national and local levels of government
	Underlying Risk drivers <i>(namely: socio-economic processes and human-environment relations that affect exposure and/or vulnerability. These processes are not linked with the hazards studied but are process / condition intrinsic in society)</i>	Demographic trends	e.g. overpopulation or depopulation, in or out migration, population aging
		Urban and rural land use patterns and processes	e.g. changes in landscape management, strong / rapid urbanization, rural abandonment, land consumption
		Environmental degradation and ecosystem service depletion	e.g. deforestation, monoculture, soil erosion, salt wage, reduction of biodiversity
		Population and social organization: Inequalities & Resources distribution	e.g. presence of vulnerable/ stigmatized groups, indigenous groups, cast system, Structural unemployment, informal job market, poor health coverage, structural inequalities
		Trends and failures in governance	e.g. lack of decision- making power, lack of trust and recognitions, lack of representativeness, lack of communication among governing bodies / administrative units

	Identification of root causes <i>(focus on deep historic patterns that can rise from social, cultural or historical processes that had structural impacts on societal structure and functioning of institutions and thus highly affect the responsiveness to natural hazards. Those processes are mainly institutional / social / economic and have a very strong influences on wealth, resources and power distribution)</i>		E.g. colonisations and post colonization heritage, slavery, religion traditions and religion influence on society, racism, militarism & dictatorship, war and post- war fragilities, globalization etc.)
Recovery- <i>(what happened in the recovery phase? What was done to restore service/ address impacts?)</i>	Implementation <i>(This part focuses on the execution of the recovery phase, thus which stakeholders had a leading role, which resources were used and which measures were implemented during the recovery phase)</i>	Available capacities during the recovery phase	e.g. policies, institutional mechanisms, capacity building, technological skills, know-how
		Available financial resources to facilitate recovery- (Expost Finance /what type, from whom, how much)	e.g international assistance, bonds, contingency and reserve funds,extrabudgetary funds, insurance
		Distribution of resources	e.g. % of resources arrived/used, distribution of resources and activities implemented, responsible body for managing the resources
		Prioritisation of sectors and people by needs	Were resources equally distributed or were they allocated to specific sectors/ institution/ groups prioritized in the recovery phase?
		Factors that enabled or constrained the use/exploitation of these resources	e.g. cumbersome bureaucracy, lack of human capital
	Time	Time needed for service restored. If multiple services are mentioned please enter multiple rows and define the time needed to restore each service	e.g. transport going fluid again, buildings rebuilt and inhabited

Building resilience for future events <i>(What has been done after the event to reduce future risks and increase resilience? Please consider also actions which eventually led to negative consequences e.g. maladaptation)</i>	Capitalisation of experience & knowledge: <i>Has this event brought change (improvement or worsening in risk management for the future?)</i>	Adjustments of physical assets	e.g. improvements in construction materials, placement of protection measures
		Creation or changes to strategies and action towards prevention	at institutional level (e.g. updated risk map or civil protection plan, CCA strategy)
			at community level (e.g. local warning system, community/ family emergency plans)
		Changes in institutional structures in regional, provincial, municipal administration	e.g. creation of institutional figures e.g. climate change officer/unit
		Consequences on social cohesion	e.g. strengthened social ties, loosening of social networks, and bonds among community members new community volunteer network
		Impact on risk awareness/ perception	e.g. of (specific groups of) society, of institutions
		Role of risk finance	e.g. new insurance scheme developed, dedicated allocation of resources & public budget
	Points to be still improved	Major unaddressed vulnerability factors	

CASE #		1	2	2	3	4	5	6	7	8	9	10	11	12	13	14	17	18
		2021 European floods (Ahrstal flood in Germany)	2021 Southern European heatwave and wildfires (Türkiye Marmaris wildfire)	2021 Southern European heatwave and wildfires (General)	2020 Gloria storm	2020-2021 Covid-19 pandemic	Landslides observatory, Lower Austria	2018 VAIA	2017 Maria and Irma	2017 Space weather event	2010 Eyafjallajökull Volcanic Eruption	2005 Flood Disaster in Tyrol/Austria	Marmara and Kahramanmaraş Earthquakes	Vrancea earthquake, Romania	August 2021 Haiti	St. Vincent and the Grenadines (SVG), Barbados in April 2021	2011 Tohoku Earthquake and Tsunami and 1995 Great Hanshin Earthquake	2005 Hurricane Katrina
Hazard	Total Hazard	12	4	6	2	10	5	16	10	10	10	5	12	16	6	14	14	14
	Total Short-term impacts	15	5	4	15	11	5	13	0	0	0	10	16	7	0	24	17	15
	Total Long-term impacts	8	2	0	0	0	3	5	0	0	0	5	10	1	0	5	6	10
Predisaster conditions	Total Vulnerability	6	1	5	2	6	4	9	0	0	0	4	10	2	0	14	7	8
	Total Underlying Risk Factors	7	1	3	4	5	8	5	0	0	0	4	10	3	0	12	10	5
	Total Root Causes	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	1	2
Recovery	Total Recovery	10	1	2	3	3	5	14	0	0	0	6	12	3	0	9	12	12
Building Resilience	Total Building Resilience	11	1	0	0	3	5	20	0	0	0	5	16	5	0	3	12	7

RELATIVELY GOOD AVAILABILITY OF DATA:



Figure 12.2 Summary of the prioritisation process based on the data availability for the Forensic Analysis



Deliverable 1.2. Report on virtual participatory workshops in all learning and Application Case Study sites, including Impact Chain diagrams



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13 Annex II

Table 13.1 Summary of the Meta-analysis of the Learning Cases

Class	Sub-class		Major outcome	Case studies where the major outcomes apply
Hazard	Short-term impacts		Damage to Housing and Buildings	Most of them, except for the Lower Austria case study
			Damage to Critical Infrastructure	All of them
			Environmental Impacts	Caribbean and Vaia storm case studies
			Health Impacts	Caribbean, Romania, and Turkey case studies
			Impacts on Agriculture and Food Security	Caribbean and Vaia storm case studies
	Long-term Impacts		Economic losses and livelihood disruptions	All of them
			Environmental degradation	Significant in Caribbean and Vaia storm case studies
	First Response and warning systems		Challenges in effectively disseminating warnings.	Sint Maarten and Vaia Storm case studies
			Need for improving public awareness and education about disaster risks and preparedness	All of them
			Challenges involved in coordinating multiple responding agencies and organisations	Romania, Turkey, and Caribbean case studies
Pre-disaster conditions	Vulnerability	Physical	Buildings and critical infrastructure with improper design	Turkey and Romania case studies
			Ageing infrastructure	Lower Austria and Sint Maarten case studies
			Material of buildings	Saint Vincent case study
			Non-redundant railway and road network	Vaia Storm and Sint Maarten case studies
		Institutional	Lack of effective implementation of existing disaster risk reduction policies and building codes	Turkey, Romania, and Caribbean case studies
			Inadequate disaster preparedness plans, warning systems, and monitoring infrastructure	Significant in Caribbean case studies
			Limited coordination among government institutions, agencies, and organisations	Significant in the Vaia storm and Caribbean case studies
			Lack of available human expertise and financial funds	Significant in the Saint Vincent case study

		Social	Lack of awareness and knowledge about disaster risks and preparedness measures	Significant in Romania and Saint Vicent case studies
			Economic	Poverty: Limited access to resources
		Need for comprehensive disaster risk financing mechanisms and insurance schemes		Caribbean, Romania, and Vaia Storm case studies
		Environmental		Susceptibility of environmental conditions
			Unsustainable Practices	Caribbean case studies
		Underlying risk drivers and root causes	Demographic Trends	
Unplanned development			Caribbean, Romania, and Turkey case studies	
Recovery	Implementation	Immediate response and search and rescue operations		Significant in Romania, Turkey, and Caribbean case studies
		The restoration of critical infrastructure		All of them
		Hazard Monitoring and Early Warning Systems		Significant in Lower Austria and Caribbean case studies
		Financial assistance and funding mechanisms		Significant in Turkey and Caribbean case studies
	Gaps	Lacked specific details on tackling community engagement and capacity building		Applied in most of the case studies
		Strong top-down and centralised approach		
		Limited evidence on monitoring and evaluation frameworks		
		Lack of address for the multi-dimensionality of recovery		
Building Resilience	Capitalisation of knowledge	Updating policies and regulations		Most of them, except for the Lower Austria case study
		Enhancing Hazard Monitoring and Early Warning Systems		Lower Austria, Vaia Storm, and Romania case studies
		Improving Disaster Preparedness and Community Awareness		Caribbean, Vaia Storm, and Romania case studies
	Gaps	Challenges persisted in mitigating physical vulnerabilities		Applied in most of the case studies.
		Need for improvement in the population's knowledge, awareness, and preparedness		
		Need for better cooperation during the emergency response and recovery phase		

		Need for better financial preparedness, risk transfer mechanisms and strategies	
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