Deliverable D1.1

Report on participatory workshops in the four application case study sites, including impact chains diagrams for each analysed event

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Abstract

This Deliverable D1.1 provides an overview on the Impact Chains developed on the basis of the inputs provided in the first participatory workshops in the four application case studies of the EU Horizon Europe PARATUS project[1]: Istanbul (Turkey), Sint Maarten (Caribbean), Brenner (Austria) and Bucharest (Romania). While D6.2 reports more in-depth information about the workshops, D1.1 mainly focusses on the impact chains design process, with the help of the knowledge gained from the stakeholders in the workshops. Although the focus of D.1.1 is on the application case studies, specific learning case studies are also presented, where these are associated with a specific application case study in terms of geographical scope, affected sectors or combination of hazards.

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[1] https://www.paratus-project.eu/

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Version	Date	Author	Description
V1	18-04-2023	Silvia Cocuccioni (EURAC)	Made the concept note
V2	12-05-2023	Silvia Cocuccioni (EURAC), Funda Atun & Cees van Westen (UT)	Adapted concept note
V2	26-05-2023	Silvia Cocuccioni (EURAC)	Provided inputs on Impact Chains chapter
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V2	17-07-2023	Till Wenzel, Philipp Marr (UNIVIE)	Provided inputs on Alps Application Case Study
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V2	19-07-2023	Marija Bockarjova (UT)	Provided inputs on economic impacts
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Disclosure Statement:

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The deliverable 1.1 submitted to the European Commission on 31/07/2023 and is waiting for approval by the Research Executive Agency. Therefore, this current version may not represent the final version of the deliverable.

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
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 D1.1 provides an overview on the Impact Chains developed on the basis of the inputs provided in the first participatory workshops in the four application case studies of the EU Horizon Europe PARATUS project[2]: Istanbul (Turkey), Sint Maarten (Caribbean), Brenner (Austria) and Bucharest (Romania). Impact Chains are conceptual models of climate and disaster risks that have been developed to streamline the analysis of climate-related impacts and provide a structured framework for the comprehensive assessment of related risks They describe in an intuitive, graphical, and logical description the complex chain of cascaded impacts induced by possibly compounded hazard-related events and trends. They can be developed through a participatory approach (e.g., working with subject-matter experts), or by desktop-analysis of empirical evidence and scientific literature.

While D6.2 reports more in-depth information about the workshops, D1.1 mainly focusses on the impact chains design process, with the help of the knowledge gained from the stakeholders in the workshops. Although the focus of D.1.1 focuses on the application case studies, specific learning case studies are also presented, where these are associated with a specific application case study in terms of geographical scope, affected sectors or combination of hazards.

The Impact Chains that are presented in this deliverable are designed and can be explored through KUMU in a project dedicated to PARATUS[3]. KUMU was adopted to efficiently collect and structure a variety of knowledge and information. In many cases indeed also the content associated to specific elements and connections of the ICs can be viewed.

Moreover, another practical example of participatory development of Impact Chains for the PARATUS Application Case studies is reported. During the VISES/PARATUS Summer School, young researchers had the opportunity to explore and develop from scratch complex impact chains for these regions, exploring also the quantification (and modelling) of their components.

In the following steps of the project, ICs will be implemented in the PARATUS platform (see Deliverable 4.1 for more details on the Platform).

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[2] https://www.paratus-project.eu/

[3] https://kumu.io/mpittore-eurac/paratus

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1 Introduction to WP1 and D1.1

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 analyzing 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 on 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 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 Maria and Irma	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 August 17th 1999 Kocaeli and February 6th 2023 Kahramanmaras Earthquakes in Turkey	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 earthquakes occurred but they were not as devastating as Kahramanmaraş Earthquakes on 6th 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" provides an overview of the workshops that have been organized in the period from January to April 2023 in the four application case studies and presents the main finding.

In particular, 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 in 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). In particular, the **objectives of D1.1** are (1) to provide an overview on the results achieved in the **participatory workshops** in the four application case study sites, mainly focussing on (2) the **impact chains** based on the inputs provided by the stakeholders.

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

Although the focus of D.1.1 is on the application case studies, specific learning case studies are also presented, where these are associated with a specific application case study in terms of geographical scope, affected sectors or combination of hazards. The analysis of specific historical disaster events serves as a baseline to build impact chains for present and future scenarios in application case studies. D1.1 and the associated ICs will serve as a basis for further work which will be presented in D.1.2. In particular, the ICs presented in this report will be improved based on further stakeholder inputs as well as backed up by quantitative analyses. Moreover, D1.2 will have a stronger focus on learning case studies. Finally, the developed ICs will be collected and consolidated in a Wiki and will be integrated into the PARATUS platform (more details in Deliverable 4.1).

After this introduction which summarises the main links to the PARATUS project, this deliverable provides an overview on the Impact Chains approach (Chapter 2) and on its application in the different Application Case Studies (Chapters 3-7). Chapter 8 summarises the experiences gained in the VISES-PARATUS summer school, where the Impact Chains methodology was applied under the guidance of PARATUS partners in the four Application Case studies. Finally, Chapter 9 (discussions and conclusions) elaborates on the challenges encountered during the development of impact chains and provides insights on the next steps in the ICs implementation.

2 Impact Chains

Impact chains (ICs) are conceptual models of climate and disaster risks that have been developed to streamline the analysis of climate-related impacts and provide a structured framework for the comprehensive assessment of related risks following the comprehensive risk management framework (UNDRR 2022). Impact chains methodology helps elicit, conceptualize, represent, and share knowledge about multi-hazard risks within a given geographical and temporal scope. They describe in an intuitive, graphical, and logical description the complex chain of cascaded impacts induced by possibly compounded hazard-related events and trends (see Figure 2.1 and Figure 2.2). Such description includes other relevant risk-related factors, e.g., exposed systems and vulnerabilities. Within the resulting conceptualization of hazard and impact cascades, adaptation measures of different types can be identified, such as early warning systems, ecosystem-based adaptation, capacity building, and technical as well as socio-economic measures.

ICs can be developed through a participatory approach (e.g., working with subject-matter experts), or by desktop-analysis of empirical evidence and scientific literature. They can be used to understand risks from a conceptual perspective and can provide a consistent framework for a semi-quantitative assessment, e.g., with composite indicators or a structured qualitative assessment (e.g., Schneiderbauer et al. 2020; Estoque et al. 2022). They are widely used in climate risk assessment at national and regional scale (Fritzsche et al. 2015; Zebisch et al. 2017; 2021; 2022) and recently also included into an ISO standard (ISO/IEC 2020). Within PARATUS they are adopted in the four Application Case Studies to analyse future events and in Learning Case Studies to analyse specific past events.

Impact chains can be first built around the current risks situation and then extended through the identification of factors and elements related to a potential future situation. This future situation ideally takes into consideration the projected future climate, but also potential future trends in exposure (e.g., urbanisation leading to higher exposure values in cities) and vulnerabilities (e.g., an aging population leading to a higher vulnerability of population). Moreover, within PARATUS new uses of the ICs are being applied: their use is being extended to identify and analyse multi-hazard interactions & different cause-effect chains or impacts related to specific historical events and to describe specific scenarios.

2.1 Shared Guidelines

EURAC Research developed a document to provide guidance to the Application Case Studies for the systematic development of ICs. This document provided all necessary information to allow the implementation of well-founded ICs, explaining in detail what ICs consist of and which elements and specifications are necessary for the description of their components. Moreover, it included an explanatory part dedicated to the process of elaborating impact chains and provided detailed instructions on what was needed to run the participatory workshop and the subsequent editing work. The guidelines will be published as a EURAC report with a DOI in 2023 (Pittore et al., 2023).

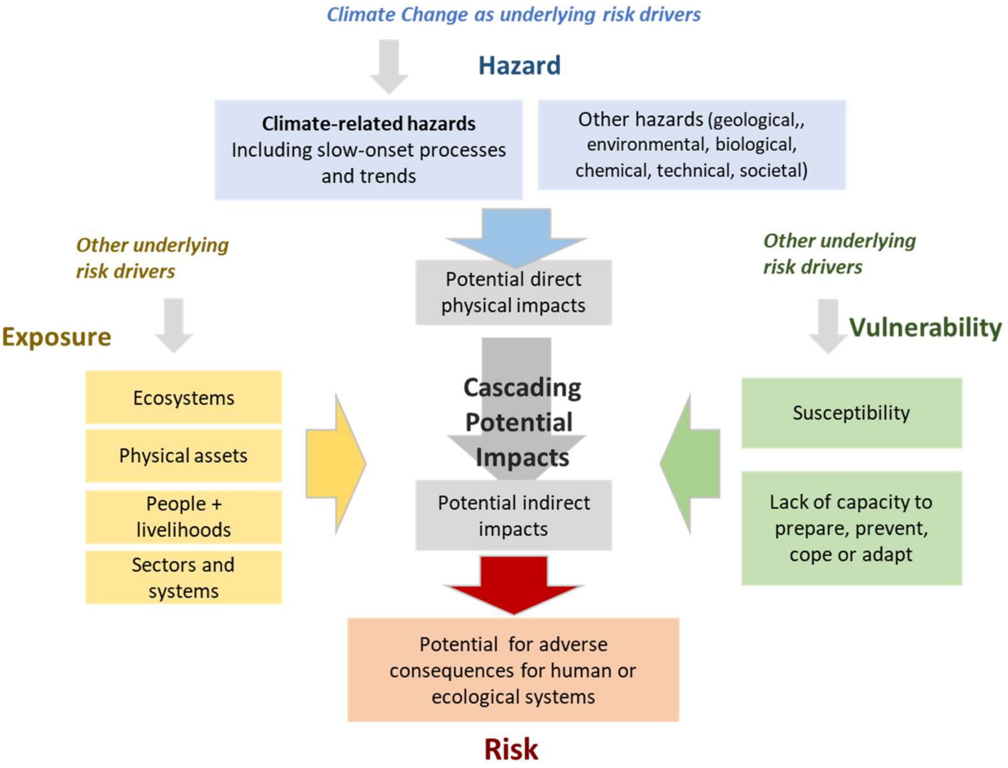

Figure 2.1: General structure of an impact chain of conceptualisation of cascading and compounding hazards and impacts and their adverse consequences for various human and ecological systems

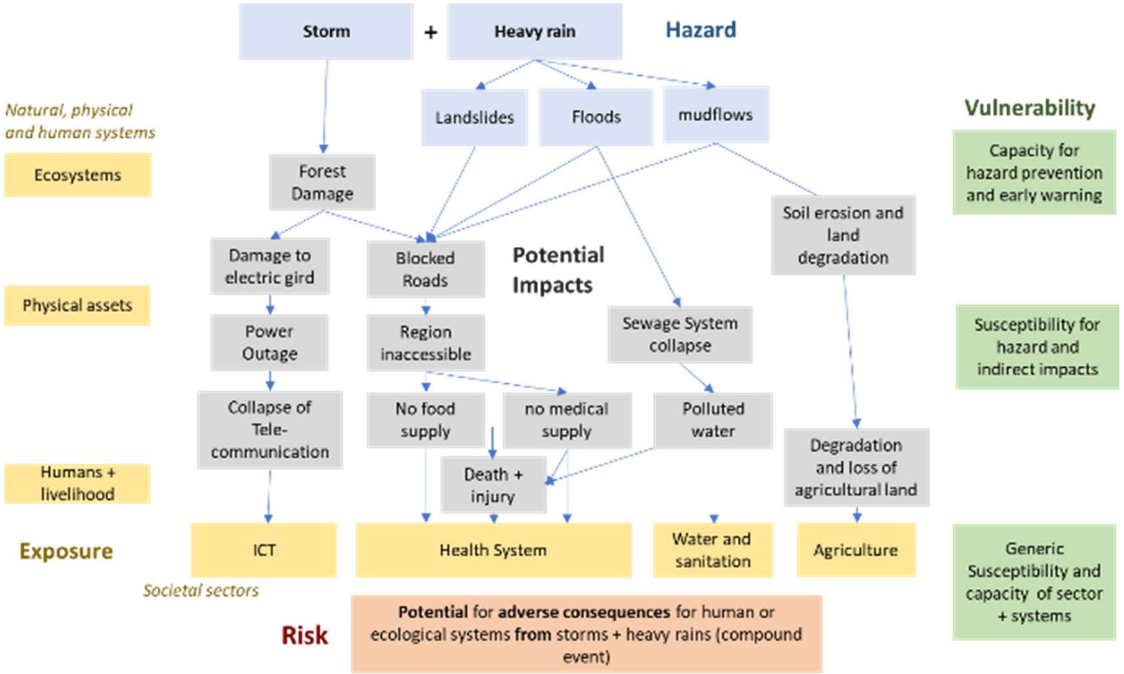

Figure 2.2 An example of conceptualisation of cascading and compounding hazards and impacts and their adverse consequences for various human and ecological systems

Each IC is developed -and must be interpreted- within a given geographical and temporal framework, which defines the limit of validity of the underlying assumptions and the individual IC components. Although the scope of the impact chain is not per se a component of the IC itself, it should be clearly stated and described and shared along the IC (as part of its metadata) to ease up further use.

The main information describing the scope are:

- **Operational framework**. This includes the main purpose of the IC, the implementation details (expert workshop, desktop analysis, machine-generated, etc.)
- **Geographical context**. Indication of the specific region where the IC is supposedly valid (mostly relevant for the connection elements).
- **Temporal scope**. Describes the time of the elicitation and the temporal validity of the underlying assumptions. If the impact chain refers to a specified or unspecified past event it can be "Past" or "Scenario" (in this case the time frame should be further specified). If it refers to a more generic set of risks it can be "Present time", "next future", "distant future" (especially important under non-stationary conditions).

The EURAC guidelines (Pittore et al., 2023) also highlight the different components of an IC: elements and connections.

The „**elements**" are the main building components of the ICs, representing as much as possible the more objective elements playing a role in the risk assessment. In a visual depiction of impact chains, the elements can be depicted as boxes and represent the most objective components. Table 2.1 lists the types of elements constituting an IC. Each element has several features to provide a thorough characterization within the IC (see Table 2.2)

Each element can influence one or more elements and can be influenced by one or more elements (except for those elements at the start of the chain). Each connection therefore represents a relationship among the different elements in the impact chain). Table 2.3 lists the possible connection types. Although this as well is a fundamental component of the ICs, they might also be largely subjective. All connections are directed, indicating therefore a specific direction of the relationships they imply.

Table 2.1. The different element types which can be found in an IC (source: edited from Pittore et al., 2023)

Element type	Description
Hazard	Climatic influence, event or trend that may constitute a hazard to the exposed assets and systems and result in an impact and possibly a risk (with damage or loss)
Impact	Possibly **negative** effect caused by a hazard or another impact
Exposure	People, assets, systems, functions and values possibly exposed to impacts and susceptible to be damaged, disrupted or negatively affected
Vulnerability	Intrinsic, environmental or institutional condition possibly amplifying the **negative** effect of an impact to the considered exposure elements. It includes sensitivity / susceptibility as well as lack of capacity to cope and adapt
Adaptation / mitigation	Measure to decrease the negative consequences of an impact by addressing one or more vulnerabilities or impacting mechanisms

Risk (Key Risk)	Combined impacts, exposure elements and vulnerabilities that describe potential risks (a key risk is highly relevant in the scope of the impact chain and should be prioritized in the assessment and evaluation phases)
External Driver	Other drivers that may significantly alter the socio-economic or environmental situations and possibly amplify negative consequences of impacts but cannot be mitigated or controlled within the scope of the impact chain

Table 2.2. List of features belonging to each element of an IC (source: Pittore et al., 2023)

Element type	Description
Type	Type of the element. It must be one of the types listed in Table 2.1.
Label	Synthetic description / title of the element for visual depiction
Description	Extended description of the element providing all necessary information to understand the role and significance of the element in the IC scope
Source	Source of the element, if already standard or authoring institution / author who proposed the element
References	References to the information sources used to justify, validate and possibly monitor the element.
Confidence	Confidence in the validity of the element, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement. Confidence is expressed qualitatively (or by means of ordinal numbers) [IPCC]
Relevance	Significance / relevance of the element within the scope of the IC
Time range	Time indication in which the element is considered active or unchanged (to be further discussed)

Table 2.3. The different connection types which can be found in an IC (source: edited from Pittore et al., 2023)

Element type	Description
“Causes“	(as in “Increase of average temperature ***causes*** melting of glaciers“. Indicates a (likey) causal relationship between the two elements. This relationship can only be defined among elements of type „Hazard“, „Impact“ and „Risk“.
“Impacts “	(as in “increase of power outages **impacts** industries“). Indicates mainly a relationship between an impact and an exposed asset.
“Affects“	(as in “Increase of average temperature ***affects*** the phenological cycle of vegetation”). Indicates a generic relationship where one element is supposed to affect the second one in some way (not necessarily in a causal link). This relationship can be defined among every type of element but could be partially hidden in the visualization.
“Relates to“	(as in “population **relates to** buildings”) – this relationship can be used to indicate connections between elements, it has more relevance for knowledge base systems - to be further discussed
“Mitigates“	(as in “improving irrigation techniques ***mitigates*** decrease of yield of crops” e.g., due to drought). This relationship can be defined only between adaptation / mitigation options and vulnerability elements or between adaptation options and impacts.

2.2 How to build an Impact Chain?

ICs can be built through a combination of participative & desktop-based activities. The following combination was proposed as an example to the Application Case Studies for the development of their ICs:

a) **Workshop - Context description, first brainstorming:** The goal is to define the scope of the IC, listing the main components of the IC and a preliminary identification of main risks. In PARATUS, together with stakeholders we sketch the impact chain itself and list entry points to further data and information sources. D.6.2 reports the preliminary results of the workshops during the six months of the project in four application case study areas: Caribbean, Istanbul, Alps and Bucharest. In D1.1 the workshops are briefly described, and more in-depth information can be obtained in D6.2. D1.1 focuses on the Impact Chain design process with the help of the knowledge together with stakeholders in the workshops.

b) **Desktop / off-line analysis:** Based on the outcomes of phase ''a'' the elements highlighted by the stakeholders can be analysed and backed up by data and reports through a desk-base analysis. An updated impact chain can be developed using a specific software, depending on the precise needs and requirements. Examples of possible software which can be used to develop and explore impact chains are, for instance MIRO[4], Excel or KUMU[5]. The pros and cons of each software are elaborated in the EURAC Impact Chains Guidelines (Pittore et al., 2023). The ICs that are in this deliverable are designed in KUMU. More details on KUMU can be found in chapter 2.3.

c) **Technical consultation(s):** The goal of this phase is to review, update and extend the impact chains drafted in phase ''b'' with the help of specific experts and stakeholders.

d) **Communication and Feedback:** Finally, phase ''d'' aims at communicating the results and receiving feedback from an ample set of experts, stakeholders, and end-users. This, for example, can be through a personalized platform, which allows an in-depth exploration of the ICs components and of their respective metadata (e.g. the PARATUS platform, see Deliverable 4.1 for more details).

2.3 The use of KUMU

Different technical solutions exist to ease up the tasks of implementing, documenting, and sharing impact chains. KUMU (proprietary, commercial) is a good solution to draw impact chains in a structured environment where not only the graphical aspect is considered but also the content to be associated to all elements and connections as outlined above. Currently it is technically the most flexible and, at the same time, structured solution to implement impact chains, also collaboratively. Unfortunately, it can be relatively complex to learn and use, and the visualization needs time to be adjusted. At the basis of each KUMU representation there is an Excel file, which can be downloaded. In the Excel file all the fields present in KUMU, which describe the elements and connections, are collected. The Excel form also allows to encode validation routines and it is machine-readable. Although the use of spreadsheet only allows to include textual content, it might largely improve the interoperability and shareability of impact chains, especially for researchers and practitioners in the field of risk. It should, nevertheless, be associated to solutions to visualize and possibly edit the impact chains in visual manner. Within PARATUS, KUMU is used to efficiently collect and structure a variety of knowledge and information, as a base for further discussion and consultation, and to initialize or update structured data management (e.g., using Excel).

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[4] https://miro.com

[5] https://kumu.io

3 Application Case Studies Workshops & Impact Chains

Overall, several stakeholder workshops have been held during the first six months of the project in the four application case study areas. The workshops are described more in-depth in D6.2, while this deliverable focusses specifically on the Impact Chain design process, which was one of the points addressed during the workshops. Chapters 4-7 focus on each Application Case study individually, providing first a brief summary of the participatory workshops and then presenting an in-depth description of selected Impact Chains. In this deliverable, 15 Impact Chains for the four different application case studies are presented. An overview of all Impact Chains can be viewed in Table 3.1.

3.1 Impact chains overview in PARATUS

In PARATUS different types of ICs are being developed, focusing on a variety of hazards and sectors. Table 3.1 presents a current overview of ICs that have been developed within the PARATUS project (July 2023). Some ICs refer to specific historical events (Learning Case Studies) but have a similar geographical scope as the Application Case Studies. For instance, the IC on Kocaeli (IC 1 in Table 3.1) and Kahramanmaraş Earthquakes (IC 2) refer to historical events but can support the development of an IC which considers future earthquakes scenarios for the Istanbul Application Case Study (IC 3). Other differences among the ICs are the following:

- Despite the ICs being developed based on shared guidelines among project partners, some variations exist across the different case studies. For instance, the size of the connection arrows varies in some ICs, according to their relevance or confidence. These differences will be further elucidated in the subsequent paragraphs.
- Some ICs present an overview of the different impacts which can occur to a broader variety of sectors and their interactions (e.g., IC 1-6, 10, 12, 13), while other go more in depth in the impacts of one single sector such as IC 9 for the telecommunication sector and IC 11 for waste management and health.
- Some ICs have been developed using the inputs provided during the stakeholder workshops as a basis, while others have been built adopting a desk-based approach and will be discussed with the stakeholders in the upcoming participatory events (e.g., ICs 10-11 for Saint Vincent). These two approaches have been combined in other cases: for instance, in the Saint Martin Application CS, the ICs have been developed initially in the workshop, then improved and subsequently validated with the stakeholders. Therefore, the combination of the phases presented in the guidelines (see section 2.2) was adapted in the different Application Case Studies.

Generally, the PARATUS ICs can be explored through KUMU being these uploaded the in a KUMU project dedicated to PARATUS[6]. In many cases also the content associated to specific elements and connections can be viewed. The links to access the KUMU environment for the single ICs are provided in Table 3.1. These Impact Chains are presented in more detail in the following chapter of this deliverable. Additional Impact Chains are still under development and will be presented in the following deliverables. The reader should be aware that the KUMU products are living documents, which are being constantly developed and updated throughout the project, thanks to follow ups with the stakeholders and interactions among project partners. Therefore, the screenshots of the ICs presented in this deliverable might not correspond to the ones present on KUMU in later stages of the project. A backup of the KUMU project (in JSON format) has been carried out in order to store a version of the ICs of this stage of the project, consistent with this deliverable.

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[6] https://kumu.io/mpittore-eurac/paratus

This project has received funding from the European Union's Horizon Europe Research and Innovation program under grant agreement No 101073954

Table 3.1 Overview of Impact Chains being developed within the PARATUS project presented in this deliverable

IC number	IC name	Responsible partner	CS associated to IC	Geographical scope	Temporal scope	Sectoral scope	Chapter of Del 1.1. where IC is described	Link to KUMU
1	IC on Kocaeli Earthquake (1999)	ITU	Learning CS	Marmara Region, Türkiye	Past, 1999	Overview, multi-sectorial	Chapter 4.2	Link
2	IC on Kahramanmaraş Earthquakes (2023)	ITU	Learning CS	East Anatolia, Türkiye	Recent, 2023	Overview, multi-sectorial	Chapter 4.3	Link
3	IC on future earthquakes scenarios for Istanbul	ITU	Application and learning CS	Istanbul, Türkiye	Future	Overview, multi-sectorial	Chapter 4.5	Link
4	IC on Bucharest historical earthquakes	UB	Application and Learning CS	Bucharest	Past, 1100-1900	Overview, multi-sectorial	Chapter 5.3	Link
5	IC on Bucharest recent earthquakes	UB	Application and Learning CS	Bucharest	Past, 1940 and 1977 events and future trends	Overview, multi-sectorial	Chapter 5.4	Link
6	IC on floods and COVID-19 pandemic in Romania (2020-2021)	UB	Learning CS	Romania	Past, 2020-2021	Overview, multi-sectorial	Chapter 5.5	Link
7	IC on Hurricanes (General IC developed based on historical events)	NRC	Application and Learning CS	Sint Maarten	General / Future	Health	Chapter 6.1.3	Link
8	IC on Hurricanes (General IC developed based on historical events)	NRC	Application and learning CS	Sint Maarten	General / Future	Food supply	Chapter 6.1.4	Link
9	IC on Hurricanes (General IC developed based on historical events)	NRC/ UT	Application and learning CS	Sint Maarten	General / Future	Telecommunication	Chapter 6.1.5	Link
10	IC on volcanic eruption of 2021	EURAC	Learning CS	St. Vincent	Past, 2021	Overview, multi-sectorial	Chapter 6.2.4	Link

11	IC on volcanic eruption of 2021	EURAC	Learning CS	St. Vincent	Past, 2021	Waste management / Health	Chapter 6.2.5	Link
12	IC on 2002 floods in the Alps	UNIVIE	Application and learning CS	Tirol	Past, 2002	Overview, multi-sectorial	Chapter 7.3	Link
13	IC on 2005 floods in the Alps	UNIVIE	Application and Learning CS	Tirol	Past, 2005	Overview, multi-sectorial	Chapter 7.3	Link
14	IC on Noeslide	UNIVIE	Learning CS	Lower Austria		Slow moving landslides	Chapter 7.5	Link
15	IC on Alps (Brenner Corridor) scenario of blockage	UNIVIE	Application and Learning CS	Tirol & South Tirol	General / Future	Transport sector	Chapter 7.6	Link

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4 Istanbul Application Case Study

Istanbul is a mega city with its population of over 15 million inhabitants. The city is prone to earthquakes and associated hazards such as liquefaction, landslides, floods, fire, and tsunami. In addition, hydrometeorological hazards (i.e., extreme temperatures, fires, flooding) are also becoming increasingly problematic. The population growth is combined with the speed of urban expansion and the integration of new migrants (both native and foreign, including refugees from countries such as Syria and Afghanistan). Besides, the income and welfare gap between socio-economic groups is more pronounced in such big agglomerations. Despite their importance to the national economy, primate cities like Istanbul can have a far-reaching impact beyond their borders. This means that the impacts of certain shocks will be propagated through diverse channels to other cities. In the case study of Istanbul, we plan to focus on urban dynamics (including demography, social factors, economy, built-up environment, etc.) to reveal systemic vulnerabilities.

4.1 Participatory workshop summary

The application case study kick-off meeting within the participation of all units of the Istanbul Metropolitan Municipality, which was held on December 20th, 2022, provided a valuable contribution on the path of co-developing a holistic comprehension on risk drivers of a mega city and production of future scenarios to reveal how to enhance resilience at different levels and sectors. The meeting resulted in improved design of upcoming project activities and ensured that all relevant stakeholders will be engaged. As mentioned in the D6.2. (Chapter 3.3.3), the participatory workshop had been scheduled for February 27th, 2023, but it had to be postponed to June 1st, 2023, because of devastating earthquakes occurred in Kahramanmaraş on February 6th, 2023 and their large-scale aftershocks. The workshop language was Turkish, and interpretation was provided for PARATUS partners. The agenda of the workshop can be found in Annex I. The preliminary impact chain analysis of the Kahramanmaraş earthquakes is presented according to the focus of this deliverable in the following sub-chapters.

Six tables for focus groups were formed in the workshop. After a brief introduction at the tables, participants were asked to provide information about their disaster experiences, disaster risk management phases and positions they have taken part in disasters. 58 out of 87 participants mentioned their experience and disaster management cases for which they had been in charge. Most of them declared that they had been involved in several phases of management (mitigation, preparedness, response and rehabilitation). 39 out of 58 defined their duty as both in the field and desk based which covers data production, policy development, communication, organization, and management. Among the participants, 5 of them were in charge in 1999 Kocaeli earthquake, 11 of them in 2023 Kahramanmaraş earthquakes and 15 of them were active in the field in both.

In the first session, the participants were asked to evaluate what kind of impact chains would take place after a major earthquake which occurred near to Istanbul. Tables were free to design their point of view according to the following questions:

- What are the natural hazards that an earthquake can trigger?
- What are the impacts of earthquake and triggered disasters?
- What are the elements, systems, sectors, and functions that will be exposed to the effects of the disaster?
- Do they have effects on each other? If yes, what are they?

- What are the vulnerabilities of the elements, systems, sectors, and functions that will be exposed to disaster?

In 90 minutes, each table developed a poster presenting their answers. The triggered natural hazards are cited such as tsunami, landslides, and inundation. Secondary hazards are given as dam breaks, fires at industrial facilities, leakage of chemicals. The cascading effects were defined as impacts on critical services, lifelines, and security. Discussion on security issues was crucial because in the first meeting which had been held on December of 2022, prior to Kahramanmaraş earthquakes, an officer from Istanbul Fire Brigade had a very strong emphasis on how security is vital aftermath of disasters. Beside the problems which might occur in the three main economic sectors, participants noted logistic issues in both response and rehabilitation phases. In terms of defining systemic risks and discussing their impacts, participants made important points in line with their past professional experiences and the experiences of the Kahramanmaraş earthquakes that occurred a few months prior to the meeting. Consequently, humanitarian issues, supply of basic needs of disaster victims, sheltering and communication were common keywords in each table. This session was successful by the means of hearing the experience of professionals within the comparison of the last earthquakes impacts to the previous disasters and their evaluation and discussion in dealing with such devastating events.

The second session of the program started with presentations by Çağlar Göksu, Ahmet A. Aşıcı and Kerem Y. Arslanlı on the reflections of the Kahramanmaraş 2023 Earthquakes on different sectors. Following these comprehensive presentations, participants were asked to evaluate impact chains of a probable earthquake that would occur near Istanbul according to the six different scenarios produced by the PARATUS ITU Team. In the last session of the workshop, spoke persons of each table presented their approach and output according to the given scenarios (see section 4.4. for details).

4.2 Impact chain - Kocaeli 1999 (Learning case study)

A 7.4-magnitude earthquake occurred in Gölcük/Kocaeli on August 17, 1999, at 03:02. Official records show that 18,373 people died, 48,901 people were hurt, 96,796 homes and 15,939 workplaces were completely or severely damaged. According to T.B.M.M. (2010), some 250.000 individuals lost their homes, and many were forced to relocate to neighboring cities. More specifically, according to Südaş (2004), 25% of the affected Gölcük people from the earthquake in 1999 moved elsewhere (Figure 4.1a and 4.1b). The economic damages brought on by the 1999 earthquake were estimated to be over 10 billion USD, or roughly 4% of GDP, in the reports created in the wake of the disaster (World Bank, 1999; Bibbee et al., 2000). Direct losses are estimated to have exceeded $5 billion in the damage report created by the Turkish Earthquake Foundation (Özmen, 2000). On the other hand, due to this significant destruction in Kocaeli, where around 23% of the intermediate goods used in Türkiye's manufacturing industry are produced (Kotil et al., 2007), intermediate goods were imported more frequently throughout the nation (see Figure 4.2 for KUMU diagram).

Physical vulnerability had the most obvious effects compared to the others. Low material quality, poor site selection, or improper implementation are possible root causes of this kind of vulnerability. These underlying factors were evident in the Kocaeli earthquake's affected area. The main causes of significant earthquake damage to structures were attributed to a number of flaws, including soft storeys, irregularities, insufficient reinforcing, corrosion, bad concrete, and flimsy infill walls (Spence et al., 2003). In addition to the inherent shortcomings of buildings, liquefaction and soil conditions caused a number of buildings (aside from those with fewer than three stories) to either sink into the ground or tilt (Mollamahmutoglu et al., 2003). In the field observations after the earthquake, it was noted "*… that ground shaking damage was not as widely*

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observed in areas of liquefaction. This phenomenon is sometimes referred to as a base isolation effect, whereby the overall damage due to ground shaking is reduced because once liquefaction is triggered, it limits the intensity of ground shaking" (Bird et al., 2004) (Figures 4.3a-d).

Figures 4.1a and 4.1b- Notes by earthquake victims: "We are fine / Bora Family" (4.1a); "We're gonna miss you / Adieu / Goodbye Adapazarı" (4.1b) (Source: Sakarya Haber, access 2023)

Figure 4.3a, 4.3b, 4.3c, 4.3d– Examples to building damage (Source: Sakarya Haber, access 2023)

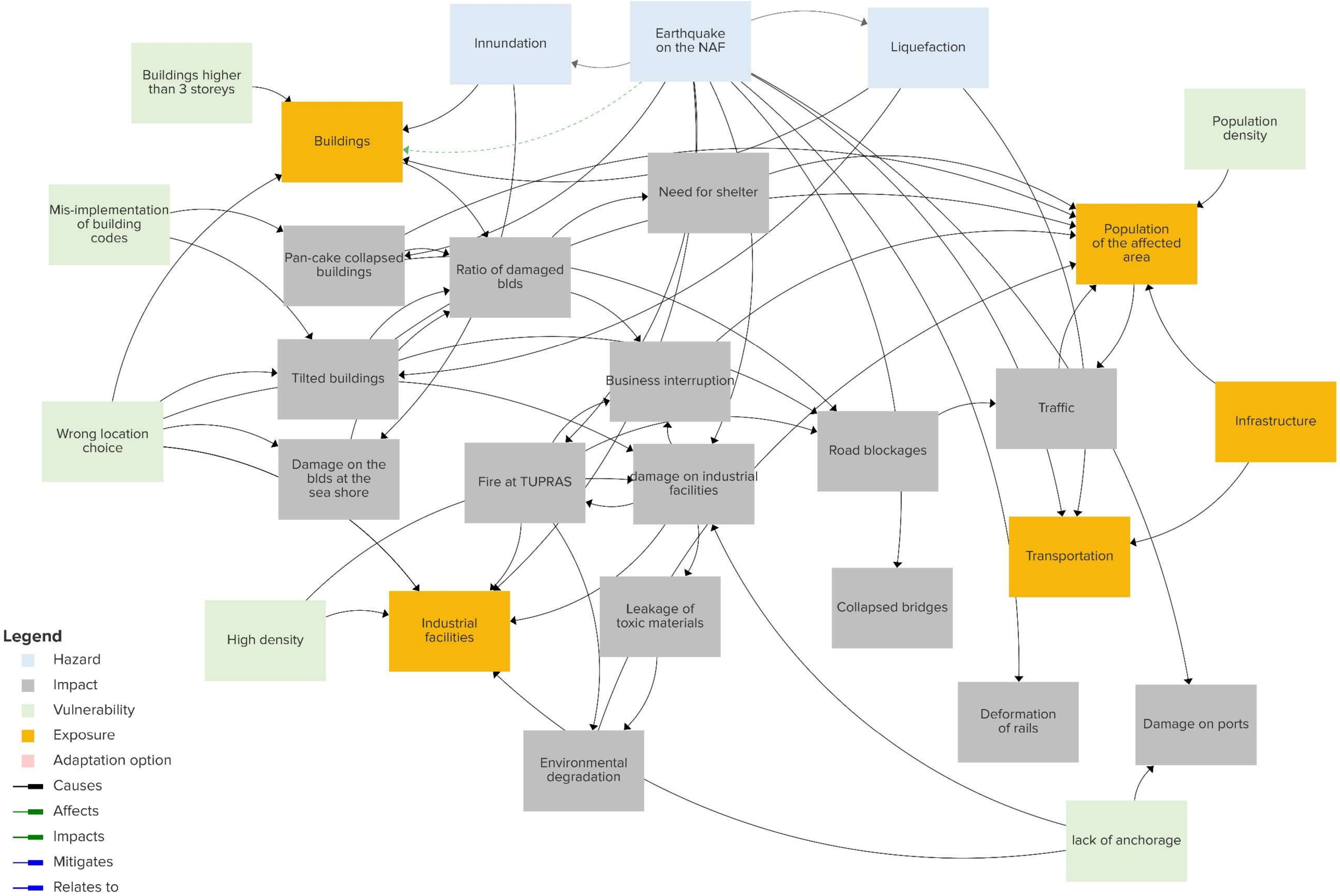

Figure 4.2- Impact chain for Kocaeli earthquake in 1999. See this link for the detailed impact chain.

One of the most significant technological incidents of recent years was the Kocaeli earthquake related TUPRAS Oil Refinery accident in 1999 (see Figure 4.4 for KUMU diagram). The difference between this earthquake and others that have happened in Turkey was that it struck major companies that deal with hazardous materials including ammonia, chemistry, and petroleum. Therefore, despite the focus on the earthquake's obvious effects, such as the collapse of buildings and the 4-day-long fire at the TUPRAS Oil Refinery, the earthquake's immediate invisible environmental damages caused by the spill or leak of hazardous materials into water, soil, and the atmosphere were later discovered. According to some field surveys 50,000 kg crude oil released into Izmit Bay; release of 1,2 million kg of cryogenic oxygen; spill of 100.000 kg of phosphoric acid; release of 200.000 kg of hazardous anhydrous ammonia; leakage of 6,5 million kg of toxic acrylonitrile; because of fires exposure of 350.000 m3 of naphtha and crude oil to the atmosphere (Steinberg and Cruz, 2004; Cruz et al., 2004). Considering the conventional and well-known location theory for industrial facilities, new enterprises need to be close to markets, labor pools, and raw supplies. Additionally, it is preferable to have a choice of transportation methods depending on the type of manufacturing and items. A model of these theories that has been put into practice is the Kocaeli region. However, natural hazards were overestimated during the process of developing this heavily industrialized region, which is why the 1999 earthquakes caused major tragedies.

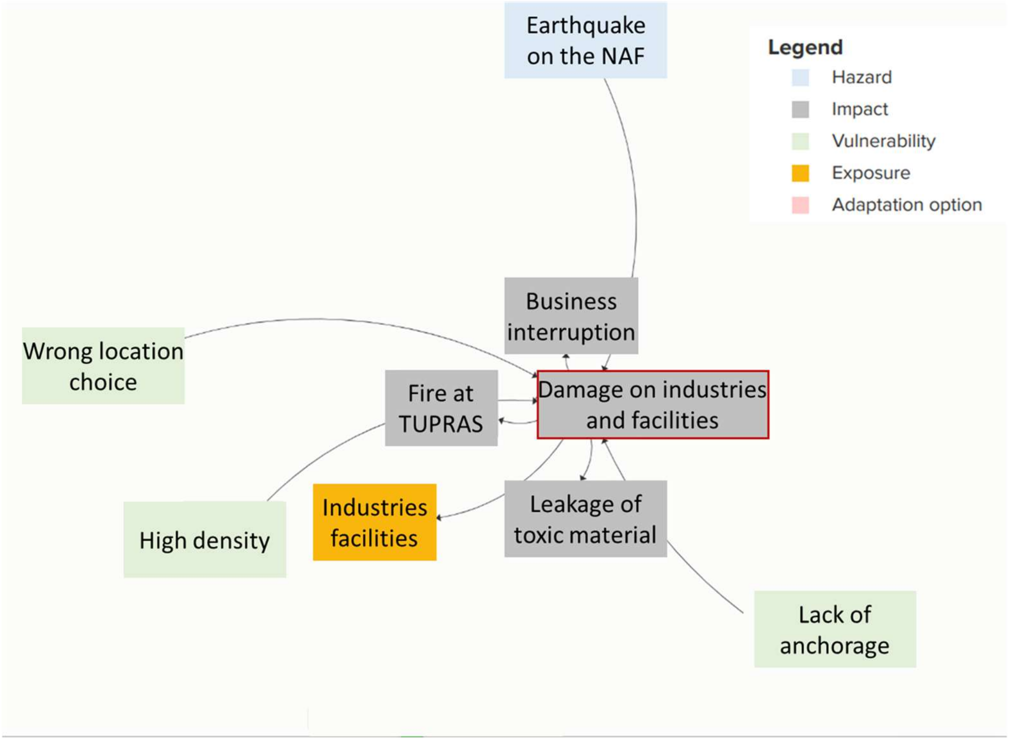

Figure 4.4- Impact chain for industrial damages in 1999 Kocaeli earthquake. See this link for the detailed impact chain.

Studying the region's seismicity and the safeguards that needed to be taken during construction was done as part of the TUPRAS establishment procedure in 1976. These investigations found that the average return period for earthquakes with a magnitude of 7,5 or higher was indicated as being 125 years, and when considering the 50-year life of naphtha tanks, the highest earthquake expected in this period would thus be about 6,5-7,0 (Danis and Gorgun, 2005). However, the Kocaeli earthquake, which had a magnitude of 7,4, happened 26 years after the founding of TUPRAS. The first fire began in a naphtha tank's floating roof, and the second one began after a 90-meter-high stack fell (Scawthorn et al., 2005). The equipment suffered damages because most of them were not anchored or fixed not only at TUPRAS Oil Refinery but also other industrial facilities in Kocaeli.

The governorship of Kocaeli ordered the evacuation of localities within one kilometer of the refinery after the first fire at TUPRAS started (Hurriyet, 1999). The TEM (Trans European Motorway) travels through this location, which is bordered by earthquake-affected residential districts. This announcement hindered traffic flow to the impacted area and temporarily suspended search and rescue operations in those locations. In addition, the affected area's fire extinguisher systems and efforts were insufficient due to cracks in the water pipe system, therefore assistance from neighboring Turkish refineries was requested (Figures 4.5a and 4.5b).

As a result, the Kocaeli earthquake is regarded as noteworthy and a landmark in many ways. First, because to the fire at the Tüpraş Oil Refinery and the leaking and release of toxic substances by industrial facilities, it was the first time that Turkey had faced a significant na-tech disaster. Second, the earthquake demonstrated how cities have become more prone recently because of fast population development and a disdain for building and planning standards. Third, the paradigm evolved from catastrophe management to risk management with a fresh outlook (Kundak, 2023). The creation of innovative tools like the Turkish Catastrophe Insurance Pool (TCIP) in 2000, the building consultancy law in 2001, the Disaster and Emergency Management Authority (AFAD) in 2009, Turkey's National Disaster Response Plan in 2012, and the Urban Transformation Law in 2012 had been evaluated as significant progress to deal with disasters and reduce risks.

Figures 4.5a and 4.5b. Tüpraş Oil Refinery Fire (Source: Kandilli Observatory, access 2023)

4.3 Impact chain – Kahramanmaraş 2023 (Learning case study)

Three consecutive earthquakes (M_w 7.7, 7.6, and 6.4) struck Türkiye in February 2023. The epicenter of the first earthquake was Kahramanmaras-Pazarcik, followed by earthquakes with epicenters of Kahramanmaras-Elbistan and Hatay-Yayladagi for the second and third earthquakes, respectively. These seismic events affected 11 provinces in Türkiye, including Kahramanmaras, Adiyaman, Hatay, Osmaniye, Gaziantep, Kilis, Sanliurfa, Diyarbakir, Malatya, Adana, and Elazig, with a combined population of over 16 million. The destructive impact resulted in massive collapses and damage to various structures such as buildings, bridges, airports, tunnels, retaining structures, hydraulic structures, and lifelines. Approximately 38,000 buildings collapsed during the earthquakes, with 12,000 of them being reinforced concrete (RC) structures (MoEUCC, 2023). The fatalities in Türkiye surpassed 50,000, and more than 100,000 individuals sustained injuries (AFAD, 2023). It is estimated that the total burden of the disaster caused by the earthquakes on the Turkish economy is approximately 103.6 billion dollars (SBO, 2023) (see Figure 4.6 for KUMU IC diagram).

Figure 4.7 provides the characteristics of the three main earthquakes that hit the region in February 2023. These seismic events led to a fault rupture, stretching over 300 km along the left lateral EAF. The fault slipped approximately 3 to 5 meters during the earthquakes (EERI, 2023). In terms of the collected acceleration data from strong ground motion stations in the earthquake-affected region, it was observed that peak ground acceleration (PGA) values reached remarkably high levels, with values as high as 2g recorded near the epicenter of the initial earthquake in Kahramanmaraş-Pazarcik.

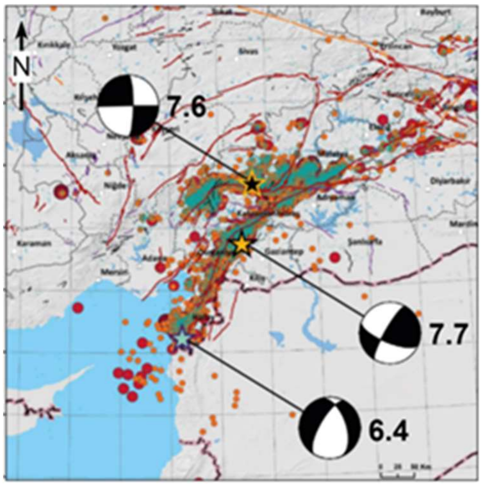

Figure 4.7 Three sequential earthquakes and distribution of their aftershocks (Modified from AFAD, 2023)

The following paragraphs provide more details on the damages which occurred:

- ***Characteristics of existing buildings and observed damages***

  Significant damages occurred in numerous buildings within the region. The severity of the earthquakes was effective on the extent of the damages. Nevertheless, as witnessed in previous earthquakes as well, the severity of seismic damage in these vulnerable structures primarily and mostly stemmed from poor and inadequate construction quality, including sub-standard workmanship and the use of low-quality building materials. Such deficiencies are commonly encountered in the existing building stock in Türkiye, especially in structures constructed before the year 2000. During our on-site inspections, structural damages from buildings, which were constructed before or after 2000 were collected. It was observed that many buildings constructed after the year 2000 have collapsed or been heavily damaged due to construction malpractices in addition to severity of the earthquakes.

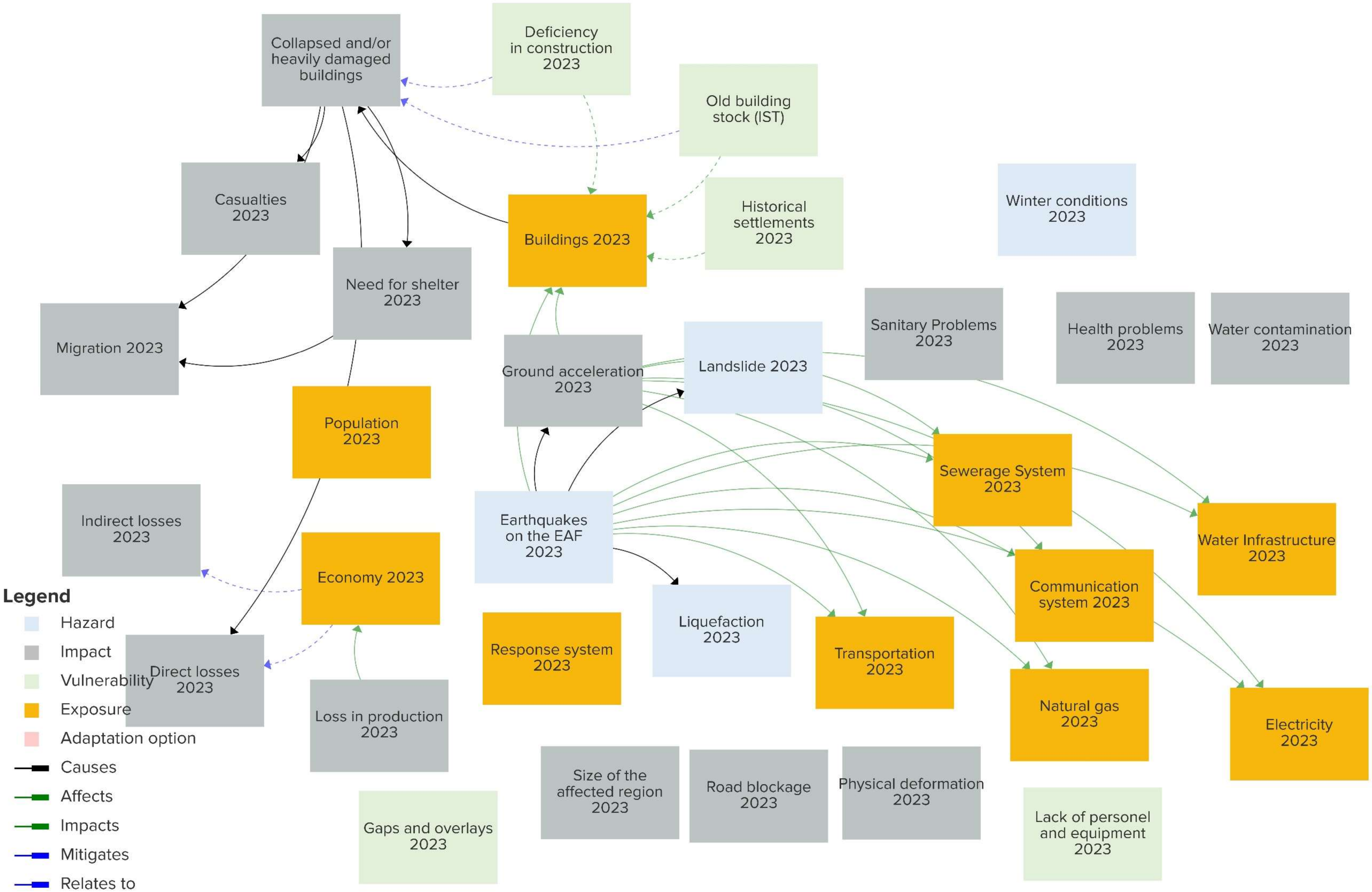

Figure 4.6 Impact chain for 2023 earthquakes. See this link for the detailed impact chain.

- ***Distribution of Damage***

  The earthquakes have impacted mainly 11 provinces, encompassing an approximate area of 110,000 km^2, which includes a diverse range of building types. These include buildings surpassing traditional non-engineered structures, historical buildings, multi-story residential or office buildings and industrial structures, as well as public buildings, such as hospitals, schools and others. According to the assessment conducted by MoEUCC (2023), approximately 1.2 million RC buildings were inspected. Out of these, 1.0% were completely collapsed, 0.9% required immediate demolition, 6.4% suffered heavy damage, 1.8% experienced moderate damage, 25.7% had slight damage, and the rest 63.2% remained undamaged. It should be noted that the post-earthquake damage assessment was conducted based on the study by Ilki et al. (2021). It should be noted that Hatay emerges as the most affected province, with approximately a quarter of the inspected buildings in the province collapsed, heavily damaged or requiring demolition.

- ***Structural Damages and Causes of Failures***

  Recent seismic design documents, such as the current seismic design code of Türkiye (TBEC 2018), aim to ensure three essential requirements for buildings: sufficient stiffness, strength, and ductility. However, in the aftermath of the recent earthquakes, it has been observed that many severely damaged buildings in Türkiye failed to meet these requirements. Figure 4.8 provides a visual representation of mid-rise RC building that did not satisfy the aforementioned requirements during the February 2023 Earthquakes.

The severe damage observed in many buildings in the earthquake-affected region can be attributed to common defects that arose from the failure to fully adhere to seismic-resistant details outlined in recent seismic design codes in Türkiye (Ilki and Celep, 2012). Several notable deficiencies were identified, including the excessive spacing of stirrups beyond the maximum limits specified in design codes, the use of 90° stirrup hooks instead of the recommended 135° seismic hooks, and the absence of crossties. As a result, these stirrups were unable to effectively confine the concrete, which is crucial for achieving ductile behavior during the seismic events. Furthermore, the insufficient amount and detailing of transverse reinforcement, coupled with low concrete strength, led to inadequate shear capacity, and ultimately triggered shear failure in structural elements. Figures 4.9a and 4.9b provide examples illustrating these deficiencies in terms of the insufficient amount and detailing of transverse reinforcement in the affected RC buildings. Columns are critical vertical structural elements, and their failure can cause severe damage or even the collapse of the entire structure. Short column failures were also noted during the field investigations. Improper arrangement of infill walls or stairs resulted in shortened effective column lengths, making these columns stiffer. Consequently, the seismic loads transferred to these short columns were exceptionally high, causing them to be unable to withstand the significant shear forces, resulting in severe damage (Figure 4.9b).

It is crucial to gain a deeper understanding of the factors influencing the performance of these seismically vulnerable structures, as their collapse contributes significantly to earthquake-related losses. The building stock of the region is somehow representative of that of the whole country. Strengthening this building stock rapidly and efficiently is of paramount importance.

Figure 4.8 Collapsed mid-rise RC building

Figures 4.9a and 4.9b. Insufficient transverse reinforcement of a column, (b) Short column.

4.4 Future scenarios for Istanbul (Application case study)

In the second half of the workshop, a scenario-based approach was conducted to reveal major impacts caused by an earthquake with a magnitude greater than Mw 7.0. In each scenario the size of the earthquakes were the same but temporal aspects differed from each other to delineate urban functioning and people's mobility (Figure 4.10 and 4.11).

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Figure 4.10 Infographics for future earthquake scenarios (part 1)

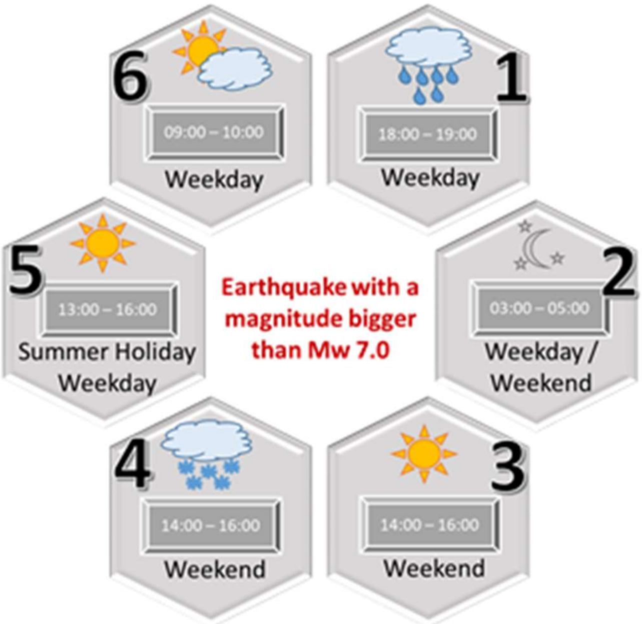

Figure 4.11 Infographics for future earthquake scenarios (part 2)

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4.4.1 **Scenario 1**

An earthquake with a magnitude greater than 7.0 strikes on the North Anatolian Fault during winter, around 18:00-19:00. It is the time when people are leaving work and heading home, and it's also the time for preparing dinner at home.

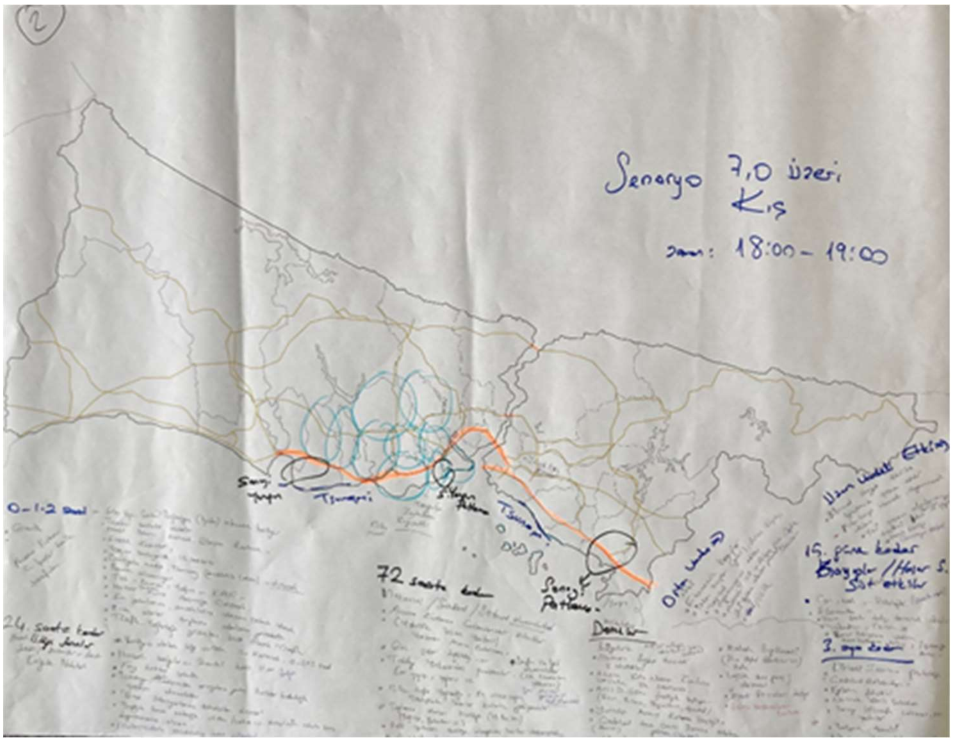

Figure 4.12 Map produced for the Scenario 1

The first 2 hours: Within the first two hours following the earthquake scenario, various developments can be expected. Substandard buildings, especially those located on soft soil or filled land, are likely to suffer severe damage or collapse. There may be a potential risk of a tsunami. The natural gas system could serve as an early warning system and automatically shut down. Mobile communication will be disrupted, transportation will face delays and difficulties, and power outages will result in a loss of electricity. Instances of looting may occur, and railway, metro, and tramway services will cease. Fuel availability will be limited, and the air will be filled with dust and smoke, causing reduced visibility. Individuals will strive to reach their homes and loved ones, while those already at home will gather at designated assembly points. Traffic congestion will intensify, leading to gridlock. Additionally, search and rescue efforts will be initiated by the public.

The first 24 hours: During the first 24 hours following the earthquake, certain challenges will emerge. Water supply may be disrupted if those on shift are not informed, and fractures in drinking water and wastewater pipelines can occur. Limited communication is anticipated due to the collapse of base stations on buildings. The cold weather poses a problem as the lack of pre-stored energy for heaters or stoves becomes apparent. It is important to involve motorcyclists in the response efforts.

The first 72 hours: In the first 72 hours, difficulties will arise due to inadequate human resources for search and rescue operations. Migration from the city will begin, and issues related to burials will be encountered, requiring the identification of new burial sites. Problems on evacuation routes will arise due to snowfall or

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rain, while densely populated districts may experience people having to walk kilometers during evacuations. Assembly areas will be limited to 13 districts, making it challenging to reach everyone. Tents and hospitals will become insufficient, and damage assessment procedures will commence.

15th day: By the 15th day after the earthquake, significant developments are expected. Road repairs will have been carried out, but the psychological impact of the loss of life and property will continue to affect individuals. The economic repercussions will become apparent, putting financial strain on both individuals and businesses. There may still be cases of fatalities due to freezing temperatures. Production and agricultural activities will have come to a halt, leading to challenges in accessing essential supplies.

3rd month: By the 3rd month after the earthquake, several significant aspects will come into play. Mass trauma psychology will emerge as a prominent issue, requiring attention and support for affected individuals. Efforts will be made to establish and maintain tent camps to provide temporary shelter for those displaced by the earthquake. Educational activities will be initiated to resume normalcy and support the recovery process. Assistance programs will be implemented to support industrial activities and help small businesses regain their operations. Proper disposal of debris will be prioritized, with efforts focused on transporting the rubble to designated waste disposal areas. Additionally, there will be a concerted effort to ensure an adequate number of operators for debris removal and clearance tasks. The focus during this period will be on gradually returning to a state of normalcy and implementing measures to support long-term recovery.

Medium term: In the medium term, several significant developments will occur in the aftermath of the earthquake. Economic losses will be experienced, impacting various sectors and livelihoods. The effects of human and vehicle losses on structural organization will be felt, requiring adjustments and adaptations. The negative health effects of debris and the release of asbestos will become evident, necessitating proper management and mitigation measures. Planning for new living spaces and urban areas will be undertaken to provide safer environments. The rise in unemployment will be a concern as businesses struggle to recover and individuals face job insecurities. Efforts to address these challenges and support the affected population will be crucial for long-term recovery and rebuilding.

Long term: In the long term, the effects of the earthquake on the process of returning to normal life and the recovery efforts will become apparent. Various aspects, including psychosocial, economic, and organizational effects, will emerge and require attention. The newly established living spaces will be handed over to their owners, providing a sense of stability and ownership. However, it's important to note that challenges may persist, such as the long-term impact of the earthquake on mental health, economic stability, and social dynamics.

Additionally, the environmental consequences of the earthquake will become evident, particularly in terms of air pollution and its adverse effects on the surrounding areas. This may necessitate additional measures to mitigate environmental damage and promote sustainable practices.

Addressing these long-term effects will require ongoing efforts, cooperation, and support from various stakeholders, including government agencies, communities, and non-governmental organizations, to ensure a sustainable recovery and a return to a more resilient and thriving state.

4.4.2 Scenario 2

An earthquake with a magnitude bigger than 7.0 occurs on the North Anatolian Fault, during the week (not a holiday season) at midnight under normal weather conditions. Since it is midnight, most people are expected to be at home sleeping, and the roads are expected to be open.

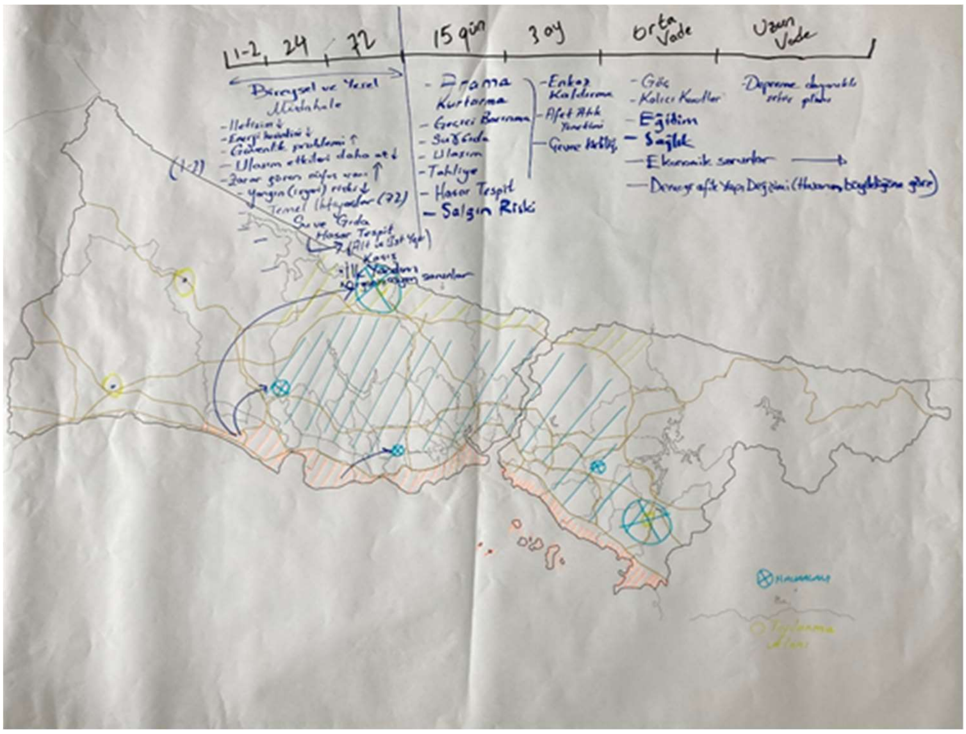

Figure 4.13 Map produced for the Scenario 2

<u>The first 2 hours</u>: Old and weak buildings, especially those which are on the soft soil and filled land, are assumed to receive heavy damage or to collapse. The fact that most of the people are at home at the time of the earthquake, a high amount of life loss along shoreline (given the age of buildings and high population density) can be expected as compared to other scenarios. Outside of shorelines (north and middle part of the city) there will be less problems but heavy burden on the communication line continues to be the case in these parts of the city as well.

Within 2 hours people help neighbors and gather at the designated meeting points. Being at the dark may make it difficult. Trying to reach out loved ones may exacerbate communication problems.

Given the low density of industrial buildings, a fire is less likely except for places with more inflammable materials.

As it is likely to have tsunami following the earthquake, seashore facilities and inhabitants are exposed to waves and ground deformation due to soil amplification in the filled land.

Public security will be an issue to guide and calm people as well as preventing looting.

<u>The first 24 hours</u>: The accessibility of damaged buildings for Search and Rescue teams will be hindered primarily due to debris blocking roads. The evacuation process is anticipated to be challenging and chaotic due to the behavior of the victims, some of whom may insist on checking the damage or staying nearby. Ensuring public security becomes crucial to guide people towards safer locations and prevent them from

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causing harm to each other. Additionally, designated areas will be equipped with temporary health response facilities, portable kitchens, sanitary cabins, and shelters. It is expected that the major logistical facilities, including three airports and main warehouses in Istanbul, will operate efficiently. The coordination between AFAD and AKOM will facilitate the implementation of the Türkiye Disaster Response Plan. Some hazardous facilities may pose secondary hazards such as fires and the release of toxic materials. Therefore, specialized response equipment will be required to manage and mitigate these risks. Communication challenges are likely to persist until portable base stations are installed in the affected area.

The first 72 hours: Istanbul, with its population of 16 million, is expected to witness heavy damage to approximately 100,000 buildings, necessitating temporary shelters for around 3 million individuals. Some of the residents, given the opportunity, may choose to migrate from the city immediately. Therefore, addressing the immediate needs of temporary shelters (primarily tents), food and water supplies, and sanitation facilities becomes crucial during this period. Search and rescue operations and debris removal are currently underway. Communication and transportation challenges have been resolved, and in the least affected areas, water and electricity infrastructure are functioning properly. The presence of volunteering activities is more noticeable in the region. However, there is a demand for fuel and equipment for vehicles. Meanwhile, the process of damage assessment has been initiated.

15th day: For those who used to reside in the most heavily damaged areas, migration becomes an inevitable outcome. Ongoing surveys are being conducted to assess the conditions of buildings. Psychological support plays a vital role during this period of recovery. The potential spread of diseases remains a concern that needs to be addressed. The recovery process has already begun, and a significant focus is placed on constructing temporary shelter centers, primarily utilizing containers, to accommodate those affected.

3rd month: Many individuals who are unable to leave the city still face challenges in finding proper shelter. The interruption of numerous services has made it difficult for people to acquire their basic necessities. The ongoing process of debris removal is still underway. Waste management and environmental issues, such as the spread of asbestos from debris storage areas, have emerged as critical concerns. The earthquake has resulted in a rise in unemployment due to the high number of deaths and migration. Some businesses are experiencing a shortage of workers. Economic hardships are evident during this period.

Medium term: Significant progress has been made in the reconstruction process in many areas of the city. However, sheltering remains a persisting issue. The national economy is facing bottlenecks due to direct and indirect losses, as well as the rapid pace of reconstruction. Depending on the extent of the damage, there may be a noticeable change in the demographic structure. Access to education and health services continues to be a concern during this period.

Long term: The long-term effects of economic disruption, including production losses, high import rates, low export rates, and unemployment, will persist. It becomes crucial to focus on re-planning the city in a manner that ensures resilience to earthquakes and other disasters. This will be an important issue to address in the future.

4.4.3 Scenario 3

> An earthquake with a magnitude bigger than 7.0 occurs on the North Anatolian Fault, in the weekend around 14:00-16:00. As the weather condition is favorable to spend time outside with friends and family, most of the population enjoy recreational and commercial zones. Population concentration for the given scenario is higher in the central districts such as Besiktas, Beyoglu, Eminonu, Kadıkoy and Uskudar, as well as at the parks in seashore, shopping streets/malls and the Princes' Islands. Some of the inhabitants spend their weekend in the forest areas at the Northern part of Istanbul. A slow traffic flow is observed due to high mobility of the people.

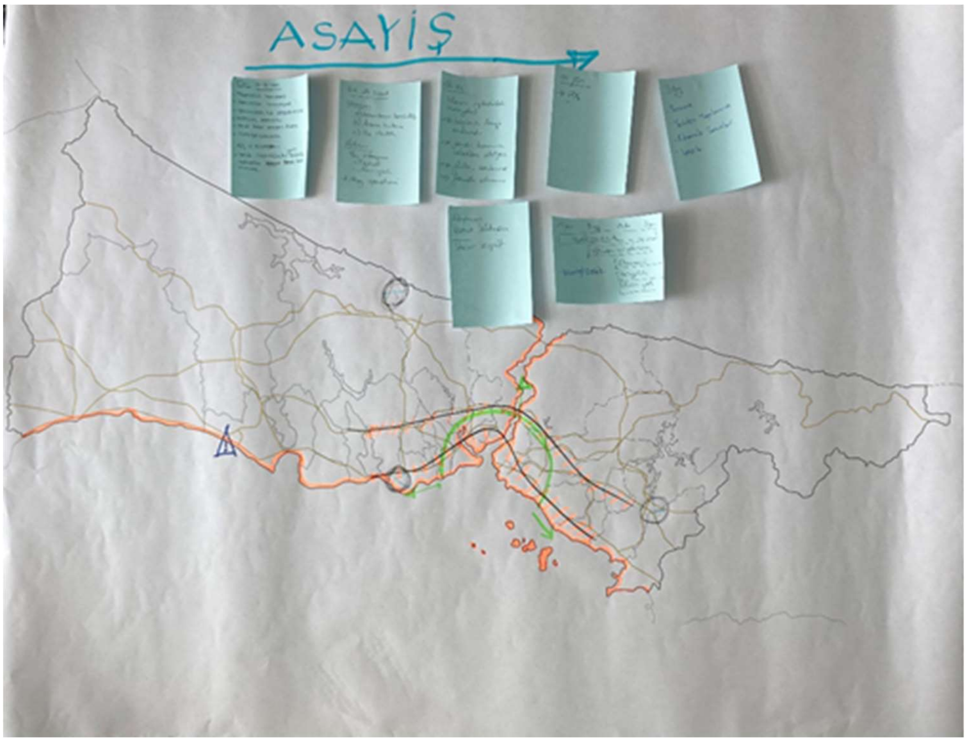

Figure 4.14 Map produced for the Scenario 3

<u>The first 2 hours</u>: Old and weak buildings, especially those which are on the soft soil and filled land, are assumed to receive heavy damage or to collapse. The fact that most of the people are outside at the time of the earthquake, it may reduce the loss of life compared to other scenarios. However, in areas with a lower registered population, a high population for the weekend can lead to chaos and panic. As it is likely to have tsunami following the earthquake, seashore facilities and visitors are exposed to waves and ground deformation due to soil amplification in the filled land. In the areas where the pedestrian flow is higher, people may get hurt by falling parts of buildings. Communication lines will be overburdened and then collapsed due to excessive demand of people. Traffic will be blocked because of ground deformation, collapsed structures and people who want to evacuate the affected areas and to reach their homes or relatives. Public security will be an issue to guide and calm people.

<u>The first 24 hours</u>: First responders will be faced to problems in accessibility due to road blockage, mostly because of vehicles stacked in main arteries. Evacuation process will be difficult and chaotic because of the victims' behavior. Either they would like to reach their home to check or to stay nearby. Public security will be crucial to guide people to safer places and to prevent them from hurting each other. Furthermore, temporary health response facilities, portable kitchens, sanitary cabins, and shelters will be installed in the designated areas. Major logistic facilities (three airports and main logistics warehouses) in Istanbul are expected to work efficiently. Coordination of AFAD and AKOM will facilitate the implementation of the Türkiye Disaster Response Plan. Some of the hazardous facilities are expected to cause secondary hazards such as fire and release of toxic materials. Consequently, special response equipment is needed to control the propagation. Communication deficiencies will continue until portable base stations would be installed in the affected area.

The first 72 hours: Istanbul has 16 million of inhabitants. It has been estimated that about 100.000 buildings would be heavily damaged, so that there will be a need of temporary shelters for 3 million people. If they have the opportunity, some of them will immediately migrate from the city. Temporary shelters, food supply and sanitation facilities are key issues in this period. Search and rescue activities and debris removal process are going on. Communication and transportation problems have been solved. In the least affected zones, water and electric infrastructures work properly. Volunteering activities are more visible in the area. On the other hand, there is a need of fuel and equipment for vehicles. Meanwhile, damage assessment has initiated.

15th day: Migration will be inevitable to whom used to live in the most damaged areas. Psychological support is crucial in this period. Recovery process has started.

3rd month: Sheltering is still a problem for many people who cannot leave the city. As many of the services have been interrupted, people have difficulties to purchase their need. On the one hand there is a rise in the unemployment, on the other hand some businesses suffer from workers. Economic struggles are visible in this period.

Medium term: Reconstruction process is almost accomplished in many parts of the city; however sheltering is still a problem. Because of direct and indirect losses and rapid reconstruction process, national economy suffers from bottlenecks.

Long term: Economic disruption and it consequences will continue in the long term by the means of loss in production, high import and low export rates and unemployment.

4.4.4 Scenario 4

An earthquake with a magnitude bigger than 7.0 occurs on the North Anatolian Fault at the weekend. Due to the bad weather conditions, most people are expected to be home with their families. Note: Adverse weather conditions may affect the road functionality except for the debris caused by the earthquake.

The first 2 hours: Everyone is in shock. People are unaware of what is happening and what they are dealing with. About 20% of the building stock in Istanbul may have more than moderate damage. Tens of thousands of people are under the debris. City’s shoreline is affected by the Tsunami after the quake. The Tsunami affected the citizens doing sports in the recreation area on the Maltepe beach. Many of them are unavailable. The entrance to the Eurasia Tunnel was closed due to the Tsunami. There is a communication problem. It is not possible to take information from others. Because of the damage to flammable buildings, fires have started in some parts of Istanbul. Earthquake creates a chaotic atmosphere in tourist areas, and tourists need help knowing where to go. Nobody knows what’s going on.

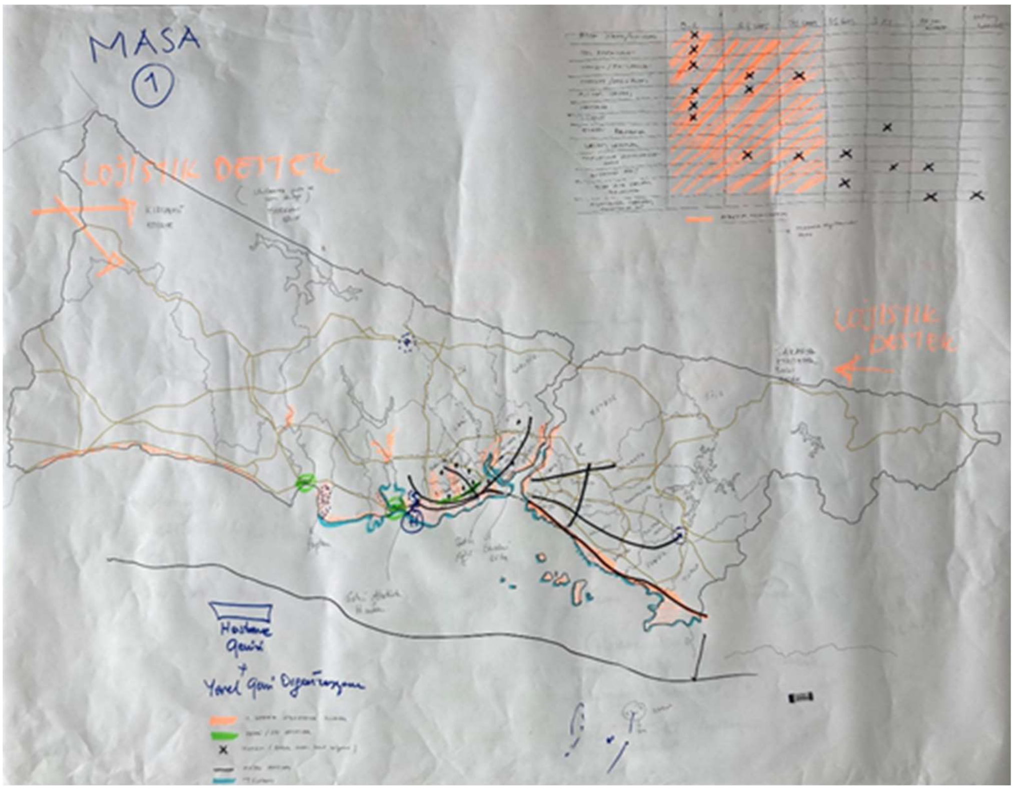

Figure 4.15 Map produced for the Scenario 4

<u>The first 24 hours</u>: İstanbul is in a state of fear and waiting for help from other cities. The biggest and most critical problem is accessibility. The debris makes it difficult to reach anywhere in Istanbul, especially the south part of the E-5 Highway. Some underpasses and overpasses also have functionality problems after the quake. Lifeline damage reduces the city's coping capacity. People don't choose to leave where they are and stay near their damaged homes. Search and rescue teams are not fully active in the field.

For this reason, the survivors are trying to carry out the rescue efforts somehow. Injured people are not treated immediately since some hospitals are damaged. Aid has begun to arrive from both national and international. Assembly areas are unknown, and their capacities are insufficient. Education was suspended. The students in dormitories are in a rush. Tourists are trying to reach airports to return to their countries.

<u>The first 72 hours</u>: There are ongoing fires. Firefighters cannot intervene because the roads are narrow, and debris is everywhere. Sheltering is the biggest problem because the weather forces the conditions. There is no electricity, search, and rescue operations are difficult at night. It is noticed that some chemicals are causing environmental problems. Since the roads are closed due to building debris, the injured cannot be taken to hospitals. Istanbul needs emergency mobile hospitals. Alternative routes have begun to create for the evacuation. Piers and ports have been checked. Robust ones have started to use in logistics and supply processes with other cities.

<u>15th day</u>: Burial proceedings are still ongoing. There is a need to find more cemeteries. Those having a house or a relative outside of Istanbul have started to leave Istanbul. Damages in SMEs and industrial processes began to become more visible. Social erosion has occurred. Logistic centers have been constructed in Kırklareli and Kefken. Water and food supply are two of the big challenges. Energy crises are still going on.

<u>3rd month</u>: Debris removal has started. It is difficult to find an excavation site. Ships have begun to be used as shelters and hospitals. Rehabilitation work continues. The business has started gradually.

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<u>Medium-term</u>: The demographic structure in Istanbul is different according to before an earthquake. The Urbanization process is being reorganized. The industrial process is being reactivated. Transportation elements is functional.

<u>Long term</u>: Istanbul has taken lessons from the earthquake and has made its urbanization processes resilient against earthquakes. The fascinating city of Istanbul has started to let in immigrants again.

4.4.5 Scenario 5

An earthquake with a magnitude bigger than 7.0 occurs on the North Anatolian Fault during July and August, weekdays between 1:00 PM and 4:00 PM. Parts of the city with low population and high tourist activity, mostly business and tourist areas. The historical peninsula, old city centre and its surroundings fully engaged with museums, old bazaars, historical buildings and open-air activities. The expected weather is typical, with no extreme conditions, which is ideal for spending extensive time outside or enjoying outdoor activities such as walking and sightseeing.

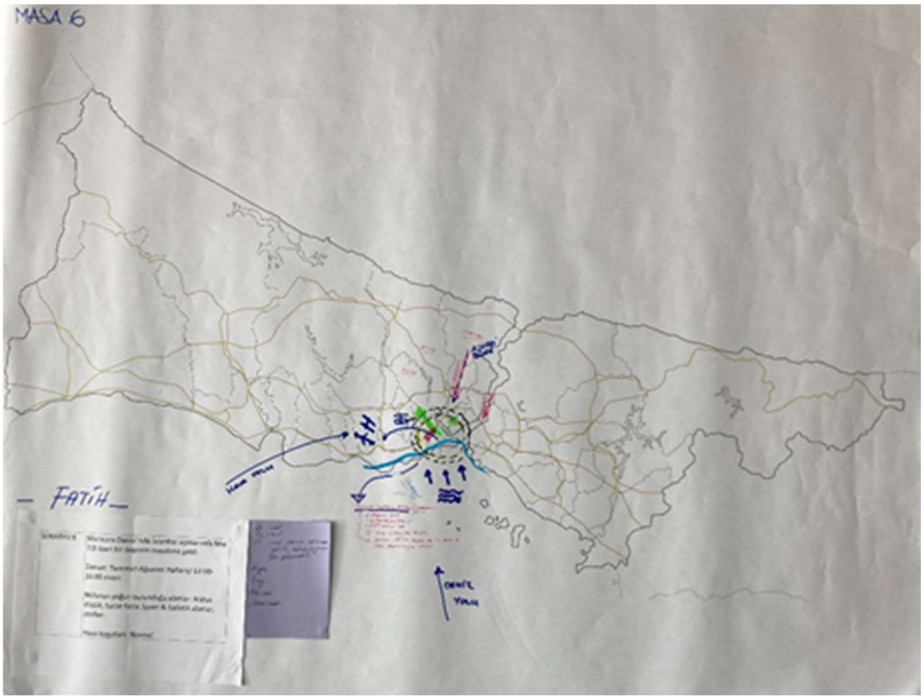

Figure 4.16 Map produced for the Scenario 5

<u>The first 2 hours</u>: Due to the tsunami, the sea route will be unavailable, and the highway will be cancelled. Moreover, the old building stock in the area means that there is likely to be significant destruction. As a precautionary measure, the metro system will also be temporarily suspended to allow for safe evacuation work. Because of the Historical Peninsula's organic pattern & the streets are narrow, transportation will completely lock. Access to the region will be significantly limited.

It is going to be challenging to identify individuals among international tourists. It is crucial when communication barriers are in place due to the many foreign languages spoken in the area.

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There are many under-the-stairs manufacturing, illegal workers, and immigrants in the back streets of the bazaars. Fire, explosion, and leakage due to chemicals might happen.

The potential security risks that may affect the Grand Bazaar and Topkapi Palace. These landmarks are not only symbolic for the city, but they also attract a significant number of visitors and locals. It is imperative that to take measures to ensure the safety and protection of these sites to prevent any harm or damage.

The health system could face significant challenges if key hospitals such as Çapa, Cerrahpaşa, and Bezmialem were to sustain damage. These facilities play a crucial role in providing medical care and assistance to the community.

Having the Fire Brigade / Department located in Saraçhane can be an advantage for emergency response. It's important to have quick access to emergency services in case of any unforeseen circumstances.

Marmaray may be the only means of escape. Even the subway will not work.

The first 24 hours: During the course of wreckage work, it is important to consider safety concerns that may arise due to the presence of historical artifacts, jewelers, and other tourist attractions. To mitigate these concerns, the Topkapı Earthquake Park, which has already completed its infrastructure and pilot application, will serve as a temporary shelter.

The Emergency Hospital located in the Atatürk Airport area can be utilized, with transportation being facilitated through the use of helicopters and motorcycles in the aftermath of the disaster. To ensure efficient and effective use of these resources, it is imperative that a network of units and institutions be established beforehand. In this regard, the consideration of small motorboats for transport should also be considered.

The first 72 hours: The ice skating spaces can be used as a temporary morgue. The closed building of Kültür AŞ (IMM's subsidiary company's building) should be used as a coordination centre for disasters. It would also be an ideal location to host the media. Additionally, it is crucial that animals are properly taken care of and given proper attention. The hospital ship must be ready to serve.

15th day: Removal of debris will continue. Evacuation of temporary shelters will begin. The region's population will decrease. The city will experience water shortages and infectious disease outbreaks.

3rd month: Removal of debris will continue. Permanent and temporary, both sheltering will be a problem.

Medium term: Economic loss in sectors production and tourism. Experiencing transportation problems as it is the most central transfer point of the city.

Long term: The city's historic site will be damaged heavily, which means a considerable loss of the city's historical artefacts. However, tourist loss will occur at the same time until the site fully ready to service.

4.4.6 Scenario 6

An earthquake with a magnitude bigger than 7.0 occurs on the North Anatolian Fault in the early morning at 9 am, around the end of commuting time. The traffic load is slightly higher than the daily average. Working population is at work and students are at school. Weather condition is considered as normal without any extremes

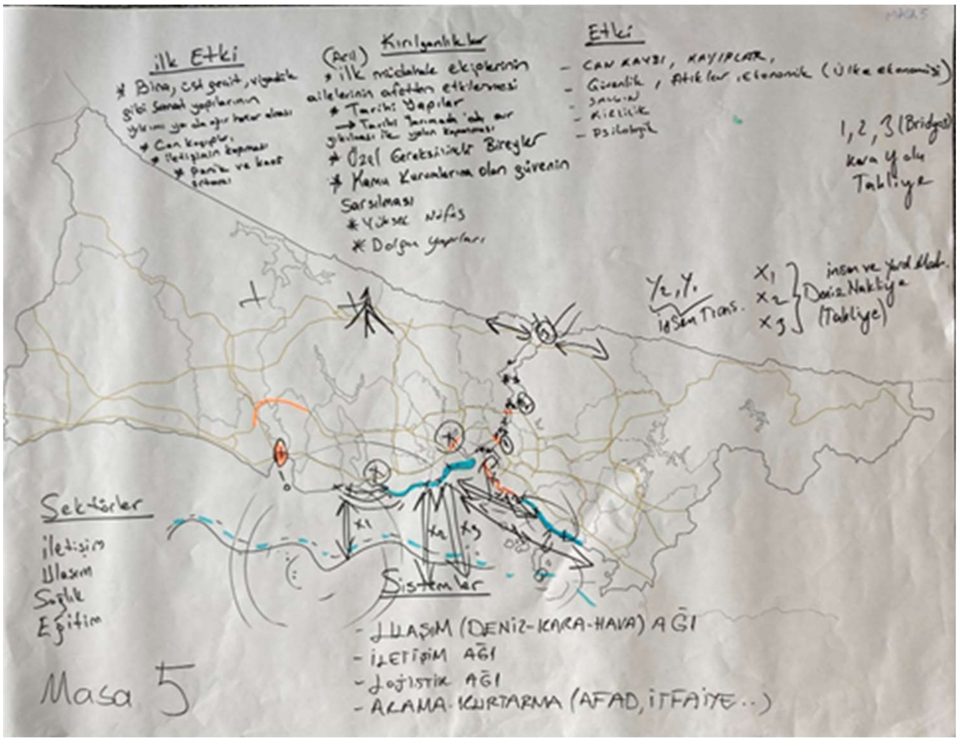

Figure 4.17 Map produced for the Scenario 6

The first 2 hours: Traffic load is high at the given time. People will reach out to their families. Large vulnerability on the two sides: Europe and Asia. Integration of transportation systems will be affected. There are urban expansions in the Marmara Sea, and there may be tsunami and liquefaction. Shorelines may be under water. Rescue teams will also want to reach out to their own family. Within 2 hours, people help neighbors and gather at the designated meeting points. Trying to reach out to loved ones may exacerbate communication problems. As it is likely to have tsunami following the earthquake, seashore facilities and inhabitants are exposed to waves and ground deformation due to soil amplification in the filled land. Sea transportation: the ports may not be used. For the coordination, they may have to ask port authorities. There are two fault lines which may affect different areas. Also, other neighboring areas close to it.

The first 24 hours: Historical buildings in the historical peninsula will be affected. Sectors: transportation, health, education. There will be flooding. As it is in weekdays, students will be affected in schools, and teachers have large responsibility. Transportation, highway, and air transportation will be blocked for some time. Extreme traffic and accidents will block the bridges connecting the two sides. Additionally, in the selected regions, temporary health response facilities, portable kitchens, sanitary cabins, and shelters will be placed. Three airports and the primary logistics warehouse in Istanbul are expected to operate effectively. The Turkish Disaster Response Plan will be easier to implement if AFAD and AKOM coordinate. It is anticipated that some of the hazardous facilities would produce secondary risks like fire and the release of

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poisonous materials. Therefore, specialized response tools are required to manage the propagation. Lack of communication will persist until mobile base stations are established in the troubled area.

The first 72 hours: The population of Istanbul is 16 million. 3 million people will require temporary housing because it is predicted that roughly 100.000 buildings will sustain significant damage. Some individuals will leave the city right away. Temporary housing—mostly tents—as well as food, water, and sanitary facilities—are major concerns at this time. There are ongoing search and rescue operations and cleanup efforts. There are no longer any issues with transportation or communication. Electricity and water infrastructure are in good working order in the least damaged areas. In the neighborhood, volunteering is more evident. In contrast, fuel and vehicle equipment are required. An evaluation of the damage has already begun. First aid and many other operations can be done through sea transport

15th day: For those who previously resided in the most affected areas, migration will be unavoidable. Building conditions are still being surveyed. During this time, psychological support is essential. Disease transmission will be a problem. The healing process has begun. A major concern at this time is the building of temporary sheltering facilities, which are often made of containers.

3rd month: Many people who are unable to leave the city still struggle with housing issues. People struggle to buy basic necessities as numerous services have been disrupted. The removal of debris is still ongoing. Key issues include waste management and environmental issues (such as the spread of asbestos from trash storage locations). As a result of the earthquake's high death toll and migration, there is an increase in unemployment. Many firms are understaffed. Economic difficulties are evident throughout this time.

Medium-term: In many areas of the city, rehabilitation is practically complete, yet there are still housing issues. Direct and indirect losses, as well as the quick rehabilitation process, pose bottlenecks in the national economy. A shift in the demographic make-up can be anticipated, depending on the extent of the damage. The availability of health and educational services is still a problem.

Long term: Long-term economic disruption and its effects, such as production loss, high import and low export rates, and unemployment, will endure. It will be difficult to redesign a metropolis that can withstand earthquakes and other disasters.

4.5 Impact chain for scenarios in Istanbul (Application case study)

As an overall evaluation of six scenarios produced by the participants of the meeting of June 1st, 2023, it has been noted that different time slots and weather conditions possess different hot spots for the first 24 hours. For instance, if the earthquake occurs in late night, accessibility faces to obstacles mostly due to road blockage because of the collapsed buildings and traffic caused by people who try to evacuate the area. However, if the earthquake occurs during the peak hours, the traffic jam would be added as a predominant obstacle to the previous scenario. Likewise, mobility during the weekends and holidays causes an increase of vulnerability by means of population concentration in certain zones (Figure 4.18).

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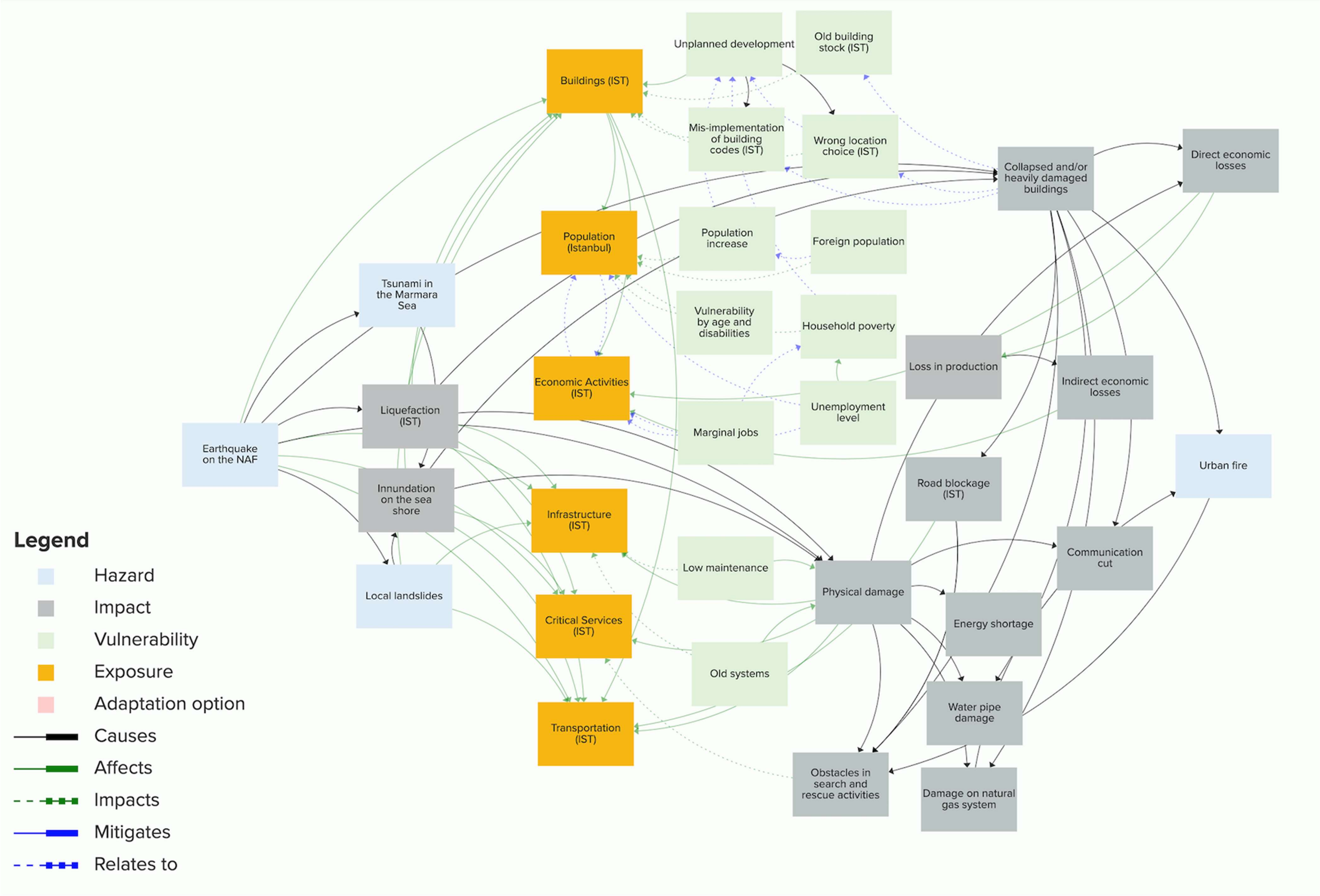

Figure 4.18 Impact chain diagram for future scenarios in Istanbul (earthquake with a magnitude bigger than 7.0). See this link for the detailed impact chain.

5 Bucharest Application Case Study

Bucharest is one of the most endangered capitals in the world due to seismic hazard, as revealed by all global and regional hazard studies, such as Giardini et al. (2003, 2013) or Jimenez et al. (2001) and proven by the reality of the XXth century. From this point of view, it can also be considered the most endangered capital in the European Union. Although located more than 130 km epicentral distance away from the Vrancea Seismic Source, significant peak ground acceleration (PGA) values, greater than 0.2 g, can occur in Bucharest. The Vrancea intermediate-depth seismic source is located at the contact of the East European Plate, the Intra-Alpine and the Moesian Subplates, 130-150 km epicentral distance away from the city. Its seismic activity is responsible for damaging acceleration values in Bucharest, according to Giardini et al. (2013). A recent seismic microzonation study (Marmureanu et al. 2010) shows that for the maximum predicted Vrancea earthquake (with Mw 7.8, at 150 km depth), PGA values ranging from 0.22 g up to 0.3 g could be recorded at surface. A significant distribution variation from an event to another is also expected, depending on the slight modifications of earthquake parameters - real recordings from the 1986, 1990 or 2004 moderate magnitude earthquakes revealed different patterns in terms of PGA distribution (Pavel et al. 2013).

5.1 Participatory workshop summary and outcomes

The first stakeholders' workshop in Bucharest took place in the Bucharest city centre, on the 20th of March from 9 am to 5 pm. The language of the meeting was Romanian and simultaneous translation into English was provided. The whole event was recorded and transmitted online via Microsoft Teams.

The aim of this first stakeholders meeting was to bring together practitioners involved in prevention, response, and recovery from major disaster events, to raise awareness regarding the consequences and effects of major earthquakes striking in Bucharest and find a common language to develop possible impact chains to feed the PARATUS platform.

The workshop was designed to fulfil the goals of the PARATUS by adding input from the PARATUS partners and invited stakeholders in different formats (e.g., presentations, focus groups, buzz groups). The meeting agenda was elaborated in cooperation with the DSU partner and with the other Application Case Studies in order to have comparable approaches and results at the end of the workshop (see Annex 9 in deliverable 6.2 for Workshop Agenda). The morning part of the workshop included presentations on what PARATUS is, the aim of the project, what are impact chains based on past events affecting Bucharest during the 12-19th centuries and what role do these disasters have in understanding impact chains, ways to develop them, who are the participants and what expectations do they have from the first meeting. Representative of the DSU exposed the intervention of Romanian rescuers in the disaster in Turkey and Syria, in order to introduce the operational frameworks of intervention/recovery as potential topics to be addressed during the focus groups discussions.

One of the premises in selecting the stakeholders for this first meeting was related to the necessity to ensure a large coverage in disaster situations, and more precisely to protect the population, which includes evacuation, accommodation, water and food provision, and other measures. Official invitations were sent to all the institutions involved in disaster response according to the HG no. 557, and we received answers from the Prefecture (Service for Government Strategies and Public Concentration Services), Bucharest City Hall, Police, Gendarmerie, MDLAP (Operative Centre for Emergency Situations), Ministry of National Defence/ National Military Command Centre (Head)/ Directorate General for Emergency Situations (and Operative Centre for Emergency Situations), MapN – Operation Department/Major State of Defence, IGJR, IGSU – Coordination and Implementation of Resilience Requirements Unit, ISU, BIF, IGPR – Road Department, IGPR

– Directorate General for Civil Protection, DSU. The Health Ministry and the Ministry of Transport were instead not present in the meeting.

We used semi-structured interviews conducted in collaboration with the Department of Emergency Situations leadership level to identify the most important local stakeholders to be invited in the case study workshop, based on the dispositions of the Governmental Decision HG no. 557, which stipulates the ministries and institutions responsible for the management of different risks and interventions.

Main outcomes of the workshop

The stakeholders' meeting in Bucharest set the stage for developing impact chains and collecting data based on close interaction with selected stakeholders focusing on scenarios and future challenges of a main earthquake event. It demonstrated the need for closer collaboration and continuous communication between all actors involved in disasters, to better understand each other's needs and different perspectives. According to project goals and the agenda established with DSU during the kick-off meeting in November 4th, the main focus of the stakeholders' workshop in Romania was on a future major earthquake in Bucharest, triggering a possible flood and outbreak of fires as secondary hazards, affecting all societal sectors. Participants mentioned that working on the impact chain provided many insights and were open to further meetings and discussions between professionals. Reasoning behind focus selection was established at project management level in accordance with specific project goals and learning case backgrounds.

Variables to estimate the relevance of impacts: Magnitude of adverse consequences, Likelihood of adverse consequences, Temporal characteristics of the risk, Ability to respond to the risk, Relevance for the study area in terms of responsibility for actions to be taken (who is the risk owner?), Unavoidable losses and damage, Irreversibility, Importance of the system(s) at risk, Interplay with dynamic vulnerabilities and underlying risk drivers.

Summarizing results of discussed past events, earthquakes were identified as the most important major risk for the city, triggering a multitude of secondary hazards with the highest relevance of direct and indirect impacts (table 5 in deliverable 6.2).

In order to understand impact chains, a large historical database including 39 large earthquakes with magnitudes over 6.5 Mw that affected Bucharest between 1100 and 1900 was analyzed and presented during the stakeholders' workshop (figures 20 and 21 in deliverable 6.2).

During focus groups, impact chains for future earthquake scenarios were developed using a set of guidelines (fig. 24 in deliverable 6.2). The impact chain focused on direct and indirect consequences on buildings, infrastructure, utilities and energy supply with blackouts, economic losses, failure of sanitation system, mental health. As possible resilience and coping strategies, stakeholders mentioned the reinforcement of buildings, implementing earthquake-resisting structures, building social networks, and rising awareness, including VR, contingency planning and developing healthcare resources.

The main element that rescuers need to focus on is the rescue of people's lives. When it comes to population-related issues, the most prominent concern for first responders was behavior. The participants expect asocial behaviors that result from panic and can put first responders to danger. The behavioral degradation in time was mentioned as another threat, as well as relationship and communication problems between people in need and rescuers. Vulnerable groups (e.g., patients in hospitals, people in tall buildings, in nursing homes, in new residential ensembles with very narrow streets that preclude the intervention of emergency management vehicles, etc.) are another social concern to have in mind when developing coping strategies. Additionally, the accommodation of the people left without homes and shelter because of earthquake-induced building collapse or damage, represents another major issue on the list of problems to be solved by first responders and local authorities.

Regarding the impact chains on the physical environment, the identified vulnerability sources concerned the modifications of the initial building plans, of the initial function of the building, the newly built additional stories, or the artificial reduction of construction materials volume, the design errors, and the plethora of buildings that present deterioration marks but have not been technically surveyed. Tall buildings may collapse over the ones with lower profiles, leading to secondary effects such as the damage of gas pipelines, which can lead to fires and explosions. Therefore, improvements in terms of gas supply cut-off measures are pre-requisite for increasing resilience. Other highlighted issues regarded the danger which stems from lifeline failure, that may be indirectly caused by building collapse; and the blockage of transport ways, with the limitation of first respondents' access to intervention spots and the hindering of evacuation and self-evacuation. Nevertheless, the resistant structure of the buildings will be affected by the earthquake, which is directly linked to long-term economic effects concerning retrofitting costs and efforts. Building damage will generate long-term vulnerabilities, which will be aggravated by the parallel incapacity to technically expertise them in a timely manner. The functionality of a building holds an important role in the impact chain on at least medium term; for instance, a building used for service provision, a building affiliated to the civil protection system, or a hospital. Building damage will impair the functionality of the institution or will affect its functioning at maximum capacity, as every institution "with certain responsibilities holds a fundamental part and a backup part" which maintain it functional in disaster situations.

5.2 Impact Chain methodology

The following methodology was used for establishing relevance and confidence for the Romanian learning and application case studies.

Confidence:

The confidence of the elements and connections included in the impact chain was established based on the type and the number of sources. Scientific papers, legislative documents, official press releases, statistical datasets, and reports were attributed the maximum confidence score (10), as their findings were ascertained by multiple experts. The confidence score of the news reports ranged from 1 to 7, depending on the number of sources: 1 point for each source. In the case of expert judgements, the confidence varied between 1 and 10 points, according to the degree of certainty assessed by the authors of the impact chain. In multiple sources of different types can be assigned to the same element or connection, the confidence score is set at highest possible value that can be given to any of the sources.

Relevance:

The relevance of the elements and connections was established according to the scope of the impact chain, namely, to identify the compounded effects of flood events and the COVID-19 pandemic. The key question that guided this process is "How important/relevant is the fact that X causes/impacts/affects/relates to Y, for both floods and COVID-19?" for connections, and "How important/relevant is the X element, for both floods and COVID-19?" for elements. Maximum scores of 10 or 9 were attributed to those elements or connections that could be included in logical pathways related to both hazards. For example, floods determined the evacuation of people, who interact during evacuation procedures and in the emergency temporary shelters, favouring the spread of the SARS-CoV-2 virus and leading to potential increases in the number of new cases. All connections and elements in this causal pathway were assigned relevance scores of 9 or 10, depending on expert judgement.

Another thing to consider when establishing the relevance of elements and connections is their type. Vulnerability elements will receive maximum scores depending on their contribution to both flood and pandemic impacts, and lower scores (1-8) if they contribute only to flood/pandemic impacts. Impact

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elements are noted with maximum scores if they can be caused by both hazards (e.g., human casualties), or with 9 points if they have important roles in the pathways that link the effects of floods to other potential COVID-19 related impacts. If a certain impact is solely caused by one hazard, it receives relevance scores of 1-8. Following the same line of reasoning, the most impacted exposure elements were attributed the highest relevance scores. In terms of hazards, floods, and the pandemic present maximum relevance (10), and the score decreases for the other co-occurring hazards (i.e., heavy rain, strong wind, landslides).

When it comes to connection types, we considered that causal links, “affects” and “mitigates” connections have the greatest relevance and can be assigned 10 points if they are part of pathways that include compounded effects, or lower scores if they relate to floods or the pandemic alone. “Impacts” and “relates to” connections were considered less relevant and were given 1-7 points.

5.3 Impact chain - Bucharest historic events; 1100-1900 (Learning case study)

Bucharest is one of the most endangered capitals in the world due to seismic hazards, as revealed by all global and regional hazard studies, such as Giardini et al. (2003, 2013) or Jimenez et al. (2001) and proven by the reality of the XXth century. From this point of view, it can also be considered the most endangered capital in the European Union.

Although located more than 130 km epicentral distance away from the Vrancea Seismic Source, significant peak ground acceleration (PGA) values, greater than 0.2 g, can occur in Bucharest. The Vrancea intermediate-depth seismic source is located at the contact of the East European Plate, the Intra-Alpine and the Moesian Subplates, at 130-150 km epicentral distance away from the city. Its seismic activity is responsible for damaging acceleration values in Bucharest, according to Giardini et al. (2013).

A recent seismic microzonation study (Marmureanu et al. 2010) shows that for the maximum predicted Vrancea earthquake (with Mw 7.8, at 150 km depth), PGA values ranging from 0.22 g up to 0.3 g could be recorded at surface. However, the study highlights that along the Dambovita River the PGA values can be expected to be smaller; but we consider that the geological datasets for the city area do not provide the clear picture of what micro-zonal differences could be. This is because there are few boreholes with depths > 100 m available for explaining the propagation from bedrock to surface in an area with deep sedimentary layers, and few strong motion recordings, which are not enough for depicting strong motion patterns. A significant distribution variation from an event to another is also expected, depending on the slight modifications of earthquake parameters - real recordings from the 1986, 1990 or 2004 moderate magnitude earthquakes revealed different patterns in terms of PGA distribution (Pavel et al. 2013).

Scope of the Impact Chain: The overall aim of Bucharest learning and application case studies on Vrancea earthquakes was to identify at cross-sectorial scale the cascading enhanced effects of seismic events.

The spatial scope fits Bucharest, the capital city of Romania, and the temporal one refers to the past, specified events in the period 1100-1900. The Impact Chain provides an overview of the triggered hazard and an overview of its multi-sectorial impacts.

The main risk pathways related to the historical earthquakes impacts and their causal links were treated synthetically in accordance with their shared vulnerabilities along 800 years of historical evidence.

- The large earthquakes produced in the Vrancea seismic zone have determined since historical times the destruction of buildings in Bucharest and human causalities (dead and injured), as major impacts. Other impacts can be summarized as follow: people evacuated and left homeless, flooding of cellars, interruption of the water supply or just the decrease in the quality of drinking water, blocking of communication routes, during- or post-earthquake fires. These are the most common impacts recorded in documents of the city hall, in testimonies of foreign travellers who either experienced the event or later, observed its destruction, in notarial documents, in personal notes, in the press of the time, in lithographs, photographs, etc. For the earthquakes produced prior to 1738, written evidence of impact is either almost non-existent or incomplete. More well-documented are the large earthquakes of this period: 1738 (7.7 Mw), 1802 (7.9 Mw), and 1838 (7.5 Mw) (Figure 5.1).

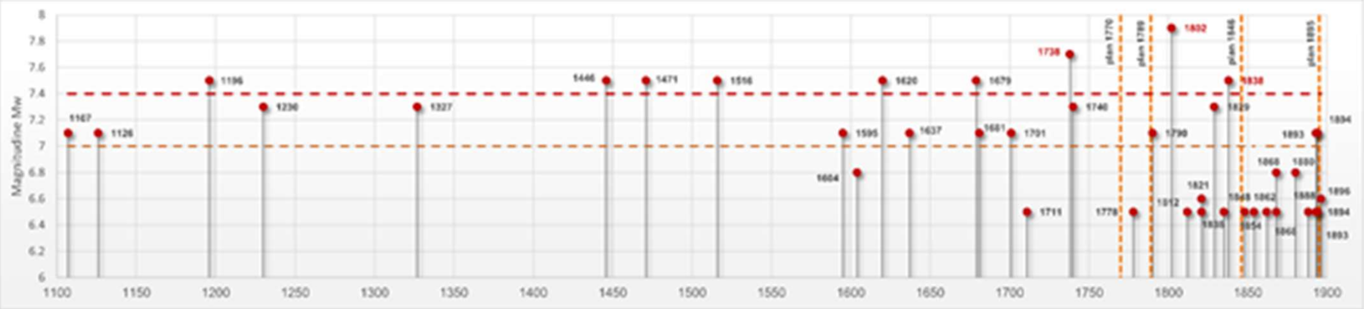

Figure 5.1 Timeline of historical major earthquakes

- For the earthquakes from the period 1100-1900 we do not have a global damage assessment. The documents that have reached us refer only to certain damages (for example, the amount needed to repair the network of ceramic pipes that supplied water to the public taps, or the amount needed to repair the walls of a certain inn, a monastery that housed a public school, etc.). We do not even know the total number of victims, the information being both incomplete and, in some cases, contradictory. However, the damage and casualties increased, in line with the increase in the city's population and the number of masonry buildings, with more and more floors. (Figure 5.2).

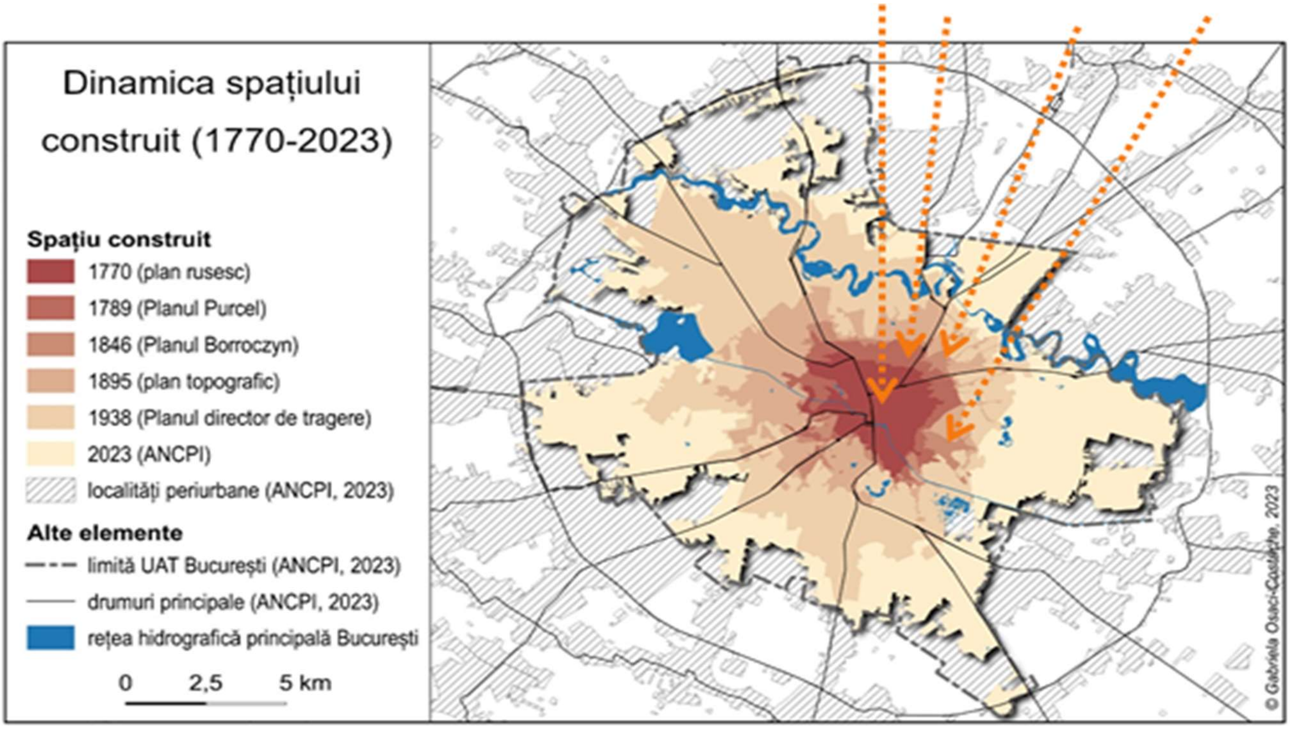

Figure 5.2. City development from historical maps

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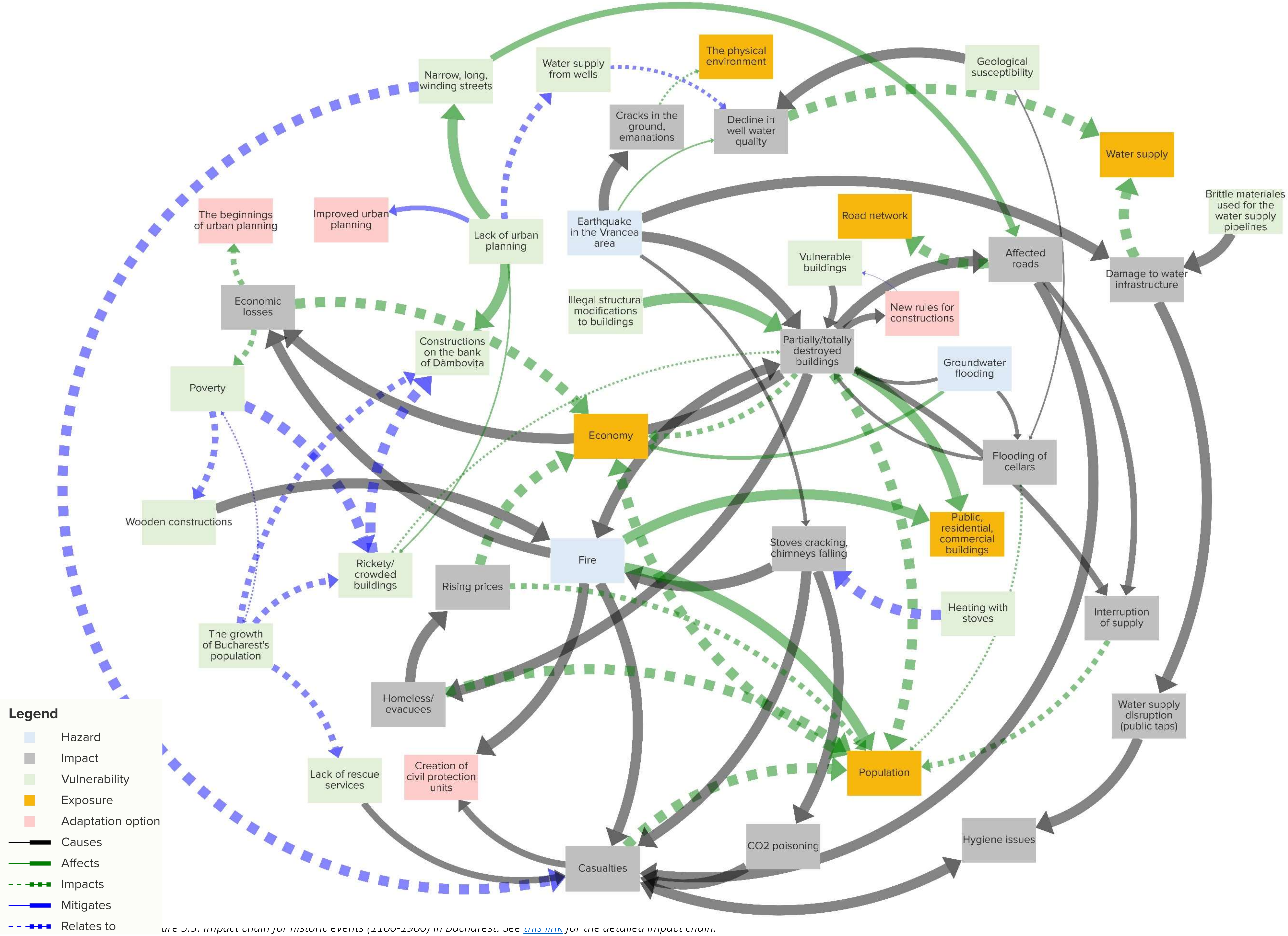

ure 5.3. Impact chain for historic events (1100-1900) in Bucharest. See this link for the detailed impact chain.

Several major and secondary impacts occurred and where therefore pinpointed in the IC (see Figure 5.3 above). More details can be found in the list below:

Major impact: partially or totally destroyed buildings
Certain vulnerabilities such as poverty and the growth of the city's population (from about 50,000 in 1710 to 232,009 inhabitants in 1899) are related to the shaky and, locally, cramped constructions that existed in the analysed period (1100-1900). The worst affected were poor-quality or unmaintained adobe and masonry constructions, and the most resistant were the elastic, wooden buildings, and the well-built manorial houses and palaces, made of brickwork. Although it is a vulnerability, poverty is also linked, paradoxically, to the limitation of damage to constructions, by the fact that the inhabitants of the poor classes could not afford constructions with a floor, but only with a ground floor. The lack of urban planning led to the crowding of residential or commercial buildings, and the collapse of some walls during the earthquakes also damaged neighbouring buildings, amplifying the damage. The crowding of constructions on the banks of the Dâmbovița River (which crosses Bucharest) was a vulnerability that could lead to the flooding of the city because of walls collapsing into the water, as happened in the 1838 earthquake.

Major impact: Geological susceptibility (liquefaction etc.)
Liquefaction caused, in addition to the demolition of some taller buildings, made of brickwork, church towers, and the flooding of some cellars, with economic damages.
Most of the buildings having only a ground floor, and there were not many victims in the historical earthquakes. However, during the earthquakes of 1802 and 1838, many buildings (churches, houses, palaces, hospitals, schools, shops, etc.) were damaged or completely demolished. Their number increased with the growth of the population and the multiplication of buildings in the city.

Secondary impact: increased price of building materials
The destruction of buildings, with the need to repair or strengthen them, as well as the large number of people left homeless, led to an increase in the price of building materials and labour, which called for special economic measures in 1802. The poor were the most affected. Churches, monasteries, schools, hospitals, and the network of public taps were repaired either with the money of the churches or with public funds. The owners of inns, shops, pharmacies, and houses were obliged (1838) either to repair their properties or to demolish them with personal funds. As a positive economic effect, the town hall's income from the tithe (tax) on construction materials entering the city increased.

Major impact: blocked/destroyed access roads
Some long, narrow, and winding streets of old Bucharest, resulting from the lack of urban planning, were quickly filled with rubble from the walls of riverside buildings, rubble that produced both victims (by burial) and the interruption of circulation, of the supply of food and goods of various shops and businesses in the city, etc.

Major impact: casualties (dead, injured, sick)
The lack of rescue/civil protection services, a vulnerability of old Bucharest, amplified the number of victims caused by the collapse of buildings or the covering of streets with rubble, even if for the earthquake of 1838 the authorities acted immediately by searching and rescuing/extracting the injured/dead, evacuating damaged buildings.

Major impact: fires

The existence of wooden buildings and stove heating, combined with the collapse/damage of chimneys during large earthquakes and the collapse or cracking of stoves, caused fires as secondary hazards, which also resulted in both damage and total or partial destruction of buildings, as well as the dead and wounded. As a result of the increasingly frequent fires in the city, the first military fire department was established in Bucharest in 1845 (but fire protection services date back to the 17th and 18th centuries). During earthquakes, the collapse of chimneys and the cracking of stoves caused, as another major secondary hazard, CO_2 poisoning (in the case of winter seismic events). The victims were mostly from the poor population (in which case the whole family lived in one room in winter, not having several rooms or not being able to heat several rooms).

Major impact: water supply disruption (public taps)

The old transport and water supply network of Bucharest was made of ceramic pipes ("olane"), which were cracked and displaced by seismic waves, which led to water supply disruption (public taps), with consequences in public health and hygiene.

Major impact: decline in well water quality (disturbance)

Also, poverty and the lack of urban planning was the reason why a large part of the city was supplied with drinking water from wells. During the earthquake, as a result of geological susceptibility (liquefaction), the water in the wells was disturbed, with a decrease in organoleptic qualities and a lack of drinking water for the inhabitants. This consequence was especially signalled in the earthquake of 1802 when the small network of public taps was also affected.

Quantifiable elements and information needed:

Both victims (by category: dead, injured, homeless) and affected buildings (residential, public utility) are quantifiable, but the few testimonies or gaps in information mean that these elements cannot be known for all past earthquakes or for the categories proposed in the research. Although there are city hall documents that describe the destruction of some buildings and even the post-earthquake interventions proposed by the town hall architects (1802, 1838), we do not have such data for all the affected buildings, but only for some of the important ones (inns, palaces, houses manors, schools, churches, and monasteries). Also, quantifiable would be the length and location of the affected ceramic pipes network as well as the number of affected residents, the number and location of public taps left without water, the number and location of wells with disturbed water, the number and location of all flooded cellars, the number and location of post-earthquake fires.

5.4 Impact chain - Bucharest recent earthquakes; 1940 and 1977 and future trends (Learning and Application Case study)

Scope of the Impact Chain: This recent earthquakes Impact Chain (20th century) describes, in a cumulative way, the consequences of major Vrancea earthquakes on November 10, 1940 (Mw 7.7, 150 km depth) and March 4, 1977 (Mw 7.4, 94 km - most damaging yet in Romania's and Bucharest's history). These two events had similarities regarding the chain of events, with the most recent event however continuing the damage started by the first. Before 1900, information but also the complexity level of the society was more limited; some aspects, such as fire being an important additional hazard, or the problem of water wells and chimney collapse started not to be so relevant after 1900. On the other hand, the 20th century came with a different challenge: the problem of vulnerable high-rise reinforced concrete buildings. The present and expected future can also be treated distinctively, as traffic became a major hazard but also the building and socio-economic vulnerability.

Several major and secondary impacts occurred and where therefore pinpointed in the IC (see Figure 5.4).

Major impact: Partially/completely damaged buildings

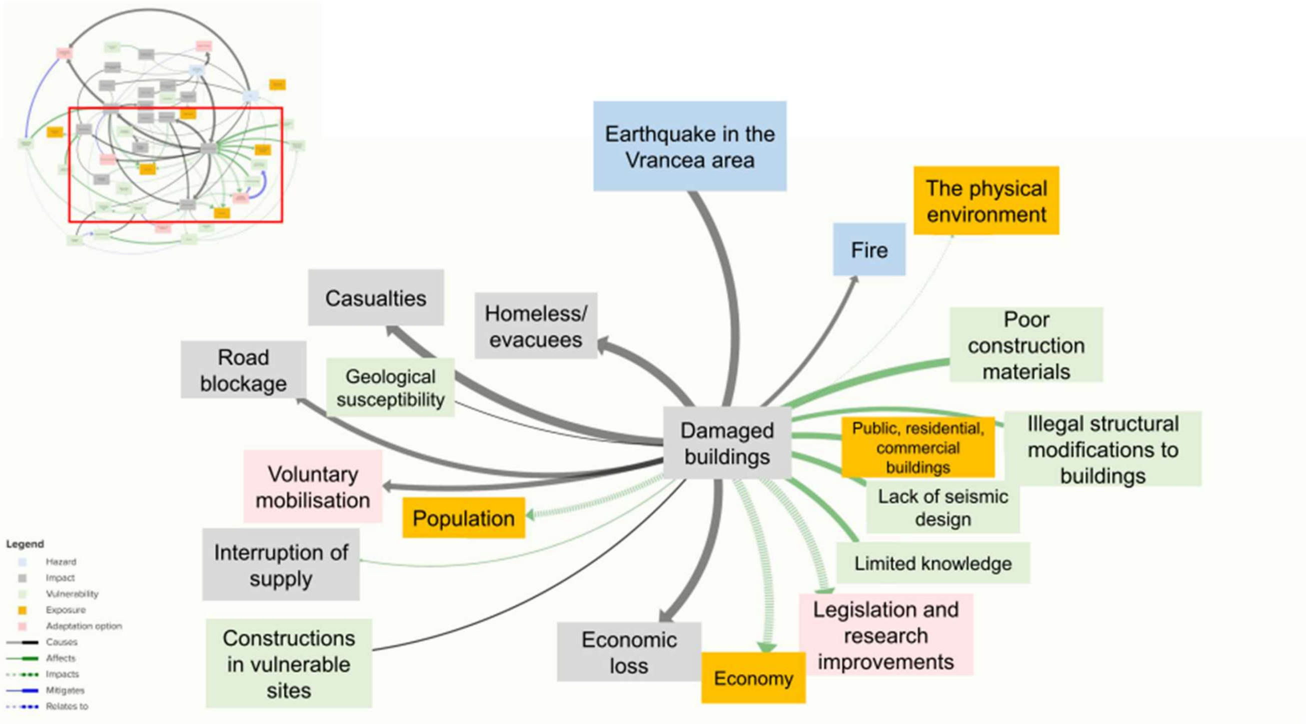

Figure 5.5 Part of the Impact Chain, with reference to affected buildings. See this link for the detailed impact chain

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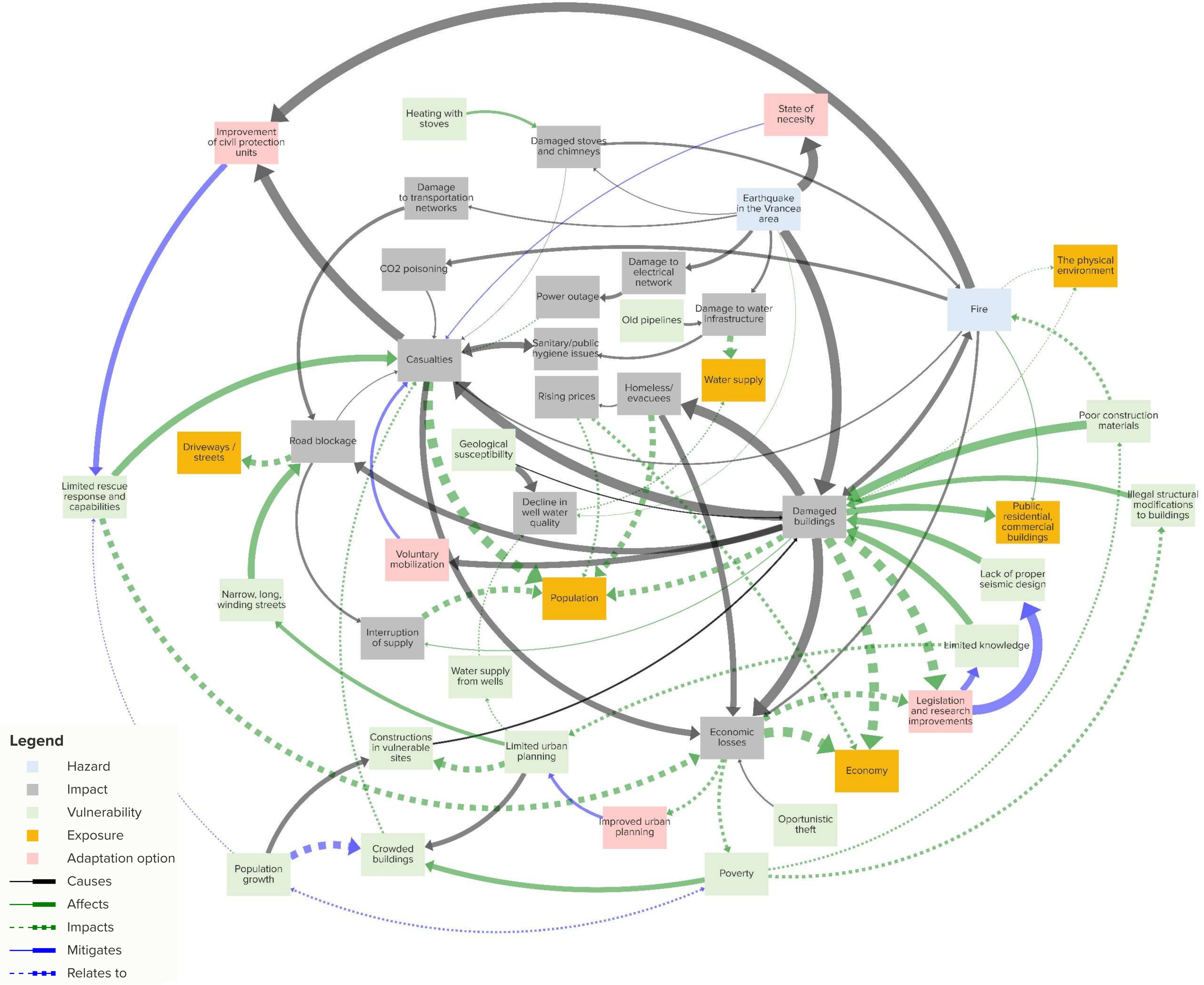


Figure 5.4: Impact chain for historic events (1940-1970) in Bucharest. See this link for the detailed impact chain.

As a consequence of the 1940 earthquake, some houses in Bucharest (200 buildings with cracked walls are reported in Sima, 1982) and churches were significantly affected, but few completely collapsed (Figure 5.5). The most notable collapse was the one of the Carlton buildings, the tallest residential building in Bucharest at that time, which lead to the most casualties. Massive public buildings did not have major damage. The dome of the Faculty of Law was moderately damaged, as well as the Romanian Atheneum, the old National Theatre, the Justice Palace, the CEC Palace, and the Postal Palace. One of the most severely damaged churches was Popa Nan. Moderately damaged churches or monasteries were Sf. Elefterie Vechi, Antim, Icoanei, Sf. Nicolae Șelari, Patriarchy Palace, Popa Tatu, Enei, Oborul Vechi, Precupeții Noi, Sf. Nicolae Tabacu, Sf. Apostoli Petru and Pavel or Italian Church. Slightly damaged were Amzei and Dobroteasa (Lungu et al., 2004).

As a consequence of the 1977 earthquake: 32 moderate or high-rise buildings in Bucharest collapsed completely or partially (Balan et al., 1982), leading to most of the deaths. Many other buildings, including newer ones, were slightly or moderately damaged. Several education, medical and industrial facilities were affected, being forced to halt their activity. 32 moderate or high-rise residential buildings (some also with businesses or restaurants on the ground floor and offices), most of them built between the two World Wars, had collapsed. These typically had reinforced concrete moment frame systems and were in the city center. Among the ones with complete collapse were Scala, Casata, Nestor, Belvedere, Colonadelor, Grădiniței, Str. Sahia (no. 1 and 58), Tudor Arghezi (no. 1) or Calea Moșilor (no. 135). With partial collapse were Dunărea, Simu, Wilson or Carpați/Metalexport. Some of them had been previously damaged by the 1940 earthquake (Figures 5.6-5.9). Two building sections constructed more recent also collapsed: the A section of flat no. 30 in the Lizeanu Area, built in 1962, and the F section of the OD16 flat in the ilitari Area, built in 1974. According to the ing. Gh. Ursu, around 350 buildings required urgent retrofitting, with 120 in very rapid need. Anoher 2000 needed serious interventions. Post-earthquake, some buildings had to be completely or partially demolished (such as Turist or Actiunea Economica a României buildings).

The upper floor of the Computing Center of the Transportation Ministry (a two-story building constructed in 1968) completely collapsed, to this contributing to the weight of the computers installed there. A building of the Faculty of Chemistry also collapsed, as well as the Victoria Hotel, previously affected by the 1940 earthquake. Hundreds of patients in one of the main buildings of the Emergency Hospital (Floreasca) had to be relocated, given the buildings poor structural safety, reflected one day following the earthquake by expert evaluation (Buhoiu, 1977). Some buildings of the Colentina Hospital (Neurological Clinic building) and Fundeni also had moderate to high damage. Antipa Natural History Museum and Geology Museum sustained some damage. Partial damage was found in the Romanian Atheneum, Justice Palace, University of Bucharest - the hall of the rectory and Faculty of Medicine (Balan et al., 1982). Monumental buildings with large openings such as Palace Hall and National Theater did not encounter significant structural damage (Balan et al., 1982).

The most affected churches were Popa Nan, Sf Apostol Andrei and Sf. Pantelimon Churches. Moderately affected buildings were Amzei, Aparatorii Patriei II, Doamna Ghica-Tei, Doamnei, Dobroteasa, Italian, Oborul Vechi, Popa Rusu, Sf. Mina Vergu, Sf. Nicolae Șelari, Sf. Nicolae Tabacu, Sf. Stelian churches and Antim or Sf. Spiridon Nou Monasteries (Lungu et al., 2004). The Patriarchal Palace and Popa Tatu Churces sustained minor damage. In cemeteries such as Bellu or Tudor Vladimirescu, monuments or crosses overturned.

Very few buildings with small height were damaged more significantly. No bridges were affected. The Otopeni international airport was operational following the earthquake.

Detailed post-earthquake inspections took place after the 1977 earthquake, revealing the need for significant retrofitting works. However, these were almost completely halted following an important meeting on 4th of July 1977, in which Nicolae Ceaușescu ordered the stop of interventions due to multiple reasons: both economical but also political. The full accelerogram of the earthquake, obtained at INCERC station in eastern

Bucharest, showing a maximum peak ground acceleration of 0,21 g but also a response spectrum characterized by high values in the range of 1.2 – 1.5 sec., contributed significantly to the revision of seismic design codes, which initially took place in 1978. The fact that acknowledgment for the need of functional seismic equipment was given and equipment donations from various world countries were received show that research as an adaptation option can be considered.

In 1940, no seismic design regulations were in place in Romania. After the earthquake, some regulations appeared, but only in 1963 a first compulsory seismic design code for most buildings was adopted. This (both the 1963 and the 1970 variants) however had limitations, especially in the consideration of response spectra specific for intermediate-depth Vrancea earthquakes. Therefore, the seismic vulnerability of buildings was an important factor of the earthquake impact on structures.

It is clear (as later also showed by recordings of the 1986 and 1990 Vrancea earthquakes in Bucharest) that local site conditions play an important role in the variance of ground motion throughout the city, which could partially corelate with damage distribution. Liquefaction was not so well evidenced, but for certain, close to the Dambovita and Colentina rivers, it can have manifestations.

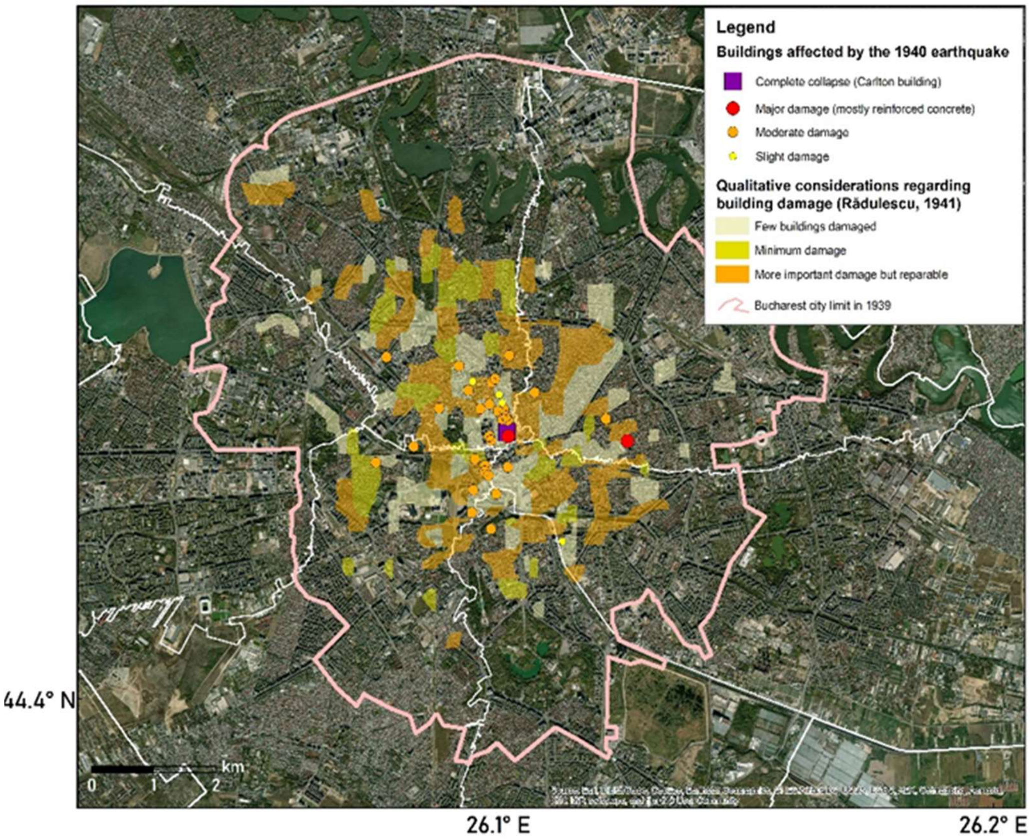


Figure 5.6 Map of the buildings and areas in Bucharest affected by the 1940 Vrancea earthquake (areas according to Radulescu, 1941)

Figure 5.7 Carlton Building before and after the 1940 Vrancea earthquake (photo sources: muzeuldefotografie.ro/Cristian Laubach for the last image)

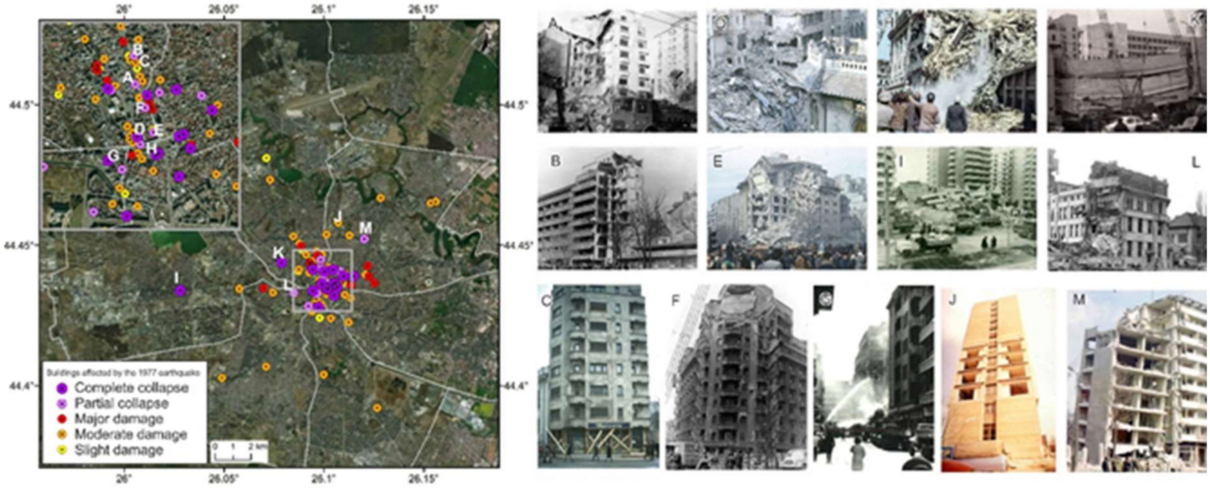
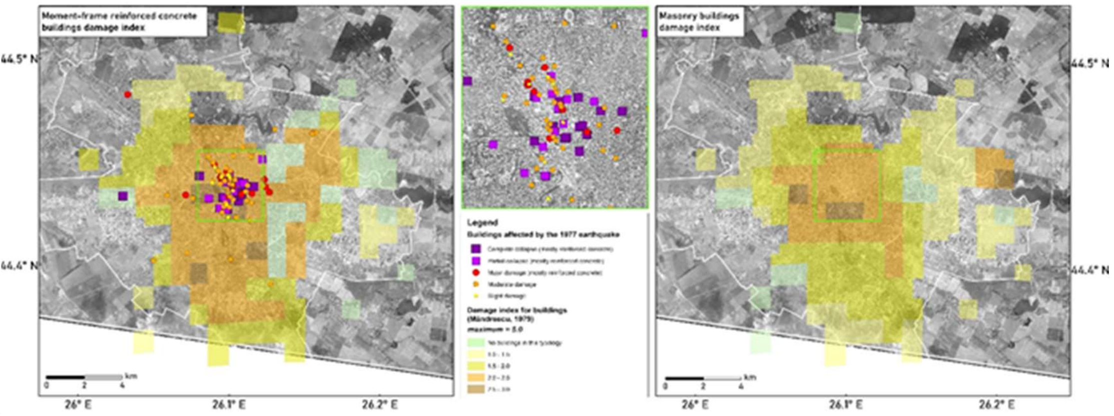


Figure 5.8 Representative buildings in Bucharest, affected by the 1977 Vrancea earthquake, and their locations. More photos and corresponding sources can be retrieved from Toma-Danila D. (2023)



Alps

Figure 5.9 Map of the buildings and areas in Bucharest affected by the 1977 Vrancea earthquake (areas according to Mandrescu, 1979)

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Major impact: Human casualties and homeless/evacuees (Figures 5.10 and 5.11)

In Bucharest, the1940 earthquake totalled: 140 dead, 300 injured (Sima, 1982). The 1977 earthquake resulted in: 1424 dead (90% out of the national total), 7598 injured (Balan et al., 1982).

In 1940, general mobilization of the army and legionary forces took place at the site of the completely collapsed Carlton building.

In 1977, state of necessity was instituted one day after the earthquake, on 5 March 1977. Priority was given to the saving of human lives. Army was also mobilized to help in the rescue efforts.

The number of homeless/evacuees is uncertain, due to the political context of the times, but it is probable that evacuees were is terms of thousand.

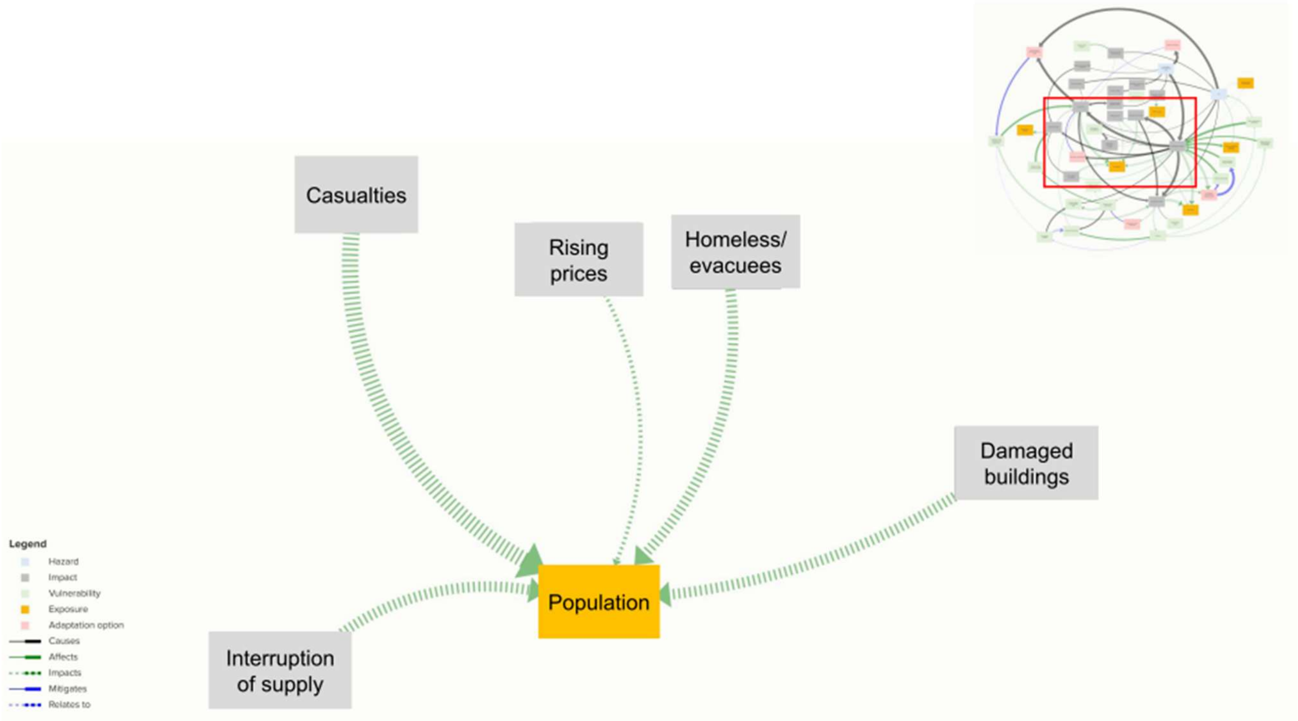

Figure 5.10 Part of the Impact Chain, with reference to influence on population. See this link for the detailed impact chain

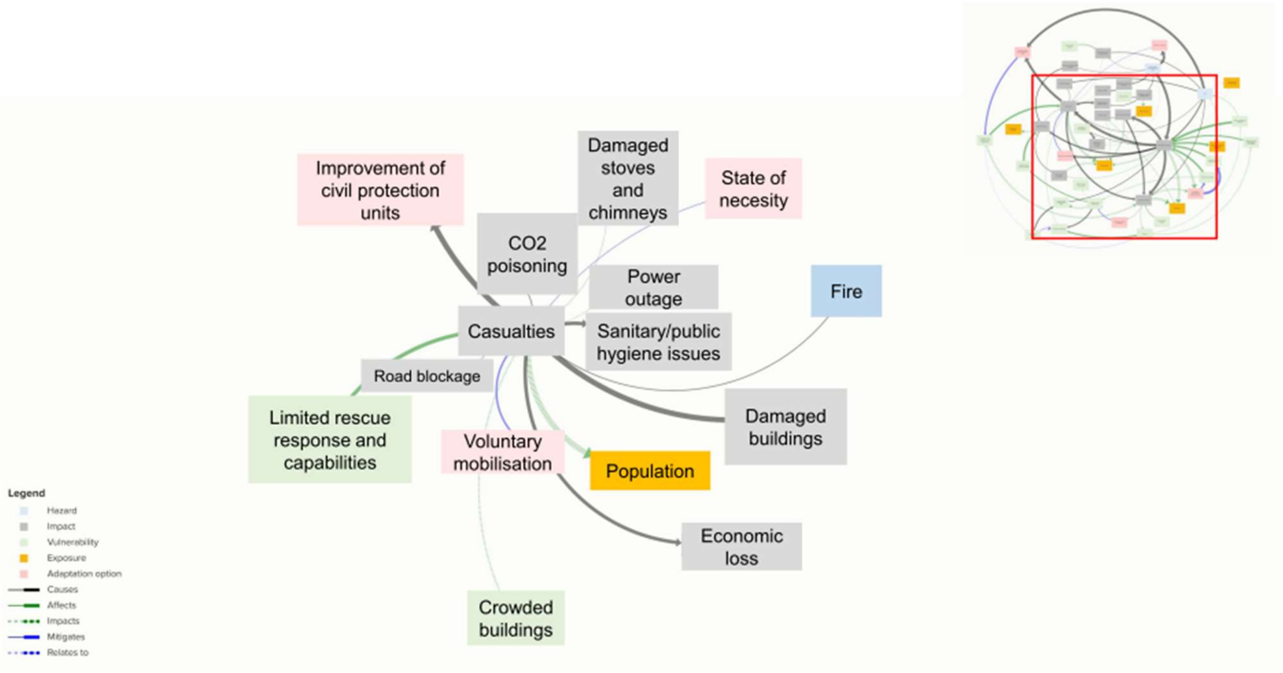

Figure 5.11 Part of the Impact Chain, with reference to casualties. See this link for the detailed impact chain

Major impact: Economic losses
At national level, total economic losses for the 1977 earthquake were higher than 2 billion dollars, which would mean in 2023, adjusted to inflation, over 9 billion dollars. 70% of these were due to situation in Bucharest.

Major impact: Power outage
In Buhoiu (1977) it is noted that some hospitals had problems with electricity, water or heat supply, in the days following the 1977 earthquake.

Moderate impact: Supply
It is noted in Buhoiu (1977) that some hospitals (such as Grigore Alexandrescu) had problems with water supply in the days following the earthquake.

Moderate impact: Fire outbreak
During rescue operations at the Carlton building in 1940, due to a fuel reservoir spill out and a spark, a fire started. This killed all survivors trapped in the building basement, who were previously capable of communicating with rescuers through telephone lines still functional (Simu, 1982).
As a consequence of the 1977 earthquake, the roof of the thermo-electric Bucharest West plant collapsed and a big explosion, given the pressure accumulation, was prevented at the last moments (Buhoiu, 1977).
At several sites were buildings collapsed (Belvedere or Galati Str. no. 33), due to fuel spill outs, fires started but were rapidly extinguished. All these experiences contributed to improvement of fire and civil protection units.

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Moderate impact: Road blockage

Some streets were blocked, especially in central Bucharest in 1977 (such as Magheru, N. Balcescu or Pacii Boulevards). But due to the limited number of cars in those times and the multiple detour alternatives provided by the urban road network, with respect to building collapse distribution, road blockage was not a considerable problem both immediately and days after the earthquake (Buhoiu, 1977).

Quantifiable elements and information needed

The following elements can be quantified, using the information we know to be available:

- Buildings completely or partially collapsed. For the 1977 earthquake there is precise data, from Balan et al. (1982). For the 1940 earthquake, the location of the sole important collapsed buildings (Carlton) is well known.
- Number of people killed and injured, because of the 1977 earthquake. Data is also available for the 1940 earthquake, although confidence in it is limited.
- Damage index for areas affected by the 1940 and 1977 earthquake (based on the works of Radulescu, 1941, Mandrescu, 1979 or Balan et al., 1982, for specific building projects) – rather in qualitative terms.
- Direct economic losses.
- Fire outbreaks, with mentions of causes, extent and duration.

Other relevant quantifiable elements, for which we don’t have yet significant data, can be represented by:

- Number of homeless and evacuees (with time intervals for departure, inferred costs etc.).
- People involved in rescue efforts and their evolution in time.
- Obstructed roads and duration of the obstruction (with some information available for 1977 in Buhoiu, 1977).
- Areas without electricity, water, gas, heat etc. or segments affected and duration of the problems.
- Number (per types) of repairs needed to buildings, lifelines and transportation networks or costs involved.
- Indirect economic losses.
- Water quality.

5.5 Impact chain - COVID19- extreme floods in Romania (Learning Case study)

Being this Impact Chain particularly complex, we provide here only the link to the Kumu project to better view it in detail.

Scope of the Impact Chain: This Impact Chain represents a Learning Case Study on the interactions between the extreme flood events and the COVID-19 pandemic in Romania. The spatial scope fits the national scale, and the temporal one refers to the past, specified events in 2020-2021. The Impact Chain provides an overview of the multi-hazard and its impacts, with special attention to the elements and connections that refer to compounded effects.

The main risk pathways relate to the impacts of extreme flood events that can be further on linked to other impacts of the COVID-19 pandemic, either by causal links or by “affects” connections. In some cases, these compounded or cascading impacts share common vulnerabilities.

Major impact: Human casualties

Both COVID-19 and flood hazards resulted in human casualties (Figure 5.12), in most cases directly, but in certain cases indirectly (e.g., due to suicide, which is linked to mental health problems like depression, that have been augmented by social isolation during lockdown). Extreme flood events caused the death of one child in Bihor County in 2021, and three men in Bacău, Iași, and Neamț counties in 2021. On the other hand, the pandemic caused the death of 15,596 people in 2020, and 43,118 people in 2021, which add up to 86.09% of the total number of human casualties in Romania (WHO 2023). The vulnerability identified in this case refers to the insufficient ICU capacity in terms of beds, ventilators, and oxygen supply, which is related to the low-performance Romanian medical system. The total number of deaths caused by COVID-19 infection in an indirect way is unknown, but not forgettable, given the effects of the COVID-19 on other diseases: excessive mortality in Romanian cancer patients (Triganescu et al. 2022) and cardiovascular patients (Tudora et al. 2023), delay in treatment for urothelial cancer (Barbos et al. 2023), acceleration of kidney pathology (Mureșan et al. 2022), augmentation of mental health problems (Cucu et al. 2021, Dionisie et al. 2022).

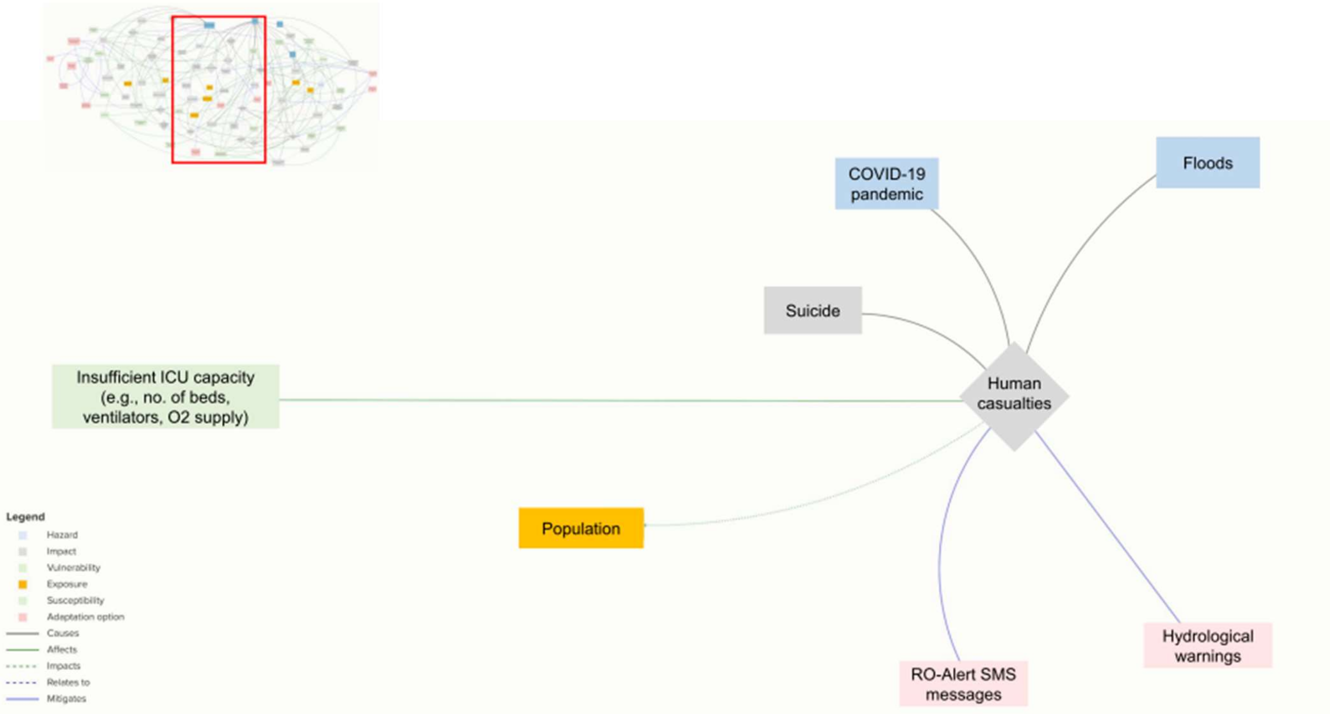

Figure 5.12 Impact Chain pathway leading to human casualties. See [this link] for the detailed Impact Chain

Major impact: Flooded/Damaged households or houses

The 5 major flood events that occurred in June (the 16th, 18th, 19th, 23rd, 26th) 2020, and the 8 events in May (13th, 18th), June (18th, 19th), July (15th, 16th, 19th, 20th) 2021 determined the flooding of hundreds of houses and households all around the country (Figure 5.13), but particularly in the Western and North-

Western regions of Romania. The damages were caused directly by river water (in most of the cases), but also by overflows from the ineffective sewage systems (especially in urban areas). Although there are no particular data on this, the most affected were the houses with mud walls, but flood water produced significant damage even in masonry buildings. This major impact resulted from a convergence of vulnerabilities such as the position of households at short distances from rivers, the low quality of construction materials, improper governance structure, and insufficient or ineffective hard engineering infrastructure/measures (which also led to the breaching of a levee near Biliești village, Vrancea County, in June 2021). In terms of vulnerability drivers, we can mention the development of inhabited areas in flood prone areas and deforestation.

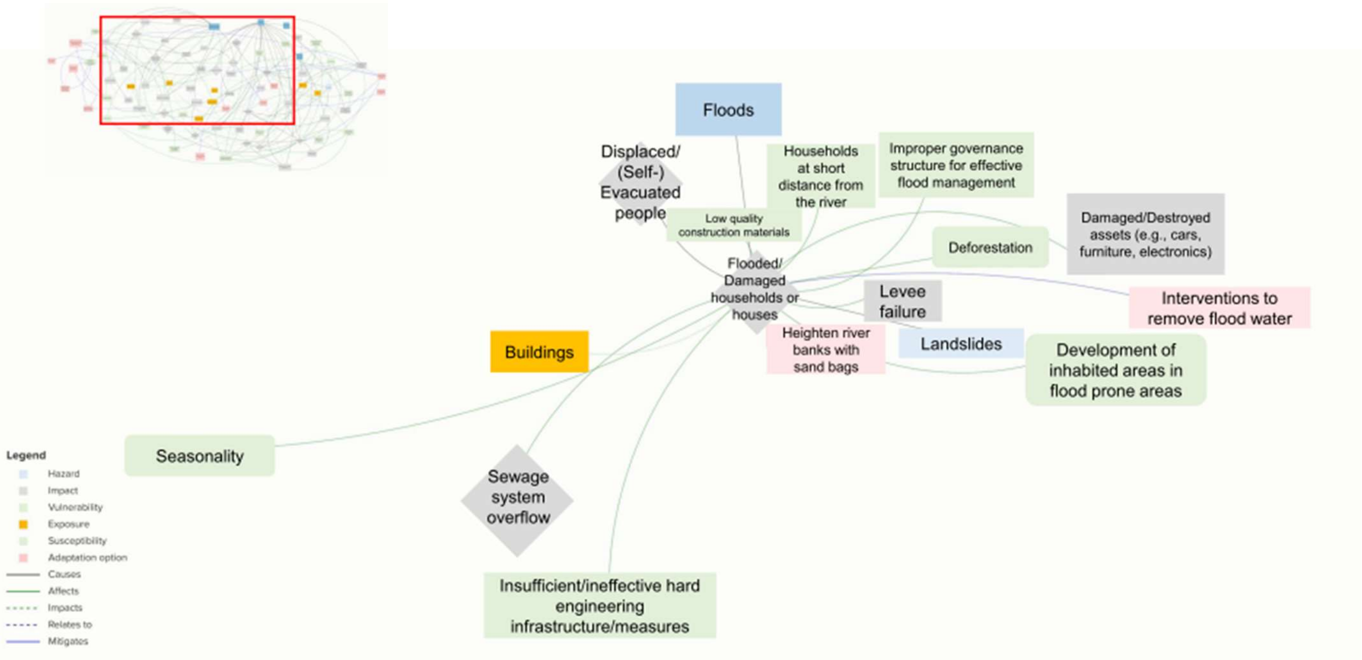

Figure 5.13 Impact Chain pathway leading to flooded/damaged households or houses. See this link for the detailed Impact Chain

Major impact: Displaced/(Self)-Evacuated people

The flood events determined the evacuation of about 340-720 people in 2020, and more than 675 people in 2021 (Figure 5.14) to put them away from harm or because their houses were severely damaged. The evacuees were housed in temporary emergency shelters, some of which were organized in local cultural buildings or indoor sports facilities (Albulescu, 2023). There is no information on the COVID-19 preventive measures implemented during the evacuation process or in emergency shelters, which means that flood management may not have been calibrated to account for them (noted as a prominent vulnerability element). Albulescu (2023) reports increases in the number of new cases in all, but one county affected by severe floods in 2020 and 2021, after 14 days (i.e., the extended incubation period of the virus) since each flood event. These increases were usually under 50 new cases, but the highest reached 208 new cases (i.e., Bihor County in NW Romania, after the flood of the 18th of June 2021).

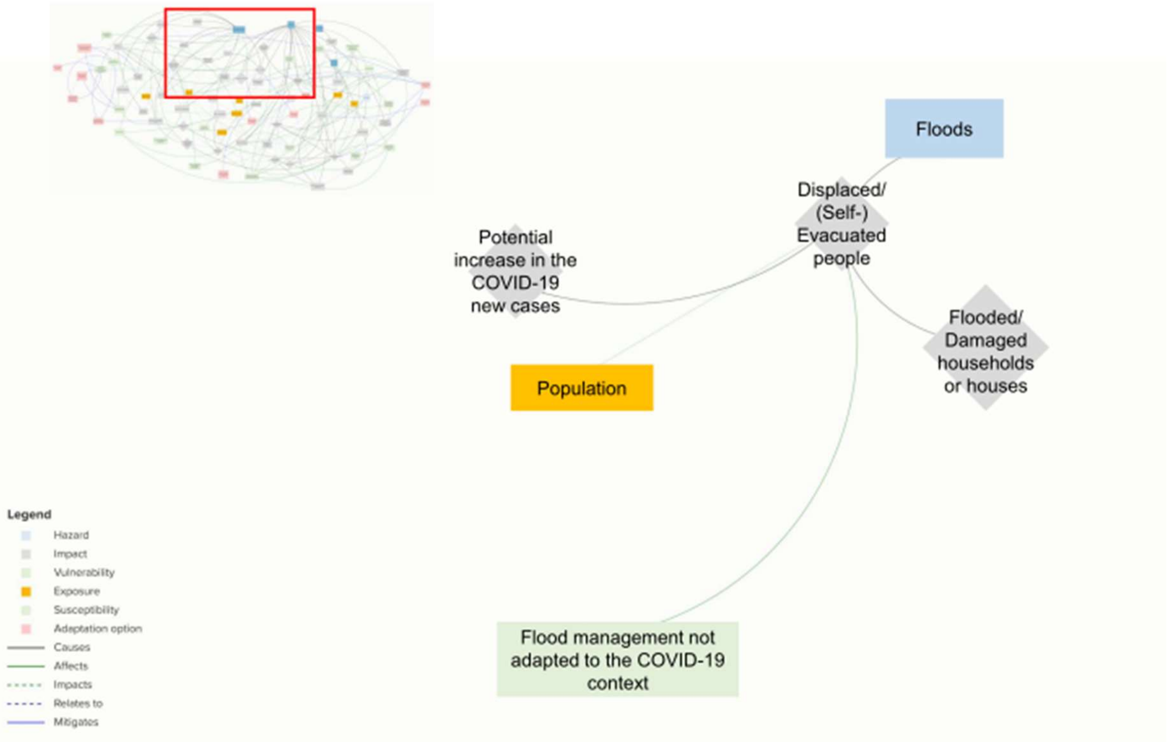

Figure 5.14 Chain pathway leading to displaced/(self-)evacuated people. See this link for the detailed Impact Chain

Major impact: Flooded/Damaged/Blocked roads

During and immediately after the extreme floods of both 2020 and 2021, many sections of national or county roads were covered by water, damaged or blocked by fallen trees and sediments brought by river water (Figure 5.15). In certain cases, urban streets were flooded by sewage water (e.g., in Buchares, Arad, Craiova, Brezoi). In all the described cases, the damaged infrastructure caused road transportation impairment, which led to other impacts, among which the impedance of the vaccination campaign, and of the ambulance service (both at local scale, in Vrancea County) stand among the most prominent. In June 2021, both the medical personnel and citizens willing to get vaccinated at the Suraia vaccination centre (Vrancea County) could not reach the facility for a few days, because the county road 204D was covered by the water of the Putna River, which previously breached the levee near Biliești village. A year earlier (June 2020), in Argeș County, one ambulance was prevented from reaching a patient in need of health care because of backbone problems. The ambulance vehicle had to stop on its way to the patient, because of the high level of a small local river. These are just examples of the impact of flood-damaged infrastructure on the medical system, and the population in need of medical care. The primary impact (i.e., flooded /damaged/ blocked roads) resulted from the development of infrastructure in flood-prone areas, which may also had been deforested. Another relevant vulnerability is the use of low-quality construction materials for the extension/reparation of the road network in Romania. In addition, both above said examples show the effects of insufficient or ineffective hard engineering infrastructure and measures.

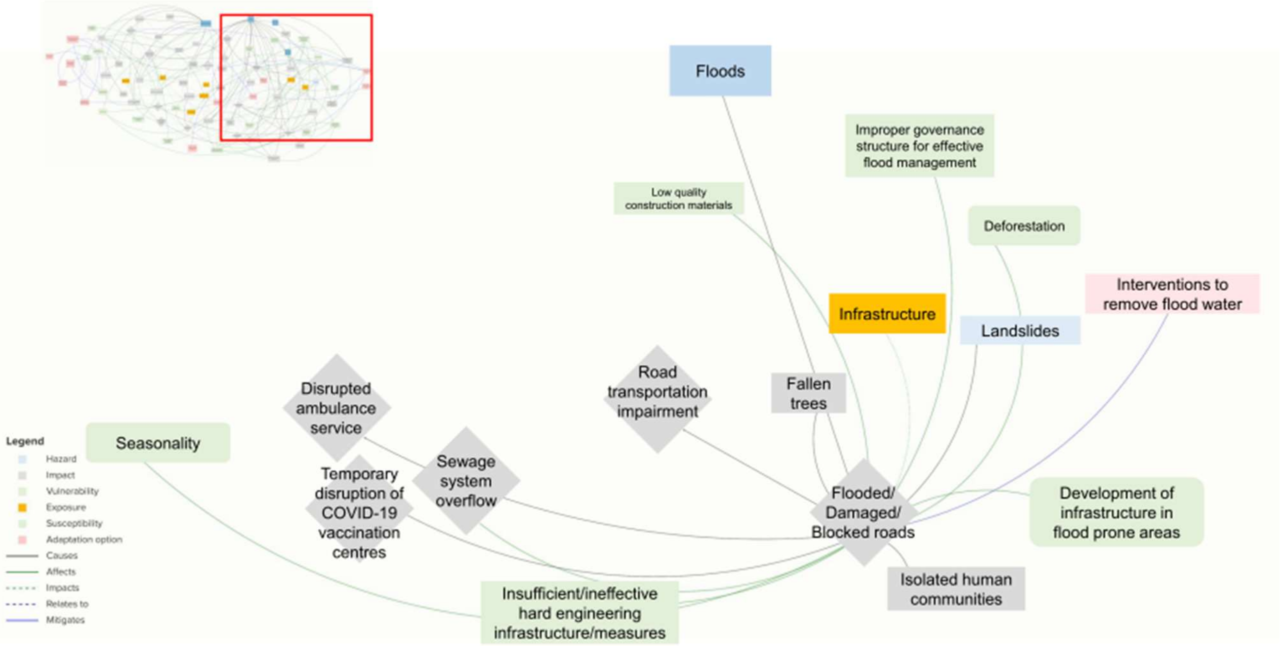

Figure 5.15 Impact Chain pathway leading to flooded/damaged/blocked roads. See this link for the detailed Impact Chain

Major impact: Sewage system overflow

A frequently encountered impact of floods and heavy rains is related to sewage system overflow (Figure 5.16), which usually occurs in cities with outdated, ineffective sewage systems of insufficient capacity (e.g., Bucharest, Arad, Brezoi, Craiova, Galați). In many cases, the overflow surfaces in poor neighbourhoods, which fall short of adequate urban infrastructure in general (e.g., Galați City, Craiova City), thus affecting the most vulnerable groups. Sewage overflow further causes flooding of the roads or even houses and households, impaired road transportation, and water contamination. Although it was not definitely proven, exposure to sewage water may facilitate the contagion with the SARS-CoV-2 virus (Han and He 2021), which means that this impact requires special attention.

Major impact: Cut off supply of electricity/gas/water

The cut off of electricity/gas/water supply is an indirect impact of floods or strong winds, which occurs after lifelines undergo significant damage (Figure 5.17), like in the case of the flood events of June 2020, May-July 2021. Such consequences were reported throughout the country in both years, affecting the population and economic activities. During the floods of June 2020, rail traffic was stopped between Mureni and Beu (Mureș County), because the electricity network that powered the trains was damaged by fallen trees. Another example is the disruption of tram transportation in Craiova City in June 2021, also happening because of a fallen tree. Such blackouts have the potential to also affect the medical system (by disrupting the functioning of medical equipment), with lethal implications for ICU patients.

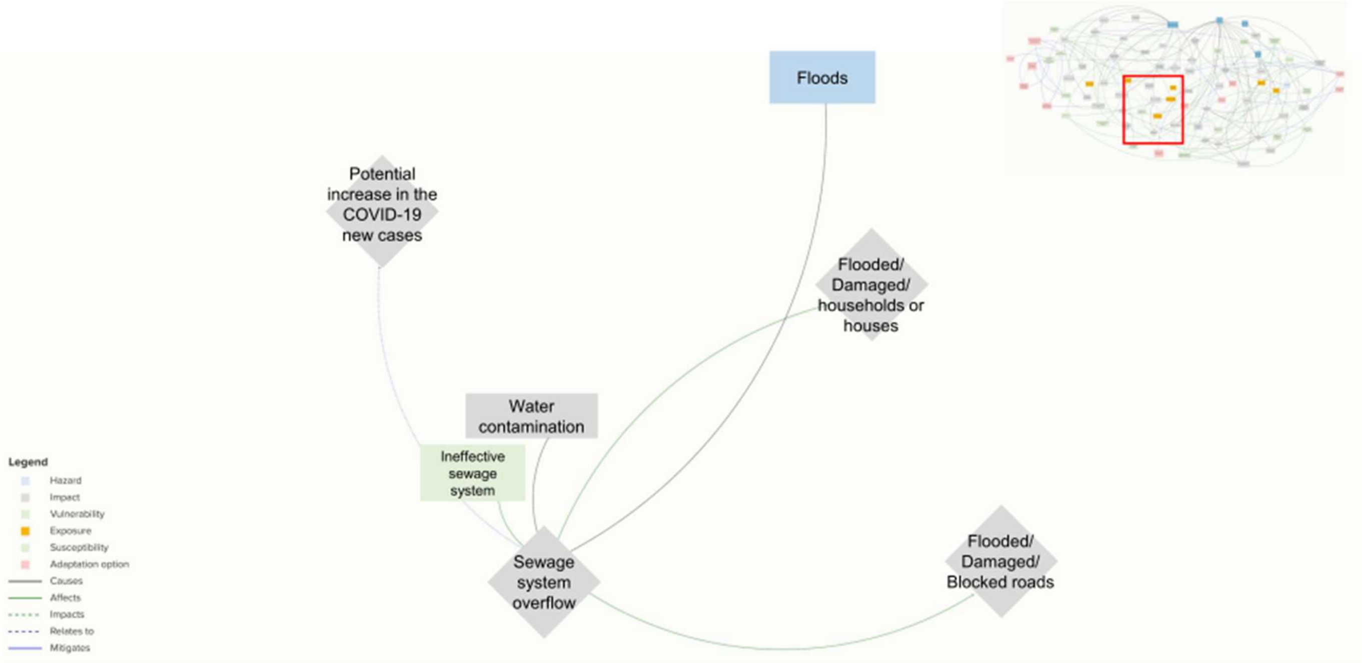

Figure 5.16 Impact Chain pathway leading to sewage system overflow. See this link for the detailed Impact Chain

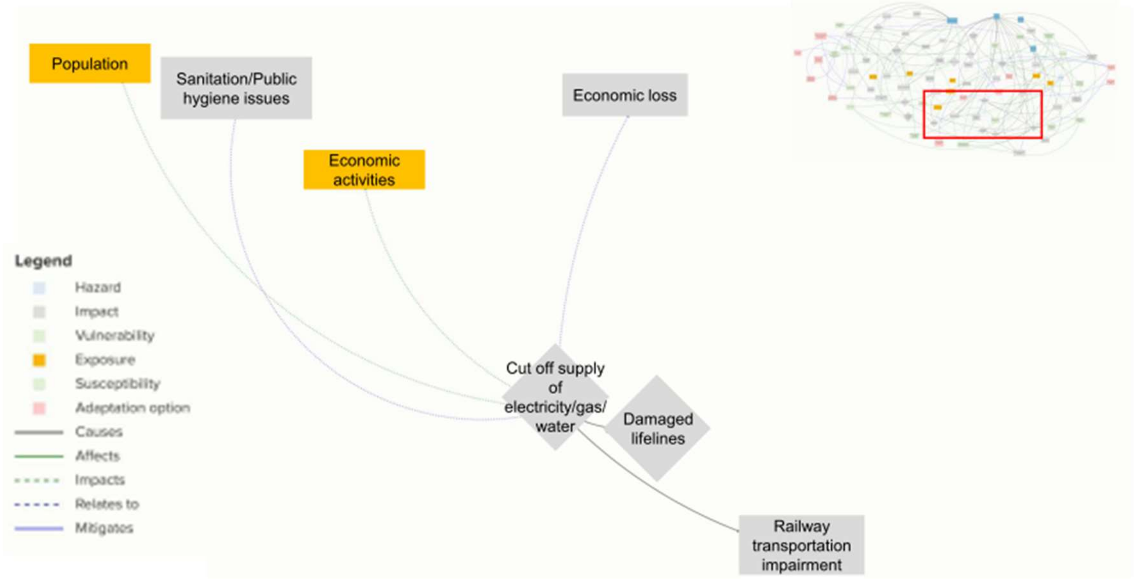

Figure 5.17 Impact Chain pathway leading to cut off supply of electricity/gas/water. See this link for the detailed Impact Chain

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Major impact: Flooded public institution buildings, including one hospital

During the floods of 2020-2021, 4 public institution buildings were flooded, and 17 others (schools and kindergartens) had their rooftops or basements damaged, either by heavy rain or flood water (Figure 5.18). In June 2020, the basement of the orthopaedic clinic in Timișoara City was flooded, hindering the health care provision at the medical centre.

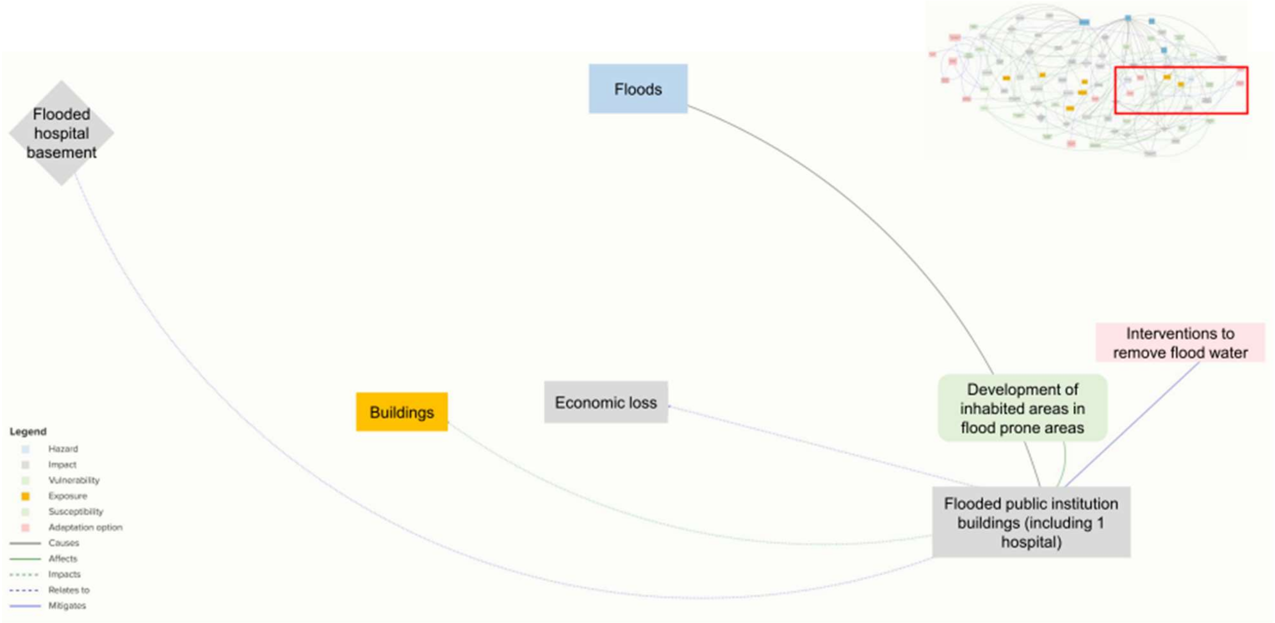

Figure 5.18 Impact Chain pathway leading to flooded public buildings (including one hospital). See this link for the detailed Impact Chain

Major impact: Temporary disruption of COVID-19 vaccination centres

An important local-scale impact of the flood event on the 18th of June 2021 is the temporary closing of the COVID-19 vaccination centre in Suraia, Vrancea County (Figure 5.19). The centre could not be accessed by road by the medical staff or the people willing to get vaccinated for several days, due to the surge of water that covered the county road 204D, after the Putna River breached the levee at Bilieşti village. The identified vulnerabilities are the development of infrastructure in flood prone areas and the construction/reparation of roads using low quality materials, which get easily degraded and call for new reparations in the next year(s). This local scale interference may have facilitated the progression of the COVID-19 infection in the nearby rural communities, which translates into potential increases in the new cases.

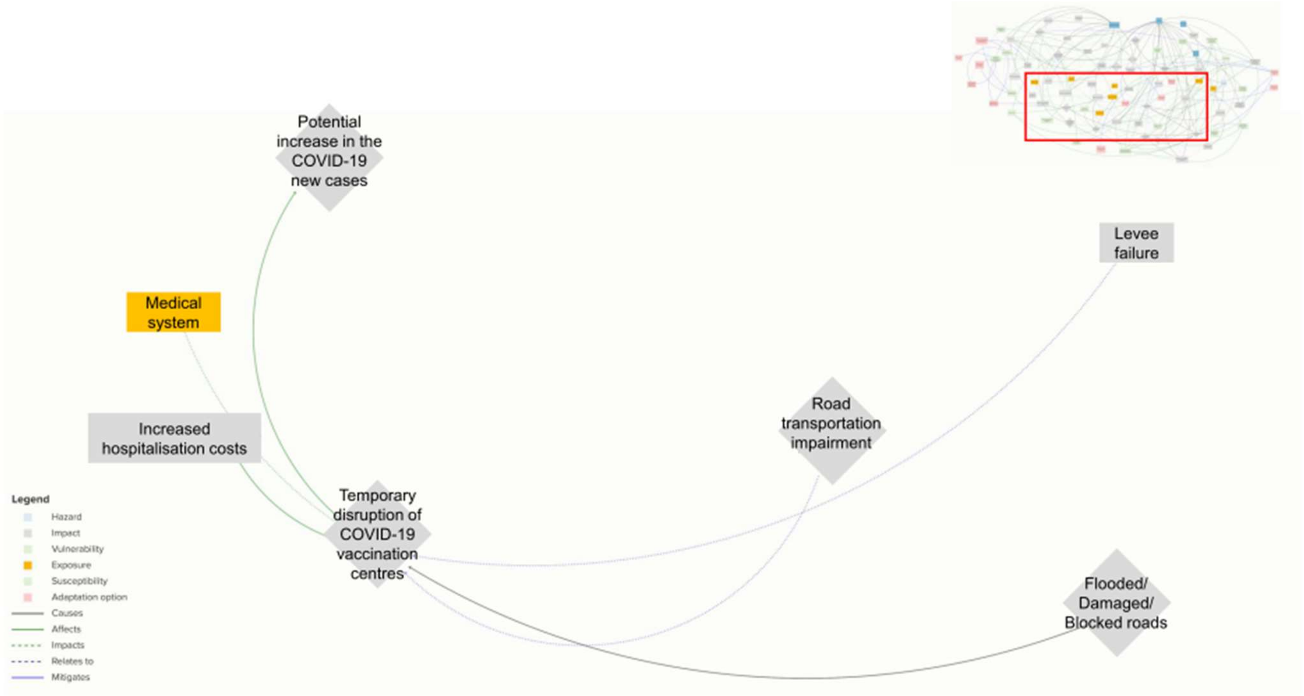

Figure 5.19 Impact Chain pathway leading to temporary disruption of COVID-19 vaccination centres. See this link for the detailed Impact Chain

Major impact: Disrupted ambulance service

The flood event of the 16th of June 2020 impeded the ambulance service in Argeș County (Figure 5.20). The ambulance vehicle was stopped on its way to providing medical care to a patient with backbone problems by the high-level water of a small river.

Major impact: Increased stress/anxiety

Increased stress/anxiety is a result of both the extreme flood events in 2020-2021, and the COVID-19 (Figure 5.21), with the noteworthy difference that the first hazard determined a local surge of these feelings, while the latter had that effect on global scale (to various degrees). In the case of floods, people were stress, worried or anxious about losing their homes and assets, and about the economic costs of recovery. COVID-19-associated stress/anxiety was a direct effect of considering the possibility of getting infected (or actually getting infected and going through the disease) and facing a new situation marked by uncertainties, in the first months of the pandemic, which temporally overlapped the lockdown. The severe restrictions imposed during the lockdown of March-May 2020 led to social isolation and changes in work patterns, significantly affecting the mental and emotional state of many people, for periods of various lengths. Another example of an indirect effect on stress/anxiety levels of the pandemic is related to the increased unemployment rate in the first months of 2020, which brought financial insecurities and additional worries for many Romanians.

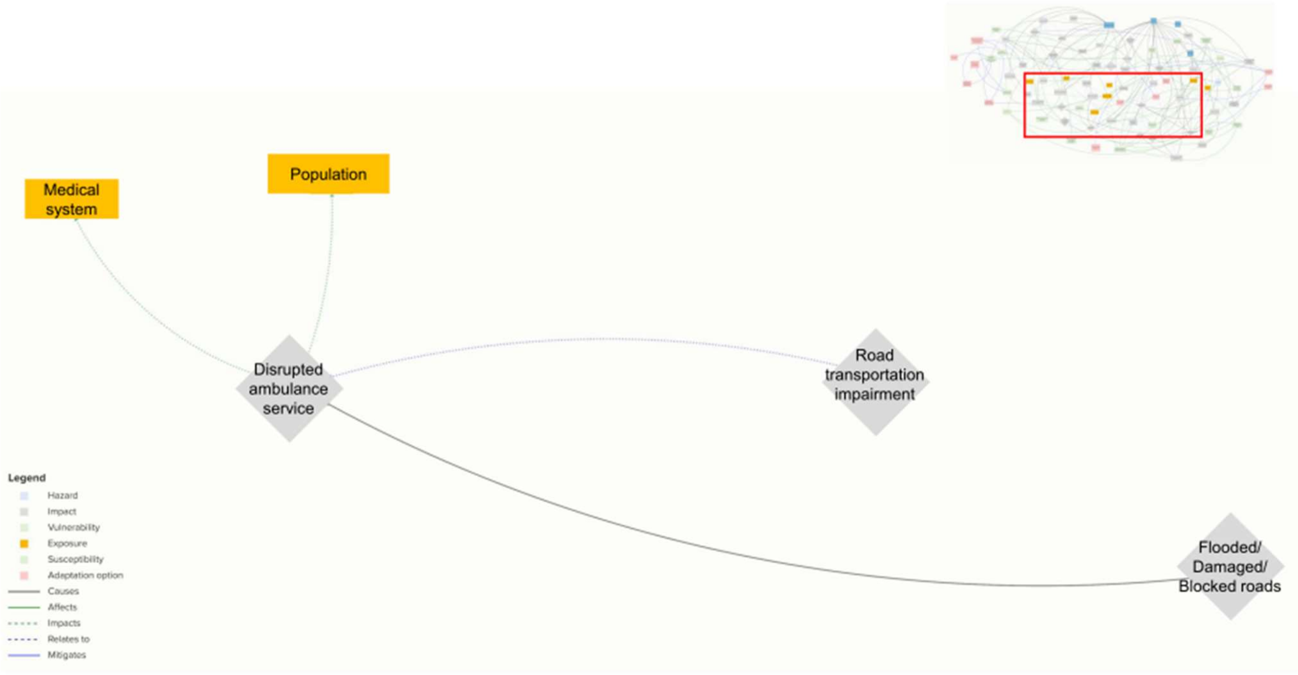

Figure 5.20 Impact Chain pathway leading to disrupted ambulance service. See this link for the detailed Impact Chain

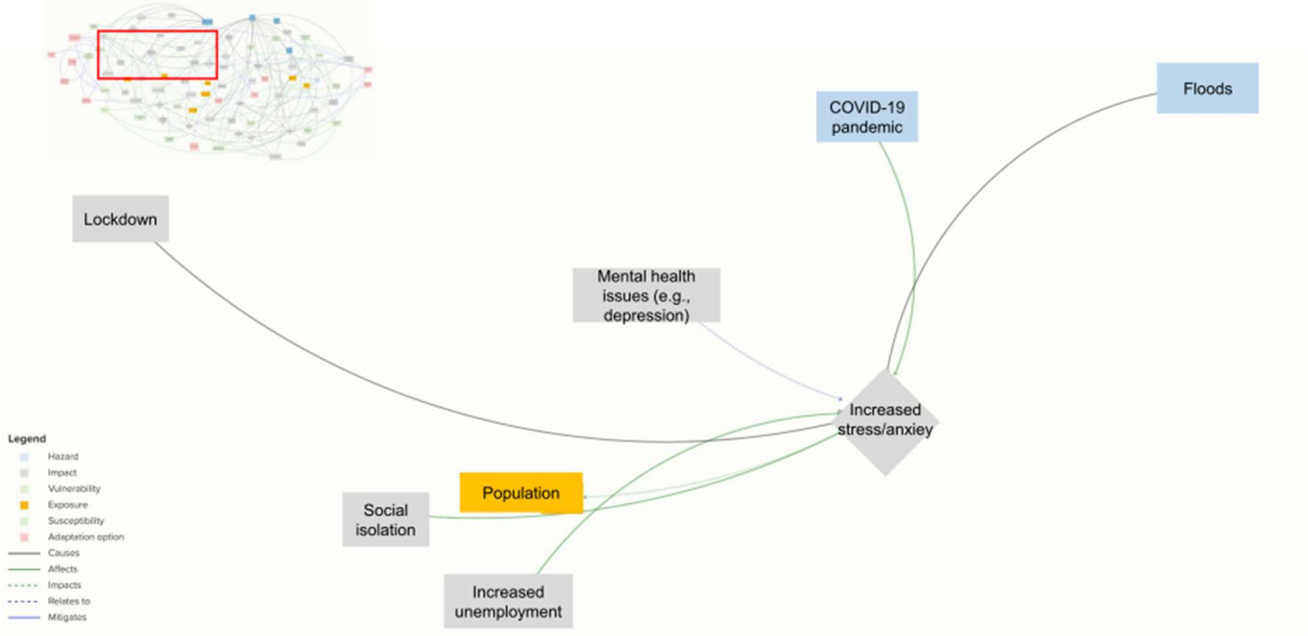

Figure 5.21 Impact Chain pathway leading to increased stress/anxiety. See this link for the detailed Impact Chain

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Other notable impacts caused by one of the two independent, but co-occurring hazards were: damaged/destroyed assets (e.g., cars, furniture, electronics), flooded croplands, dead or missing animals, flooded business buildings including tourism accommodation, disruption of tourism activities, damaged bridges, river water contamination with garbage – in the case of the 13 extreme flood events in 2020-2021, and changes in work patterns, economic challenges, increased unemployment, work overload on medical personnel, decreased life expectancy – in the case of the COVID-19 pandemic.

Quantifiable elements and information needed

The elements that can be quantified are mainly of impact type: human casualties, displaced/self-evacuated people, flooded/damaged houses and households, flooded business/public institution buildings, economic loss, dead or missing animals, fallen trees, destroyed assets (e.g., cars), decreased life expectancy, increased unemployment, potential increase in the COVID-19 new cases, increased hospitalization costs. The quantitative data can be extracted from official reports of WHO (WHO 2020, 2023) and OECD (OECD 2021), or from news reports (the first 73 references) and vary from one flood event to another. Also, statistical data can be consulted to estimate the reduction of life expectancy because of the COVID-19 pandemic, at national level (Eurostat 2021). Other data (e.g., a potential increase in the COVID-19 new cases, increased unemployment) emerge from the scientific literature (Albulescu 2023, Davidescu et al. 2021, Lorenzovici et al. 2022).

In contrast, other impacts of the pandemic (i.e., health problems, effects on other diseases, increased stress/anxiety, social isolation, work overload on medical personnel, mental health issues, changes in work patterns, economic challenges) or of the floods (e.g., disruption of COVID-19 vaccination centres, road/railway transport impairment, disruption of tourism activities, cut off supply of electricity/gas/water) are harder to quantify or cannot be quantified at all. However, these are (in most cases) thoroughly described in scientific literature.

6 Caribbean Application Case Study

The Caribbean Application Case Study is composed by two different study sites: St Maarten and St Vincent, where the various project activities are proceeding independently and at different speeds. We decided to select two case study sites in the Caribbean to better represent the range of hazard types, therefore including one case study that focuses on tropical storms, and another on additional geological hazards (e.g. volcanic hazards). These are described separately in the two sub-chapters below.

6.1 St Maarten

St. Maarten, also known as Sint Maarten, is an autonomous country within the Kingdom of the Netherlands, situated in the northeastern Caribbean Sea. The island shares its territory with Saint Martin, a French overseas collectivity. The capital of the Dutch side is Philipsburg, and the population is approximately 42,000. Like many Caribbean islands, St. Maarten faces several natural hazards. These include hurricanes, which can bring strong winds and heavy rainfall, as well as potential volcanic activity from other volcanic isalnds (e.g St. Vincent, Chapter 6.2).

6.1.1 Participatory workshop summary

The first stakeholders' workshop, held in St. Maarten, marked the beginning of the co-developing phase in the PARATUS project for the Caribbean Application Case Study, including the knowledge of stakeholders and practitioners.
The stakeholder workshop took place at the Simpson Hotel on the 1st and 2nd of March from 9 am to 5 pm. The language of the meeting was English. The whole event was recorded and transmitted online via Microsoft Teams, in order to facilitate the presence of stakeholders and practitioners that were located on Bonaire, Curaçao and in the European part of the Netherlands.
The aim of this first stakeholders meeting was to bring together practitioners involved in prevention, response, and recovery from major disaster events, to raise awareness regarding the consequences and effects of major hurricanes striking in Caribbean and find a common language to develop possible impact chains to feed the PARATUS platform.
One of the premises in selecting the stakeholders for this first meeting was related to the necessity to ensure a large coverage in disaster situations, and more precisely to protect the population, which includes evacuation, accommodation, water and food provision, and other measures. Official invitations were sent to all the institutions involved in disaster response according to the ESF 6. The list of attendees can be found in Annex 2, deliverable 6.2.

The meeting agenda was elaborated in cooperation with the Caribbean Response Preparedness department of the NLRC and with the other Application Case Studies in order to have comparable approaches and results at the end of the workshop (see Annex 3 in deliverable 6.2 for Workshop Agenda). The workshop was designed to fulfil the goals of the PARATUS by adding input from the PARATUS partners and invited stakeholders in different formats (e.g., presentations and focus groups,). The morning part of the workshop included presentations on what PARATUS is, the aim of the project, and presentations of the participants on the previous hazards they have suffered from. In the afternoon, we had in dept focus group discussion to identify direct and indirect impacts of the hazards people in St. Maarten, Saba and St. Eustatius are suffering from, and identifying the vulnerabilities that make people more vulnerable. On the second day, we zoomed in to the consequences and influences of external drivers on the hazard – impact systems that were designed by the participants.

Main outcomes of the workshop:

The stakeholders' meeting on Saint Maarten set the stage for developing impact chains and collecting data based on close interaction with selected stakeholders focusing on scenarios and future challenges of a hazard event. It demonstrated the need for closer collaboration and continuous communication between all actors involved in disasters, to better understand each other's needs and different perspectives. More specific it emphasized the need for inter- island communication between Saba, St. Eustatius, and St. Maarten due to the high dependence of the first two on the latter. Participants mentioned that working on the impact chain provided many insights and were open to further meetings and discussions between professionals.

An important focus group section was applied on past events affecting the Dutch windward islands.

Variables to estimate the relevance of impacts: Magnitude of adverse consequences, Likelihood of adverse consequences, Temporal characteristics of the risk, Ability to respond to the risk, Relevance for the study area in terms of responsibility for actions to be taken (who is the risk owner?), Unavoidable losses and damage, Irreversibility, Importance of the system(s) at risk, Interplay with dynamic vulnerabilities and underlying risk drivers.
In the past events that have been discussed, hurricanes have had a significant impact. Specifically, there was a discussion about the effects of hurricane Irma, which was followed closely by the COVID-19 pandemic. This quick succession of disasters left little time for the affected areas to recover fully.

Hurricane Irma, known for its destructive force, caused extensive damage in the affected regions. The aftermath of the hurricane resulted in a strain on resources, infrastructure, and the overall economy. However, before the affected areas could fully recover from the hurricane's impact, the world was hit by the COVID-19 pandemic.

The COVID-19 pandemic had a global impact, including the areas affected by hurricane Irma. The measures taken to control the spread of the virus, such as travel restrictions and lockdowns, severely affected tourism, which is a crucial economic resource for the affected regions. The lack of tourists and their spending further delayed the process of rebuilding and recovery.

The combination of the hurricane's devastation and the subsequent economic impact of the pandemic created significant challenges for the affected areas. Rebuilding efforts were hindered due to limited economic resources and the need to prioritize public health measures. The communities had to navigate through these challenges, seeking alternative sources of support and implementing measures to mitigate the impact on their economies.

Overall, the discussion highlighted the compounding effects of natural disasters and the unforeseen challenges posed by the COVID-19 pandemic. These events created a prolonged recovery process for the affected regions, particularly due to the economic strain caused by the decline in tourism.

During the discussion, it became apparent that it is crucial to clearly understand the direct and indirect impacts on specific sectors that were heavily affected by the combined impact of hurricane Irma and the

COVID-19 pandemic. Three sectors stood out as particularly important: the telecommunication sector, the health sector, and the logistics/food sector.

The telecommunication sector played a critical role in disaster response and recovery efforts, but it suffered significant failures during hurricane Irma. The loss of communication infrastructure hindered coordination and hindered timely assistance to affected communities. Understanding the direct and indirect impacts on the telecommunication sector is essential to improve its resilience and ensure effective communication during future disasters.

The health sector also faced unique challenges due to the link between the hurricane and the COVID-19 pandemic. The strain on healthcare facilities caused by hurricane Irma was further compounded by the need to respond to the pandemic. The discussion emphasized the importance of comprehending the interplay between these two events to develop robust healthcare strategies and infrastructure that can withstand and effectively respond to dual crises.

In addition, the logistics and food sectors were highlighted as critical for the islands of Saba and Statia, which heavily depend on imports for their food supply. The disruption caused by the hurricane and the subsequent economic impact of the pandemic significantly affected these sectors, leading to potential food shortages and logistical challenges. An in-depth understanding of the direct and indirect impacts on these sectors is crucial to develop resilient supply chains and ensure food security in the future.

In summary, the discussion underscored the importance of clearly understanding the direct and indirect impacts on specific sectors that were heavily affected by hurricane Irma and the COVID-19 pandemic. By focusing on the telecommunication, health, and logistics/food sectors, policymakers and stakeholders can develop targeted strategies to address the vulnerabilities and enhance resilience in these critical areas.

6.1.2 Impact chain methodology

Following the comprehensive workshop outcomes delineated in the aforementioned section, a decision was reached to undertake a more extensive development of impact chains for three sectors: (1) telecommunication, (2) health, and (3) food supply. The spatial scope of these impact chains was centred on Saint Maarten, Saba, and St. Eustatius, warranting an assessment of potential impact pathways for each hazard within a forward-looking perspective.

The impact chains under development shall elucidate the trajectory of potential hazards within these sectors, outlining their direct and indirect consequences on the target areas. The goal is to attain an in-depth understanding of the potential ramifications, ensuring that decision-makers and stakeholders can adopt effective strategies to mitigate vulnerabilities and enhance the overall resilience of these vital sectors.

The development of the impact chains drew upon a rich array of reliable and diverse sources, ensuring a robust analytical framework. These sources included the output derived from the focus group discussions during the kick-off workshop, which provided insights from stakeholders and enhanced the depth of analysis.

In addition, expert knowledge gleaned from interviews played a role in fortifying the impact chains. Authorities in the respective fields shared their expertise, contributing valuable insights that added depth and accuracy to the analysis. Scientific literature sources formed a foundation for the development of the impact chains. The incorporation of peer-reviewed studies, scholarly articles, and research papers helped establish a reliable evidence base. This integration of scientific knowledge added credibility and substantiated the findings of the analysis.

By integrating these diverse sources, the development of the impact chains embraced a comprehensive approach, ensuring a balanced and informed understanding of the subject matter. The combination of input from focus group discussions, expert insights, and scientific literature allowed for a rigorous analysis that can facilitate informed decision-making and promote resilience in the face of future challenges.

Furthermore, the confidence and relevance of each impact chain element and connection was assessed through the ranking system provided by the IPCC (Ridge et al.,2010).

Confidence

The confidence of the elements and connections included in the impact chain was established based on the type and the number of sources. Scientific papers, legislative documents, official press releases, statistical datasets, and reports were attributed the maximum confidence score (5), as their findings were ascertained by multiple experts. In the case of expert judgements, the confidence varied between 1 and 5 points, according to the degree of certainty assessed by the authors of the impact chain.

Relevance

The relevance of the elements and connections was established according to the scope of the impact chain, namely, to identify the compounded effects of hurricane events and the COVID-19 pandemic. The key question that guided this process is "How important/relevant is the fact that X causes/impacts/affects/relates to Y, for both hurricanes and COVID-19?" for connections, and "How important/relevant is the X element, for both hurricanes and COVID-19?" for elements. Maximum scores of 5 were attributed to those elements or connections that could be included in logical pathways related to both hazards. For example, hurricanes determined the evacuation of people, who interact during evacuation procedures and in the emergency temporary shelters, favouring the spread of the SARS-CoV-2 virus and leading to potential increases in the number of new cases. All connections and elements in this causal pathway were assigned relevance scores of 5, depending on expert judgement.

Another thing to consider when establishing the relevance of elements and connections is their type. Vulnerability elements will receive maximum scores depending on their contribution to both hurricanes and pandemic impacts, and lower scores if they contribute only to hurricane/pandemic impacts. Impact elements are noted with maximum scores if they can be caused by both hazards (e.g., human casualties), or with 5 points if they have important roles in the pathways that link the effects of floods to other potential COVID-19 related impacts. If a certain impact is solely caused by one hazard, it receives relevance scores of 1-4. Following the same line of reasoning, the most impacted exposure elements were attributed the highest relevance scores. In terms of hazards, hurricane and the pandemic present maximum relevance (5), and the score decreases for the other co-occurring hazards (i.e., heavy rain, strong wind, landslides).

When it comes to connection types, we considered that causal links, "affects" and "mitigates" connections have the greatest relevance and can be assigned 5 points if they are part of pathways that include compounded effects, or lower scores if they relate to floods or the pandemic alone. "Impacts" and "relates to" connections were considered less relevant and were given 1-4 points.

Below we will first discuss the health sector impact chain, thereafter the food supply sector impact chain, and lastly the telecommunication sector impact chain. All the impact chains aim to showcase the potential impacts on each sector in Sint Maarten in the event of a Hurricane.

Hurricanes produce winds of 74mph or higher. When a hurricane makes landfall it can cause heavy rainfall, strong winds, storm surges, and coastal erosion. Those lead to floods and landslides (Stillman, 2014).

6.1.3 Impact Chain-Hurricanes impacts with focus on Health Sector (Learning and Application Case study)

The complete Impact Chain on the hurricanes impacts for Sint Maartin, with a specific focus on the health sector can be viewed at the following link*: [PARATUS • Caribbean - Sint Maarten - Hurricane - Health sector - draft / A Paratus View • Kumu]*

A major impact that a hurricane can cause on the health sector is the increased demand for healthcare (see Figure 6.1).

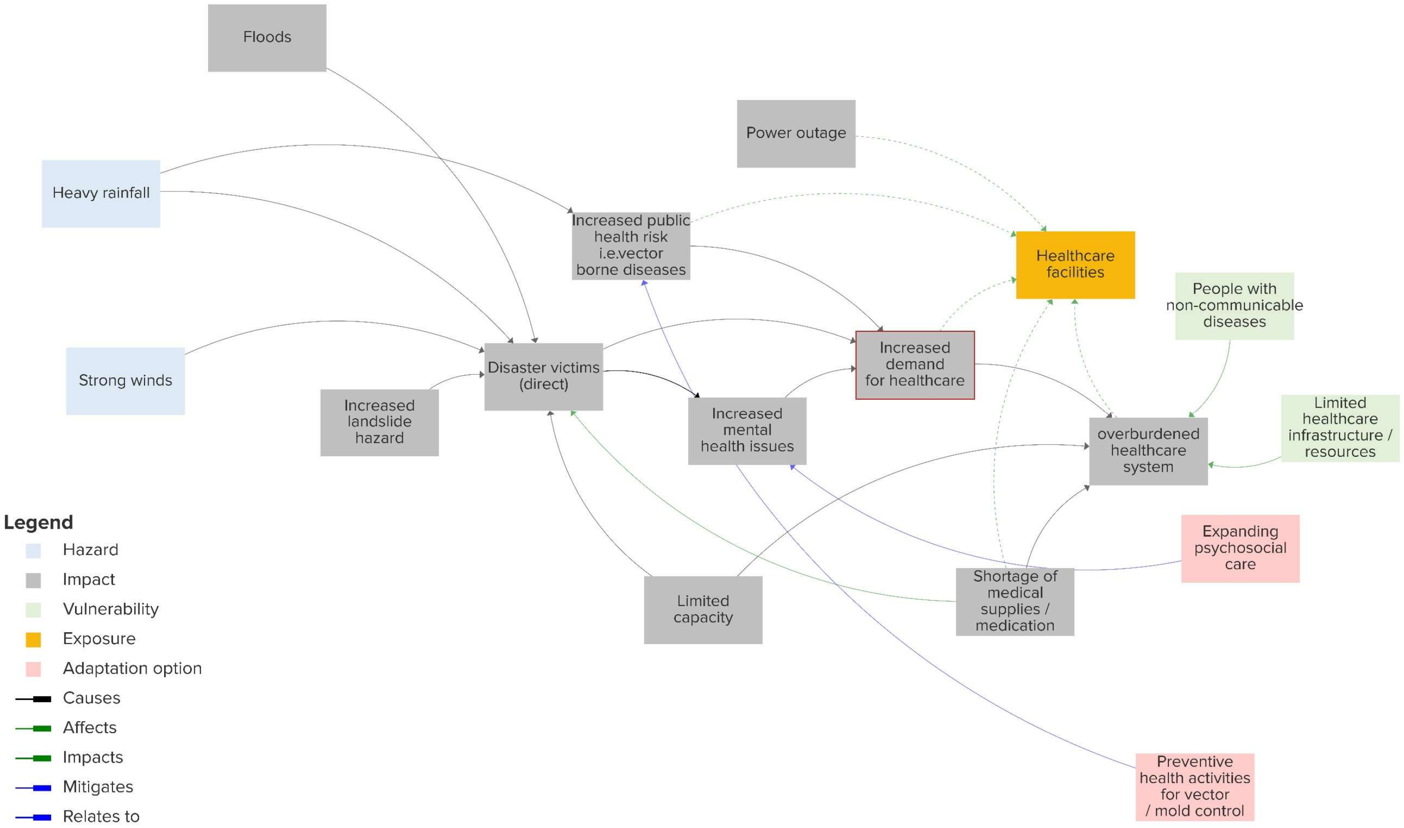

Figure 6.1 Increased demand for healthcare. See [this link] for the detailed Impact Chain

Due to floods, landslides, and heavy rainfall, people can get injured and then they may require medical attention. Also, disaster victims are highly prone to mental health-related issues. That also puts pressure on the healthcare systems. Most hydrometeorological disasters are followed by increased public health risks i.e., vector-borne diseases. These immediate impacts lead to a high risk of increased demand for healthcare. This impacts healthcare facilities which is an exposure element. Increased demand for healthcare can cause overburdened healthcare systems. Pre-existing vulnerabilities like limited healthcare infrastructure, resources and personnel, and people with non-communicable diseases affect overburdened healthcare systems. Increasing the capacity of healthcare services is an adaptation option that can mitigate the issues

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that arise due to the limitations of healthcare services. Also, the expansion of psychosocial care helps in addressing increased mental health related issues.

Talking about the quantifiability of the mentioned elements, some elements are directly quantifiable, while some could be quantified using different quantifiable indicators. The number of disaster victims is a direct count. But quantifiable indicators like the percentage of people with non-communicable diseases, population/ hospital beds or Intensive Care Unit (ICU) beds ratio, and population/available doctors' ratio, also help in quantifying elements.

6.1.4 Impact Chain- Hurricanes impacts with focus on Food Supply (Learning and Application Case study)

The complete Impact Chain on the hurricanes impacts for Sint Maartin, with a specific focus on the food supply sector can be viewed at the following link: PARATUS • Caribbean - Sint Maarten - Hurricane - Food supply sector - draft / A_Paratus_View • Kumu

The food supply sector is one of the main sectors that get affected during a disaster. Sint Maarten, as a small island developing state, faces a unique set of challenges in addition to the sector's standard obstacles. 'Decreased availability and access to food' can be identified as a main risk in this impact chain (Figure 6.2). The definitions used when discussing food availability and access to food are as follows.

Food availability: The availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (including food aid). FAO (2016)

Food access: Access by individuals to adequate resources (entitlements) for acquiring appropriate foods for a nutritious diet. Entitlements are defined as the set of all commodity bundles over which a person can establish command given the legal, political, economic, and social arrangements of the community in which they live (including traditional rights such as access to common resources). FAO (2016)

Food availability and access get decreased due to disruptions in logistical services as a result of road closures and airport closures. Also, the available food stock in the country is limited given the pre-existing vulnerabilities of limited storage facilities. This main risk leads to price hikes of food, increased looting, and even health problems.

Most of the elements in this impact chain cannot be counted directly but can be quantified using quantifiable indicators. Percentage of market closures, inflation, and the capacity of available warehouses are some of them.

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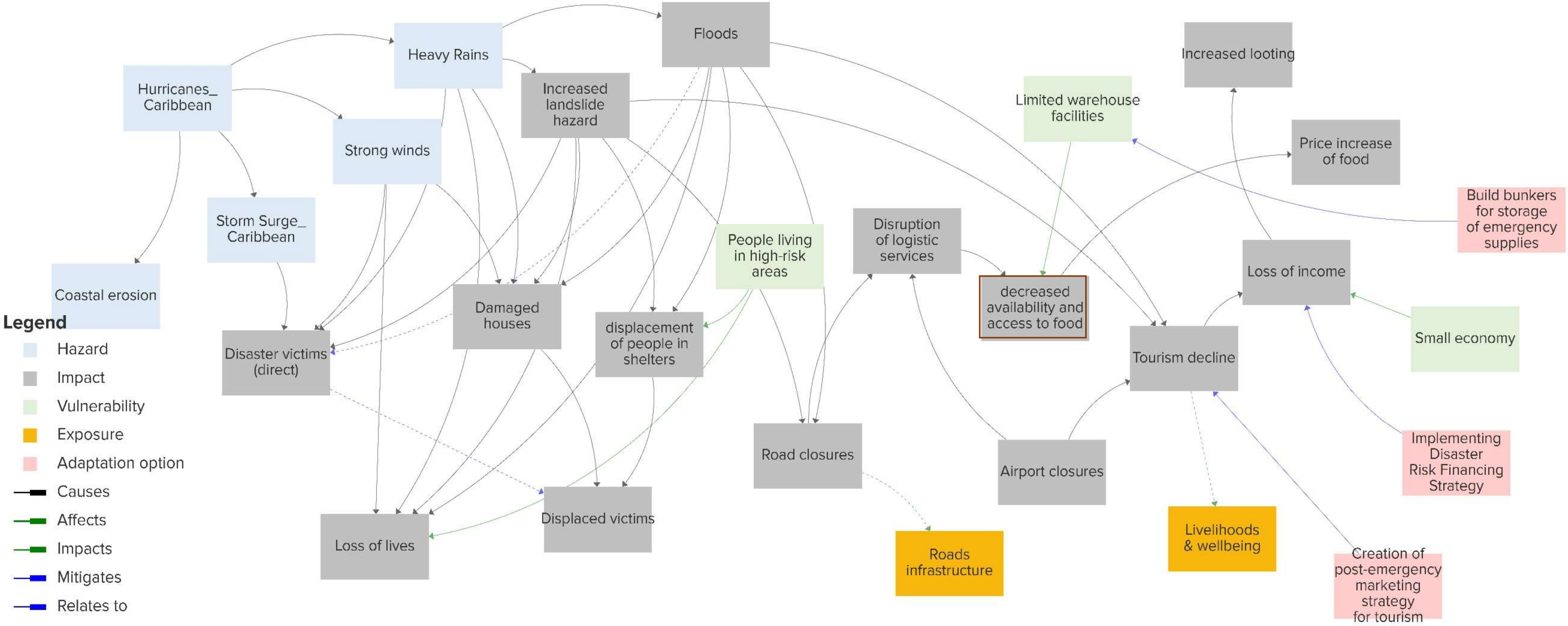

Figure 6.2 Decreased food availability and access. See this link for the detailed Impact Chain

6.1.5 Impact Chain-Hurricanes impacts with focus on Telecommunication (Learning and Application Case study)

During hurricane Irma and other major storms, damage to the telecommunication and electrical infrastructure have seriously hampered mitigation efforts during the storm and relief efforts in the aftermath of the storm. From experience the telecom sector estimates that a category 5 storm takes out 50% of the telecommunication towers, which in the accidented terrain of St. Maarten seriously reduces the coverage of mobile phone and Tetra, the communication system of the first responders. Co-siting of equipment increases the vulnerability, as FM broadcast antennas, point-to-point radio links and wireless internet distribution antennas installed on those masts may be affected simultaneously.

All inter-island and international communications are transported via sea cable. If this cable, which runs over the ocean floor, is damaged, the island becomes isolated from the outside world, and coordination of medical evacuations, the planning of the transport of food and supplies between Saba, St. Eustatius and St. Maarten becomes exceedingly difficult. The sea cable carries the internet, fixed and mobile telephone, and data communication for all inhabitants, but also data communication for the banking sector, harbour, airport, hospitals, and other industries.

When the sea cable would be damaged, for example by a boat anchor dropped at the wrong spot, repairs could take months. To reduce this risk, two independently routed sea cables connect the island. However, both cables have a common landing point, where they are more vulnerable for a common cause of failure. One such cause could be land erosion due to sea swell generated by a nearby hurricane, which would expose the cables at the landing point.

All telecommunication systems and the related user equipment depend on electricity. The electrical supply to the telecom towers may fail when cables are ruptured due to landslides or when distribution points are flooded. Also, if the power plant of the island would fail, all telecom systems would be affected. When mobile phone cannot be charged, connection of the inhabitants to the network will eventually be lost.

If the supply of electricity to the telecom towers – which are mostly located in the mountains – fails, they fall back on generators. In case of a longer power outage, their individual fuel tanks must be refilled manually. Fuel theft after a major disaster may require police protection of these critical sites.

A comprehensive map of the telecom impact chains, and the interdependencies of the different telecom systems can be found in Figure 6.3. These impact chains were described after discussions with telecom operators, telecom authorities, and telecom users during the St. Maarten workshop and in separate discussions. A zoomable version with descriptions of each block can be found here.

Unavailability of telecommunication systems has a direct impact on society, as information exchange and coordination between groups that are not co-located becomes impossible. The impacts chains due to telecommunication system failure can be found in Figure 6.4. The blocks on the left are the output of the telecommunication impact chains, which were shown in Figure 6.3.

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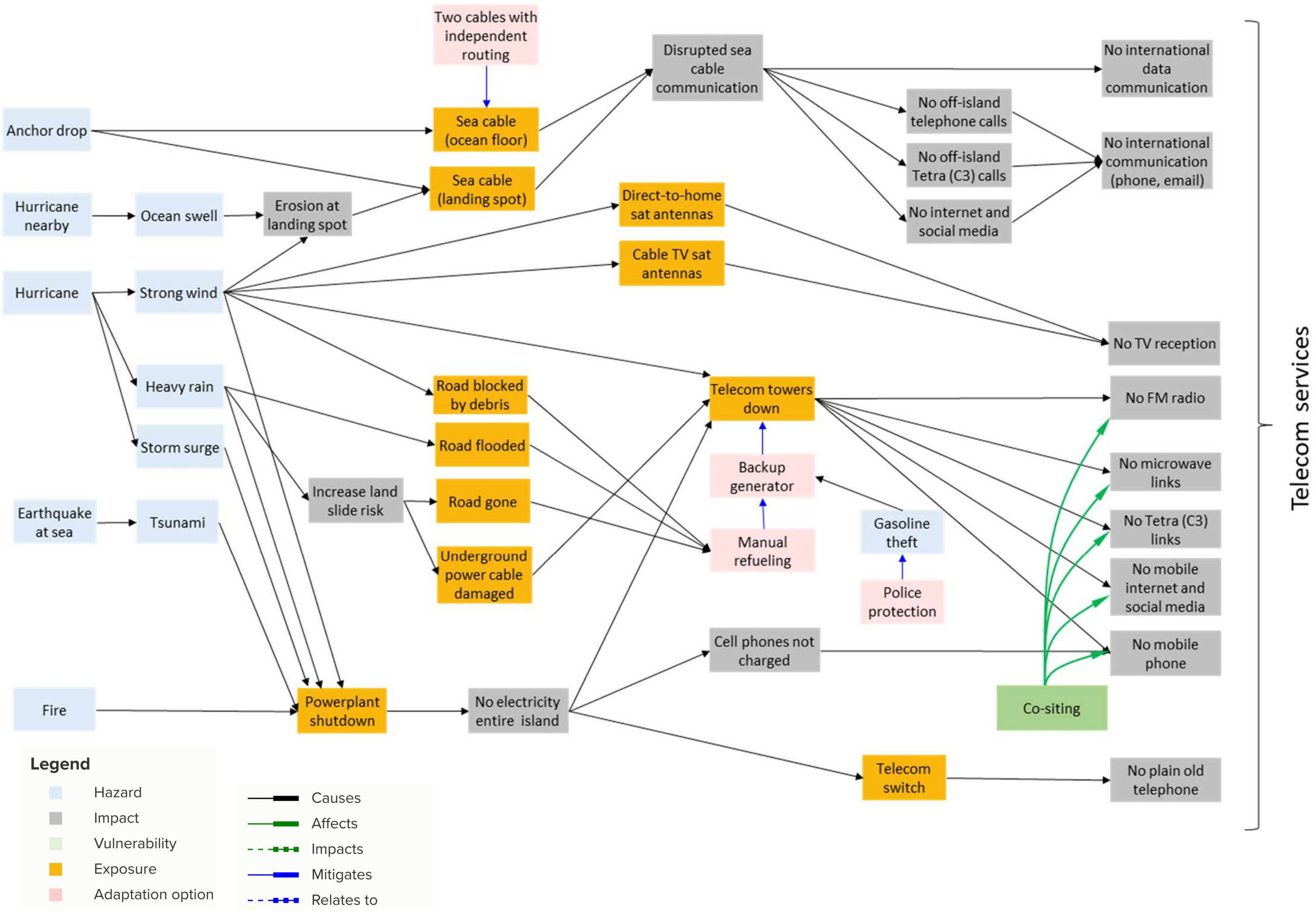

Figure 6.3 Telecommunication systems impact chains. A zoomable version with descriptions of each block can be found at this link. The impact of telecommunication system failures on society is depicted in Figure 6.4.

Impact on public information
Information to the public is distributed via radio and video bulletins, transmitted via FM radio and via the internet (streaming and social media). Newsgathering also depends on the availability of the telecom networks. The FM radio transmitters are co-sited with mobile telephone systems, on high mountain locations. Rupture of sea cables will disable social media and the internet.

Impact on first responders
The first responders rely primarily on mobile phones and Tetra (C3). Failure of both these telecommunications systems will make their work next to impossible. A fallback on social media via mobile internet is generally not possible for field work, as mobile internet is part of the mobile telephone network and therefore fails simultaneously. VHF portophones may provide line-of-sight communications as a Plan B, but their range is limited in the mountainous areas of St. Maarten.

Impact disaster management
The first responders and the Emergency Operations Center (EOC) and the Emergency Support Functions (ESF's) rely primarily on mobile phones and Tetra, with a limited fallback to satellite phones. If all these systems fail, their work will be severely hampered. They need telecommunication to receive meteorological

information, damage reports, and to coordinate with disaster relief teams in the field. Additionally, if the sea cables are ruptured, coordination of disaster with other islands and The Netherlands will become impossible.

Impact on banking

Financial transactions rely on on-island and international data communication links. Rupture of the sea cables will isolate the island from the international financial markets and make international financial transactions impossible.

Impact on airport and harbour

Operation of the airport requires international meteorological information and flight information. It also requires telecommunication on the airport itself for security. Similarly, the harbour depends on international meteorological information and information about shipping traffic. It also requires telecommunication for security. Both airport and port rely on the banking sector for financial transactions.

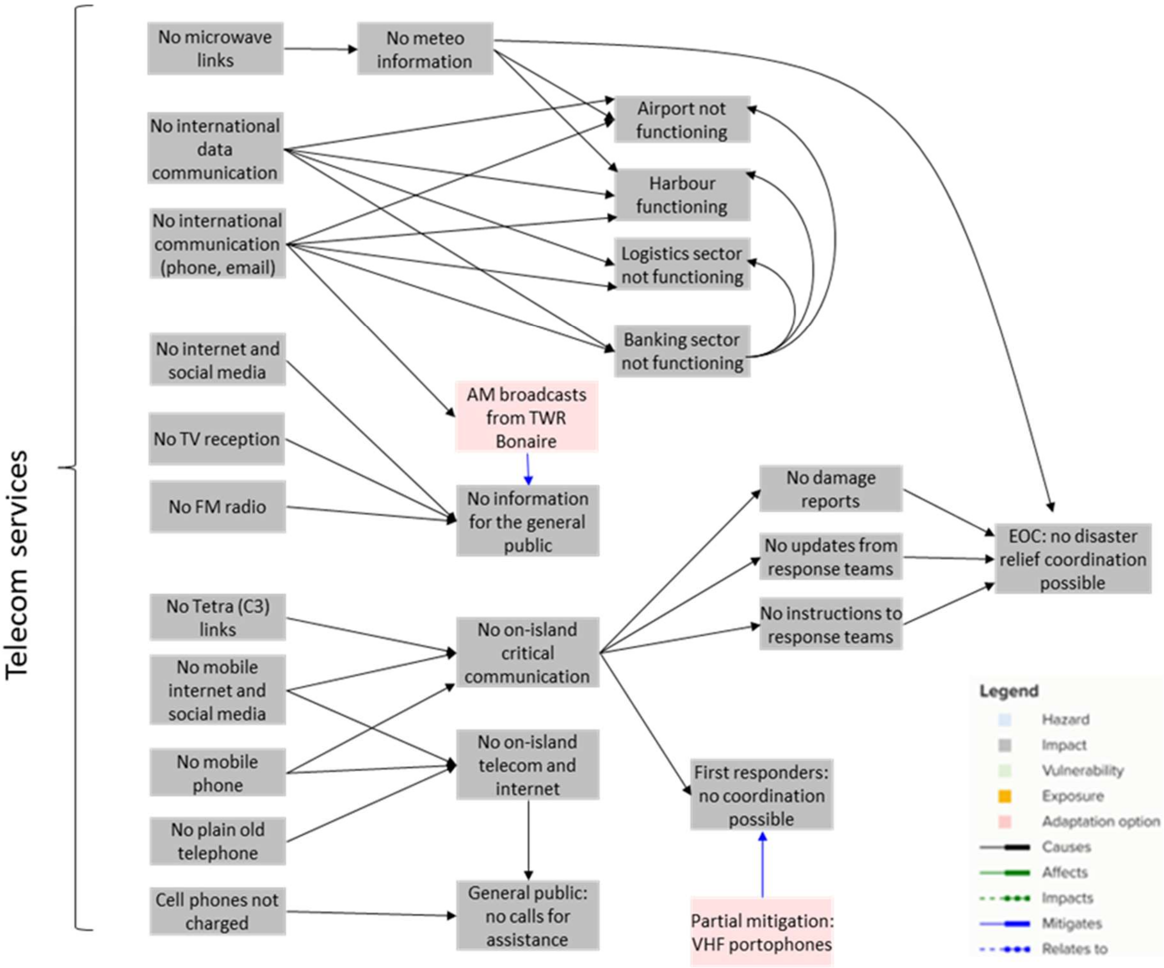

Figure 6.4. Society impacted by telecommunication failure. A zoomable version with descriptions of each block can be found at this link.[7]

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[7] https://kumu.io/mpittore-eurac/paratus#caribbean-cs-telecom-correct

6.2 St Vincent

St. Vincent Island, also known as Saint Vincent and the Grenadines, is a sovereign island country in the eastern Caribbean Sea. Its capital is Kingstown, and the population is around 110,000. The main natural hazards are hurricanes, volcanic activity (La Soufrière volcano), earthquakes, landslides, and flooding. Despite these challenges, St. Vincent Island remains an attractive Caribbean destination.

6.2.1 Preparatory action for future workshop

Unlike other application case studies in the project, the Impact Chains deepening the impacts of La Soufriére volcano eruption (St. Vincent and Grenadines Island_ 9th of April 2021) have not been developed based on the results of a participatory workshop. The two-day workshop scheduled for the beginning of June 2023 had to be postponed to November 2023 as some key stakeholders were not able to participate earlier.

However, we developed two preparatory Impact Chains based on desk research that will be the starting point for the future discussion with stakeholders planned for November 2023.

The development of the here presented Impact Chains is mainly based on four sources of information:

- 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., UWI-SRC, NEMO)
- Scientific articles produced after the eruption (e.g. Graham et al., 2022; Miller et al., 2022).

The future workshop will aim to:

- Provide to stakeholders the systemic view of La Soufriére volcanic eruption and ask for confirmation of the most relevant direct and indirect impacts reported
- Identify most outstanding risks in a context of multi-hazards situation (considering the impacts triggered by the three hazardous event that compounded the volcanic eruption: COVID-19 pandemics, DENGUE outbreak, ELSA hurricane)
- Provide to stakeholders the systemic view of risks and explain the causal connections among main sectors affected in a multi-risk environment
- Complete and complement the Impact Chains based on literature review with inputs from key stakeholders involved in response and recovery operations
- Identify potential adaptation / prevention measures to the risks identified that could reduce current sources of vulnerabilities and prevent damages in exposed systems
- Identify impacts which can be quantified and specify respective data requirements

The workshop will be targeted to high-level stakeholders who had participated in post-eruption emergency and recovery processes. In particular, we are planning to invite stakeholders belonging to the following categories:

- Representatives of governmental agencies directly involved in the coordination, supervision, and management of: (i) monitoring and early warning activities, (ii) emergency response, (iii) recovery processes,
- Scientists and technicians working for research centres and universities involved in the monitoring of seismic and volcanic activity in the island,

- Emergency managers and civil protection agents involved in the emergency response and recovery operations,
- Local and regional representatives of: (i) UN agencies (e.g., UN OCHA, JEU, WHO, FAO); regional agencies (e.g., PAHO, CDEMA, CDB); national and international NGOs (e.g., 510_ Netherland Red Cross, WWF, French Red Cross, ADRA),
- Representatives of key economic sectors and local community organizations.

6.2.2 Introduction to La Soufriére Volcanic Eruption

The explosive volcanic eruption of the 9th of April 2021 marked the peak as well as the end of a series of effusive eruption events that started on the 27th of December 2020 (Joseph et al., 2022). The explosive phase lasted 11 days, from 9th to 22nd April and was characterized by 30 explosive events. The most affected island was St. Vincent, where the volcano is located, but the impacts were not limited to the Island alone. Neighbouring islands, including Barbados, Saint Lucia, and other Grenadines islands, also experienced ash drifts and ashfall. This had implications for the local communities, as it affected various economic activities and threatened the health of the population(Nelson et al., 2013)
The eruption ejected ash in the atmosphere that reached a rose up to 18 km of (Nelson et al., 2013).The heavy ashfall caused by the eruption affected almost 80% of the island, with varying thickness levels. The areas closer to the volcano experienced ash deposits as thick as 304 mm. This ashfall had detrimental effects on the landscape, soil erosion, and agricultural activities. The volcanic eruption also resulted in an increased level of sulfur dioxide in the air, posing risks to the health of the population (Global Volcanism Program, 2021) Additionally, several pyroclastic flow currents surged after the different explosions, affecting in particular the Eastern slope of the volcano, destroying the landscape of the affected valley and increasing soil erosion.
During and in the aftermath of the eruption several lahars took place, due to heavy rainfall brought by Hurricane Elsa falling on the large amount of ash deposits erupted by the volcano earlier. The lahars occurred in the valleys at the base of the volcano. Due to the high risk of being remobilized- reactivated by furhter rainfall, continuous monitoring is necessary to ensure the safety of the population in the post-eruption phase.
Overall, the volcanic eruption of the La Soufrière in April 2021 had wide-ranging effects on the environment, landscape, and communities in the region. To identify which areas would have been more exposed to the volcanic impacts a hazard zoning map was developed by the Seismic Research Centre (SRC) of University of West Indies based on previous volcanic hazards (Figure 6.5).
The map together with an alert level system allowed to timely evacuate the population of the potentially affected areas. As a result, there were no injuries or casualties directly attributed to the volcanic activity and related hazards.
Approximately 21% of the population, equivalent to 23,032 individuals, were evacuated from the red and orange areas. These individuals were either accommodated in public shelters located in the southern part of the island, hosted by relatives, or transported to a nearby island (PAHO, 2021a). After a duration of five months, in September 2021, the government deemed the red and orange zones safe, allowing the displaced individuals to return to their homes (IFRC, 2022).
Figure 6.6 illustrates in detail which areas and communities have been directly impacted by the different volcanic hazards, and where the displaced population has been relocated.

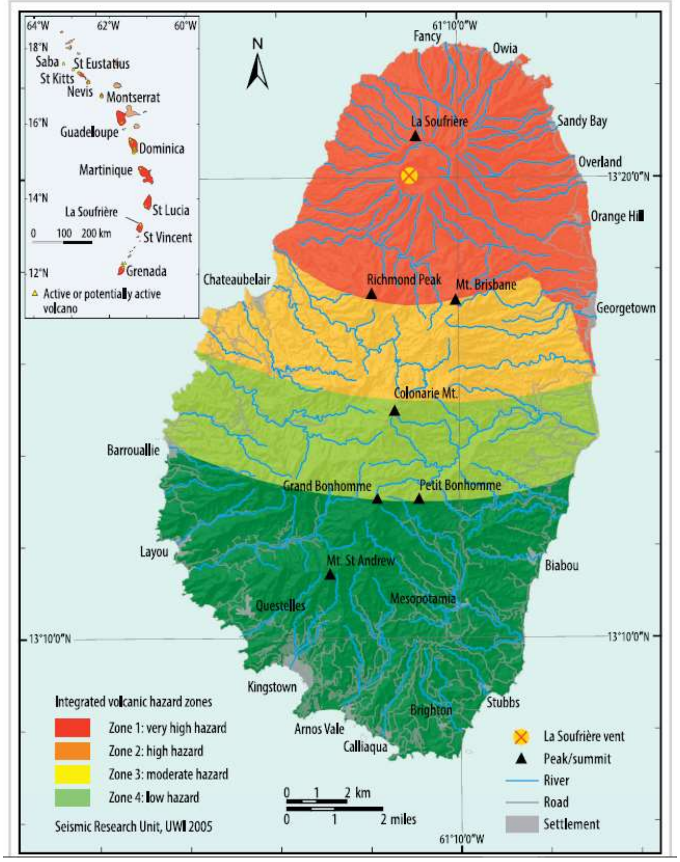


Figure 6.5 Integrated volcanic hazard map for St. Vincent, where red identifies areas exposed to highest risk hazard and green lowest risk hazard. Source (UWI-SRC, 2005)

The eruption had remarkable impacts in multiple sectors. The Post- disaster need assessment estimated an overall economic impact of more than 234 million of US $ (Government of Saint Vincent and the Grenadines, 2021a) This total sum is composed of more 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)

These numbers are even more impressing 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). The economic impacts triggered by the La Soufriére Eruption must be combined with the reduction of economic activities due to COVID- 19 pandemic that affected mainly the tourism sector and the internal logistic.

Beyond the economic impacts, the eruption strongly affected the marine and terrestrial ecosystems (Miller et al., 2022)The topography of the territory was profoundly modified, and its geomorphologic processes disrupted, especially in the red zone where almost the totality of forests were damaged and 100% of agricultural land was destroyed (Government of Saint Vincent and the Grenadines, 2021a).

This project has received funding from the European Union's Horizon Europe Research and Innovation program under grant agreement No 101073954

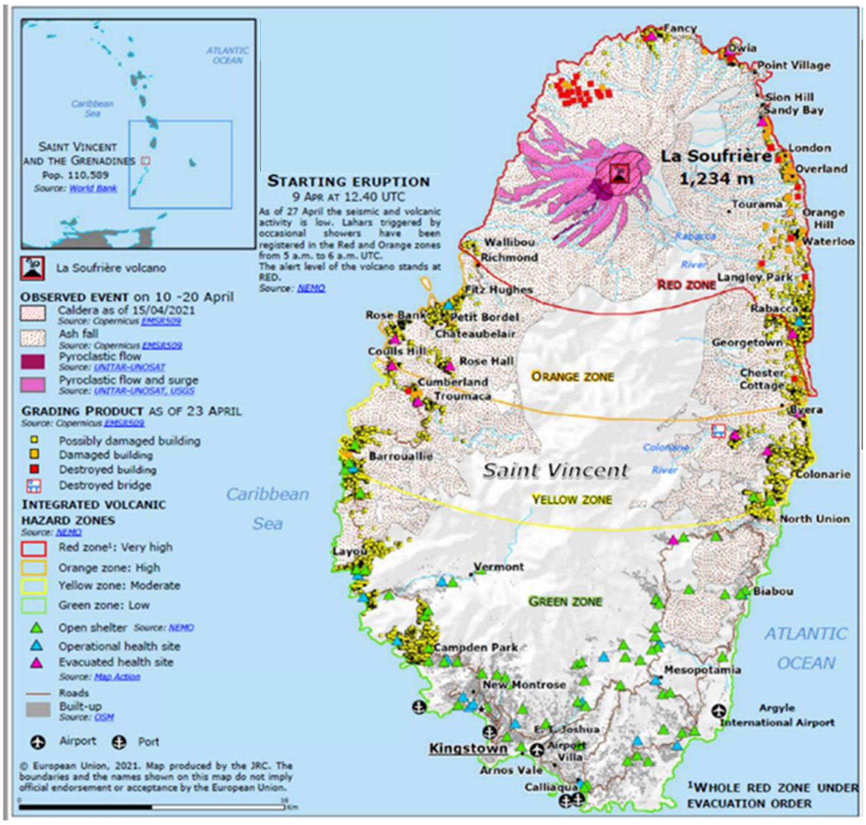


Figure 6.6 La Soufriére Volcanic Eruption_ volcanic activities, direct impacts on building and population displacement. Source (ERCC, 2021)

6.2.3 Impact chain methodology

La Soufrière explosive volcanic eruption that affected the island in April 2021 is a highly interesting case study and a key opportunity to improve existing prevention and response strategies in the context of a multi-hazard environment. The eruption was compounded by three hazardous events: the ongoing COVID pandemic; a dengue fever outbreak that affected the country from January 2021 onwards and the passage of Hurricane Elsa in July 2021. The simultaneous presence of these events further complicated the post-volcanic response and recovery phases, and in certain cases intensified and worsened the overall effects of the volcanic eruption.

Through the Impact Chain methodology, we aimed at unravelling the complexity characterizing this multi-hazard situation. Its purpose was to identify major impacts, feedback loops, and cascade effects among the main sectors affected by the La Soufrière volcanic eruption and the compounded hazardous events. By using this methodology, we sought to understand how the impacts of these events reciprocally influenced each other and amplified existing vulnerabilities.

Furthermore, the confidence and relevance of each impact chain element and connection was assessed adopting the following principles.

Confidence:

The different elements and connections composing the Impact Chain were collected through publicly available formal sources such as scientific papers, legislative documents, statistical datasets, and reports of international organizations.

Relevance:

We did not assign any relevance level to the elements composing the Impact Chain as they were developed based on literature investigation without having the possibility to consult with any stakeholder. Different relevance scores will be assigned to the impacts after the workshops with stakeholders, to be held in November 2023.

Scope of the impact chain

The development of two Impact Chains serves two distinct objectives:

- We firstly developed a systemic impact chain that aims at visualizing the overall complexity arisen by the interconnections / overlapping of the three compounding hazards with the volcanic eruption. Major direct and indirect impacts of the main sectors affected were identified. Furthermore, we show the most relevant cause-effect relations and feedbacks loops connecting multiple sectors. Additionally, we uncovered underlying sources of vulnerabilities that contributed to exacerbating the consequences of the volcanic eruption or hindered the recovery process.
- The second Impact Chain narrows its focus to the waste management and sanitary/health sectors. It performs an in-depth analysis of how the COVID-19 pandemic and the dengue outbreak influenced emergency response activities carried out to respond to La Soufriére eruption. Reports have highlighted the strong interlinkage between these two sectors in the aftermath of the eruption (Government of Saint Vincent and the Grenadines, 2021a; IFRC, 2022; Miller et al., 2022; UNOCHA, 2021). Moreover, the management of the sanitary system (that also included the shelters camps) and waste / debris collection operations emerged as among the mostly costly activities in the overall emergency response. Both sectors were facing limitations: On one hand both were affected by strong lack of resources, in terms of personnel and equipment. On the other hand, both sectors were burdened by certain levels of inefficiencies, in relation to managerial aspects: coordination among stakeholders and coordination in the development of the relief operations.

Spatial Scope

The Impact Chains developed restrict their spatial scope to the impacts verified and recorded on the St. Vincent Island. However, it must be mentioned that the impacts of the eruption transbounded the borders of the island, affecting also neighbouring states. The ash plumes and the sulphur dioxide affected livelihoods and health of population of the nearby islands Barbados, Grenada, and Saint Lucia, and also interrupted the air traffic in the area. Grenada and Saint Lucia islands were mainly affected by a reduction of air quality. Barbados was hit by a significant amount of ash, which covered Barbados' infrastructures, causing a blockage of the airport for several days (Nelson et al., 2013).

Temporal Scope:

The impacts recorded range between a short-term scope and a medium-term scope.

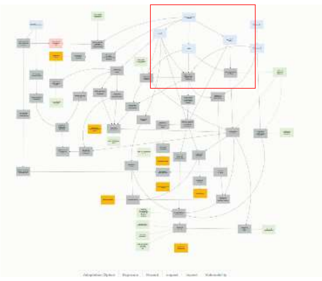
The Impact Chain on waste management and health sector focuses on short term direct and indirect consequences that the eruption and the co-occurring COVID-19 pandemics had in these two sectors, as well as on the causal loop arising from the causal interconnections.

The systemic Impact Chain has a broader temporal focus and takes into consideration the disruption that the eruption had on income, employment, agricultural production, and other economic activities. Impacts on these sectors will have long term repercussions in community's livelihoods and will be perpetuated along time until a full recovery will be met. From an environmental perspective, the volcanic activities such as lahars, lava flows, ashfalls, and Pyroclastic Density Currents caused significant morphological changes in the affected regions. These changes frequently lead to an increase in slope instability, where loose materials and debris could be remobilized by rainfall and landslides for several years after the initial volcanic event. Similarly, volcanic ash can remain susceptible to remobilization for extended periods if not adequately stored in appropriate locations.

6.2.4 Impact Chain –La Soufriére Volcanic Eruption, systemic; 2021 (Learning Case Study)

The complete Impact Chain on the systemic impacts of La Soufriére Volcanic Eruption in Sint Vincent can be viewed at the following link: [8] . Several major and secondary impacts occurred and where therefore pinpointed in the IC mentioned above. More details can be found in the list below:

Major Impact: loose material, debris flow and landslides
Primary (pyroclastic flows, ashes, and lava flows) and secondary (lahars, mudflows) volcanic hazards strongly contributed to the surge of multiple landslides and debris flows during the event. Furthermore, the presence of steep slopes (> 30%) and the heavy rainfall that affected the island during and after the eruption, increased the likelihood of re-mobilization of material also several months, and potentially several years after the volcanic event (Global Volcanism Program, 2021). The surge of landslide and debris flows strongly modified the morphology and the landscape of the area closed to the volcano, modifying slope terrain, land cover, riverbanks and river mouth and beach morphology (Figure 6.7).



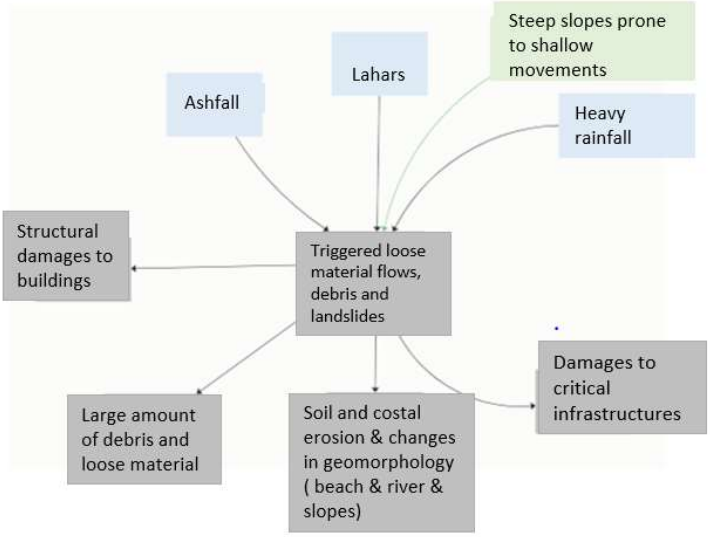


Figure 6.7 Impacts triggered by loose materials, debris, and landslides. See this link for the detailed Impact Chain

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[8] https://www.kumu.io/mpittore-eurac/paratus#st-vincent-systemic-impact-chain

The increase in landslide events, and of loose material and debris led to several connected impacts. First of all, soil and costal erosion increased, exacerbated by heavy rainfall (Constantinescu et al., 2024). Secondly shallow movements and debris flows (Figure 6.8) strongly affected dwellings and infrastructures, in particular with respect to transportation and water supply. Damages to building and infrastructure produced a significant amount of debris that caused blockage of roads, disrupting logistic and humanitarian actions, but also increased the amount of waste to be managed after the eruption.

Figure 6.8 Lahar (mudflow) deposit, Sandy Bay Village. Jawid Collins, UWITV

Major impact: destruction of ecosystems & agricultural damages

The environment was deeply affected by the eruption (Figure 6.9). The volcanic hazards (ash, lahars, and pyroclastic flows) strongly modified the landscape but also affected the chemical and physical characteristics of ecosystems. Both terrestrial and marine ecosystems were heavily disrupted. Approximately 23.000 hectares of forest were destroyed, leading to an enormous loss of biodiversity, especially considering that the island hosts several endangered species (WWF, 2021).

Marine and riverine ecosystem were affected to a minor extent. On one hand due to changes in river and beach morphology and on the other hand due to changes in ecosystem characteristics (e.g., water chemical composition / water clearness) caused by ashfall into the water.

Together with the ecosystems, several ecosystem services were disrupted, in particular it is worth mention the provision of fresh and drinking water. The Island mainly rely 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).

Another major sector impacted by the eruption is agriculture and livestock, which suffered damages and losses of an estimated USD 52.7 million (FAO Subregional Office for the Caribbean, 2021). More than 40% of the agricultural production of the island is concentrated in the red and orange areas of the island (see Figure1). The eruption caused the disruption of the supply of agricultural goods: the highest damages were recorded for fruits and vegetables sector, where the ash affected 100% of the production (Figure 6.10a & 6.10b). Also crops and tree crops suffered extensive damages, however in a lower percentage (60 / 70% of total production) (Government of Saint Vincent and the Grenadines, 2021).

The disruption of agricultural production caused important reduction in food availability, threatening the food security of the overall population.

Losses and damages suffered by the agricultural sectors are likely to have long repercussions on the livelihood and wellbeing of St. Vincent community. The agricultural sector is a driving sector for economy of the island and is one of the major sources of employment, thus destruction of yields and agricultural infrastructures is expected to have strong long-term repercussions, increasing unemployment, food- insecurity and potentially also poverty rate.

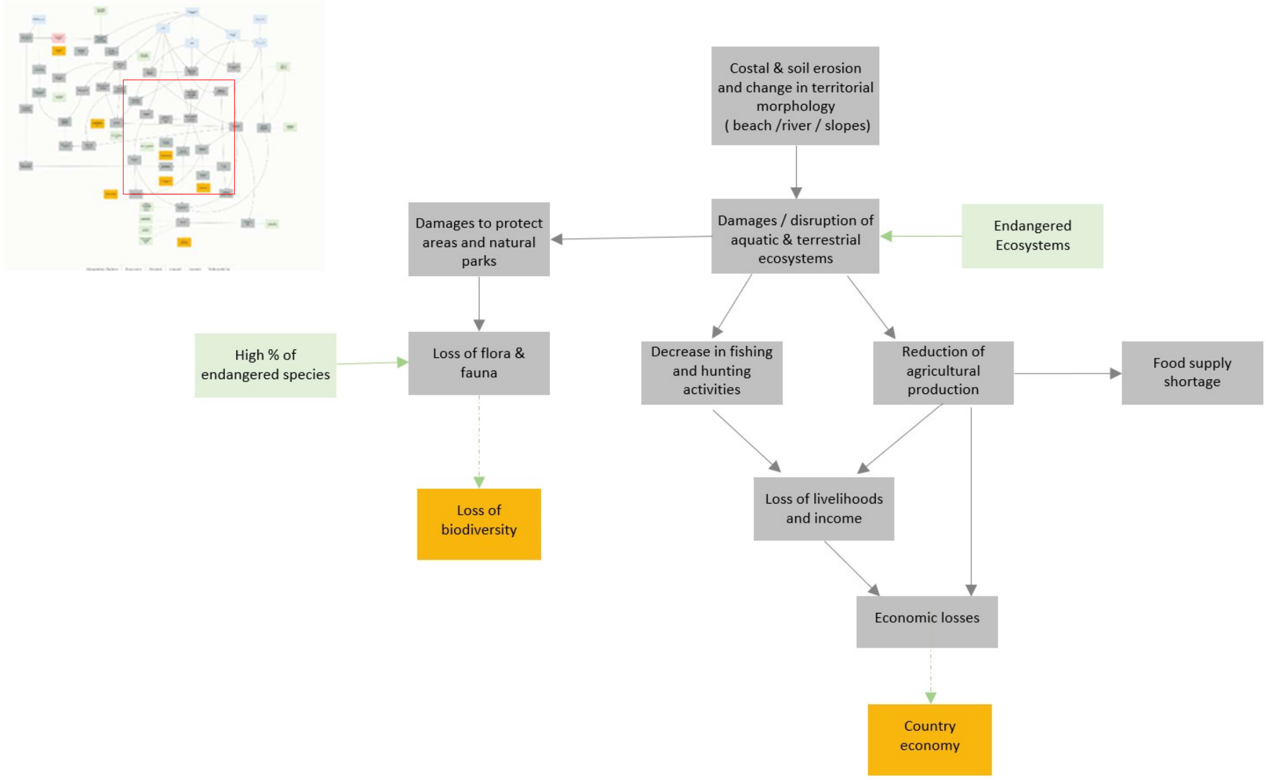

Figure 6.9 Zoom in on the impact chain referring to environmental impacts. See this link for the detailed impact chain

The quantification of impacts in the agricultural sector also must take into consideration the compounding effect of COVID-19 in the agricultural supply chain. The Pandemic disrupted the logistic and the trade of agricultural products with neighbouring islands, reducing the external request for commodities (FAO Subregional Office for the Caribbean, 2021**)**

Figure 6.10a & 6.10b Damages to crops and plantation. Source: FAO, 2021

Major impact: damages to buildings

Damage to the housing sector has been one of the most critical effects of the eruption. The housing sector recorded damages, that amounted to more than 97 million of US$(Government of Saint Vincent and the Grenadines, 2021a).The majority of damages were caused by ash that loaded the roof with extra weight, causing the collapse of ceiling and further structural damages to the buildings (Figure 6.11). Lahars and pyroclastic flows provoked important damages to dwellings, too, but only in the area close to the volcano. On the contrary, damages caused ashfall were widespread in all the island (UNOCHA, 2021). An important factor to consider concerning damages in the housing sector is the poor quality of the building material and its high vulnerability to natural hazards, especially volcanic ones. 90.8% of the houses' roofs of the island are made out of metal, which easily collapse under the weight of ashes (Figure 6.12). Another aspect of relevance is the lack of a proper urban plan that restricts construction of dwellings in areas at high risk. The absence of such rules increases the likelihood of structural damages(UNOCHA, 2021).

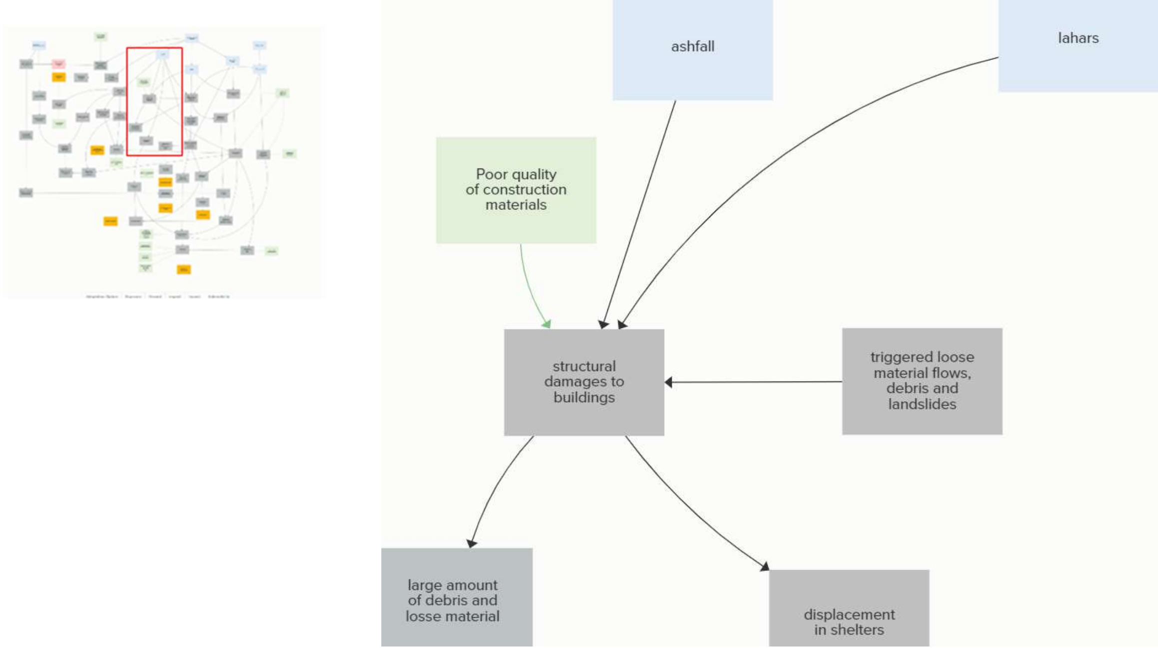

Figure 6.11 Key impact: Damages to buildings. See the link for the detailed impact chain

The destruction of houses led to two important spillovers effects that played a major role in the management of the overall emergency: (i) displacement of people and (ii) a high amount of debris that had to be cleaned and stored after the eruption.

Major *impact: Ash management and cleaning operations*

Management of ash was one of the most urgent issues in the aftermath of the eruption and it constituted one of the most burdening actions in term of financial and human resources (Figure 6.13). Only for what concerns ash removal in the transportation sectors (roads and bridges) the costs of the operations amounted to Us$16 million dollars(Government of Saint Vincent and the Grenadines, 2021a).

Figure 6.12 Damages to roof due to ash load. Source: NewsAmericaNow

The call for urgently clean the ashes was determined by several factors:

- The need of fasten all the emergency operations and of restoring logistic supply chain, as all the roads and main transportation channels were covered by a large quantity of ash;
- The need to decrease the load of ash on buildings and infrastructure to avoid further collapse and damages, also considering the increase of ash weight due to expected rain;
- The need to reduce the risk of ash remobilization, that on one hand would have affected human health (producing high risk of irritation and infections) (PAHO, 2021a)and on the other hand would have worsened the blockage of drainage and sewage system as well as water supply(UNOCHA, 2021)

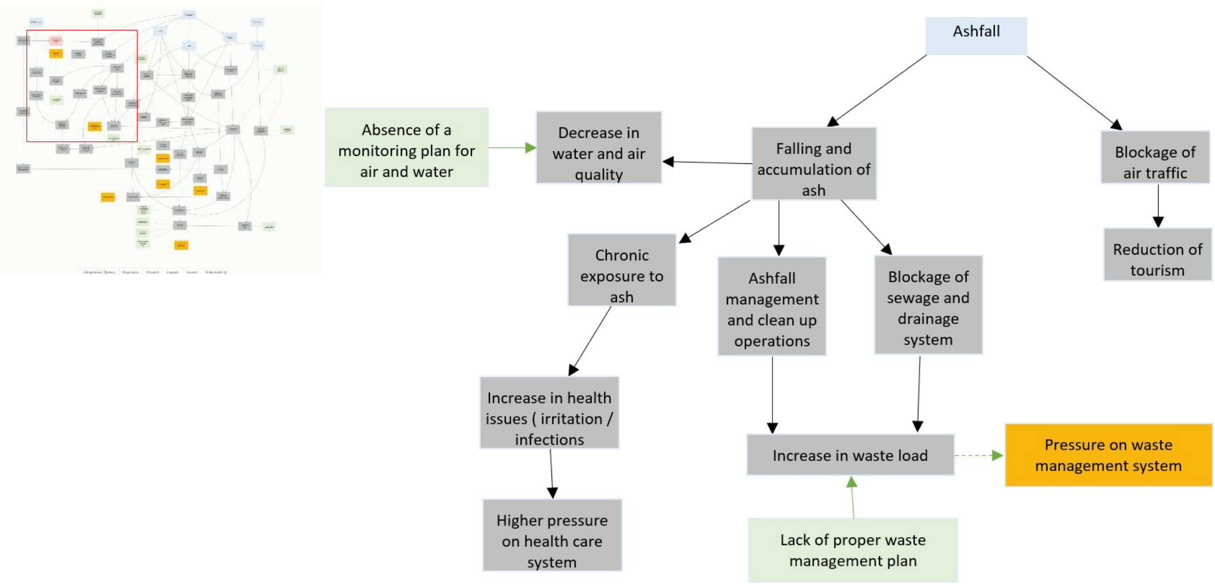

Figure 6.13 Chain of impacts and risks resulting from ashfall and ash management. See [the link]() for the detailed impact chain

The ash cleaning operations posed a strong problem related to the storage of ash and ash deposits (Figure 6.14a & 6.14b). One of the most critical issues was the identification of ash storage deposits as the sites must not be exposed to natural hazards and not be close to residential areas, to avoid any potential negative effects due to ash remobilization.

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The lack of a disaster waste management plan, particular the absence of one tailored to volcanic hazards, slowed down all the operations related to management of "hazardous waste" namely all the waste items constituted by volcanic material.

The ash management and particularly the ash clean-up operations were identified as extremely dangerous from a health perspective, as they strongly increased the risk to respiratory issues. The risk of contracting respiratory problems was particularly high among citizens that often did not use adequate equipment to undertake ash cleaning procedures.

Figure 6.14a & 6.14b Ash cleaning operations source: phsy.org

Major impact: People displacement & shelter management

One of the major impacts at societal level was the displacement of people (Figure 6.15). From governmental official data, 23.032 persons were evacuated and 13,000 were displaced in public shelters situated in the yellow and green zone (see Figure 6.1)(UNOCHA, 2022). The displacement of people, further than disrupting daily activities and routines, had several repercussions both from the sanitary and economic point of view.

At sanitary level gathering people in shelters increased the risk of spreading infections and disease, this risk was even higher considering the ongoing COVID-19 pandemics. From the management point of view, the compounding pandemic situation imposed a higher use of personal hygiene kits and personal protective equipment that strongly increased the amount of waste produced in the island.

At economic level the displacement to shelters posed in stand-by all the economic activities, reducing income and livelihood sources. Among the people evacuated 48% declared to be unemployed, and among them 27% declared to be unemployed as direct consequence of the eruption (CDB, 2022).

Major impact: higher pressure on health care system

The volcanic eruption, the ongoing pandemic and the dengue outbreak that occurred in January 2021 strongly put under pressure the health system and the possibility of providing a timely and effective sanitary response (Figure 6.16). No causalities and major injuries have been caused directly by the eruption. However, the concurrence of eruption, covid-19 and dengue stretched the limited resources in terms of medical equipment, medications and available personnel. This resulted in delays in medical consultations and hospitalization in case of chronical diseases, leading to an increase in causalities due to dengue infection. The volcanic eruption led to a suspension of vaccination for COVID-19 that casued a peak in COVID-19 spread, expecially in shelters camps(Government of Saint Vincent and the Grenadines, 2021b). Furthermore, the eruption combined with the isolation and fear of contagious had relevant psychological and emotional impacts on the affected population.

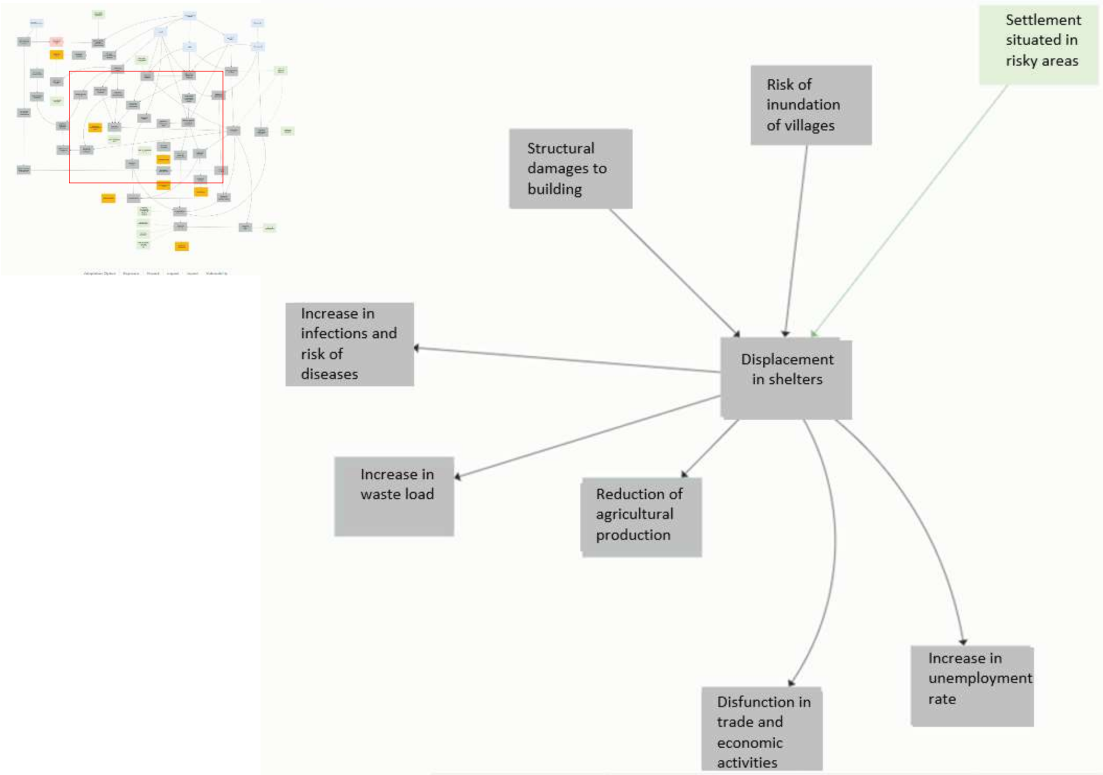

Figure 6.15 Risk pathways related to people displacement. See [the link] for the detailed impact chain

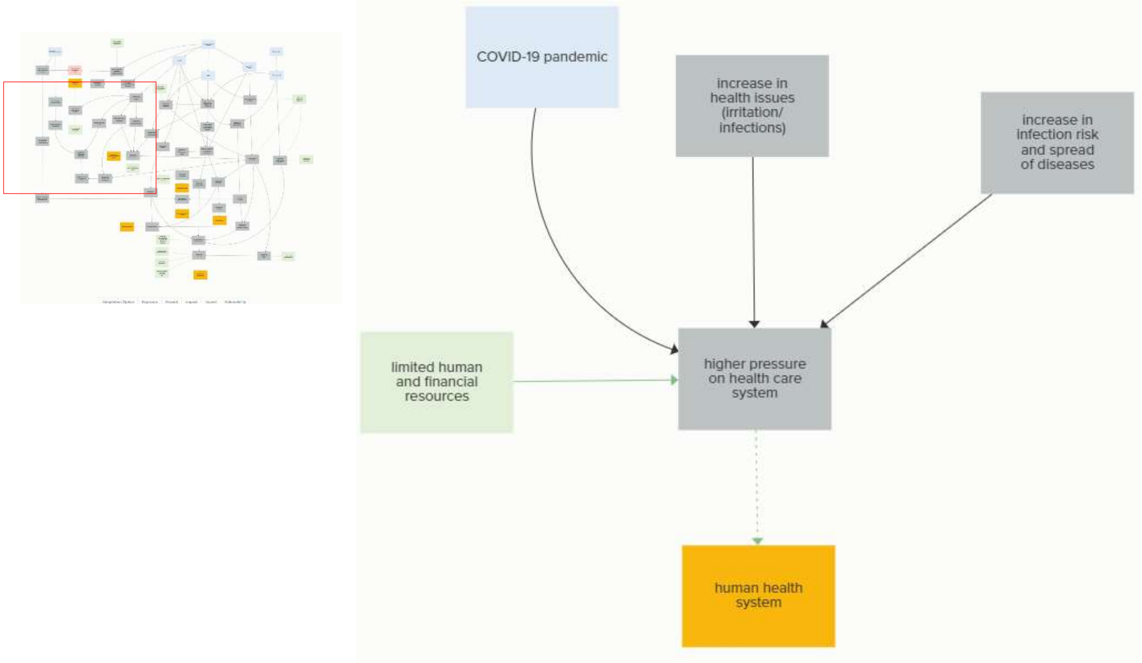

Figure 6.16 Compounding impact of La Soufriére eruption & COVID-19. See [the link] for the detailed impact chain

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Major long term impact: potential increase in poverty

The reduction in income and livelihood sources caused by the compounded effects of COVID-19 and La Soufrière eruption could potentially lead to an increase in poverty rate, as well as an exacerbation of existing structural inequalities that affect St. Vincent community (figure 6.17). According to the World Bank, the impacts of the volcanic eruption compounded with COVID -19 reversed years of progress made in poverty reduction (World Bank, 2021). Prior to the eruption, severe poverty was expected to increase from 3% up to 11% due to COVID-19 impact. After the eruption, according to IMF and UNICEF, poverty is expected to worsen of another 10%(UNICEF, UNDP, UN WOMEN, 2020). Households and individuals characterized by previous vulnerabilities (unemployed people, single-mother households, elderly people, and people with chronic disease) face a higher risk of being pushed below the poverty line.

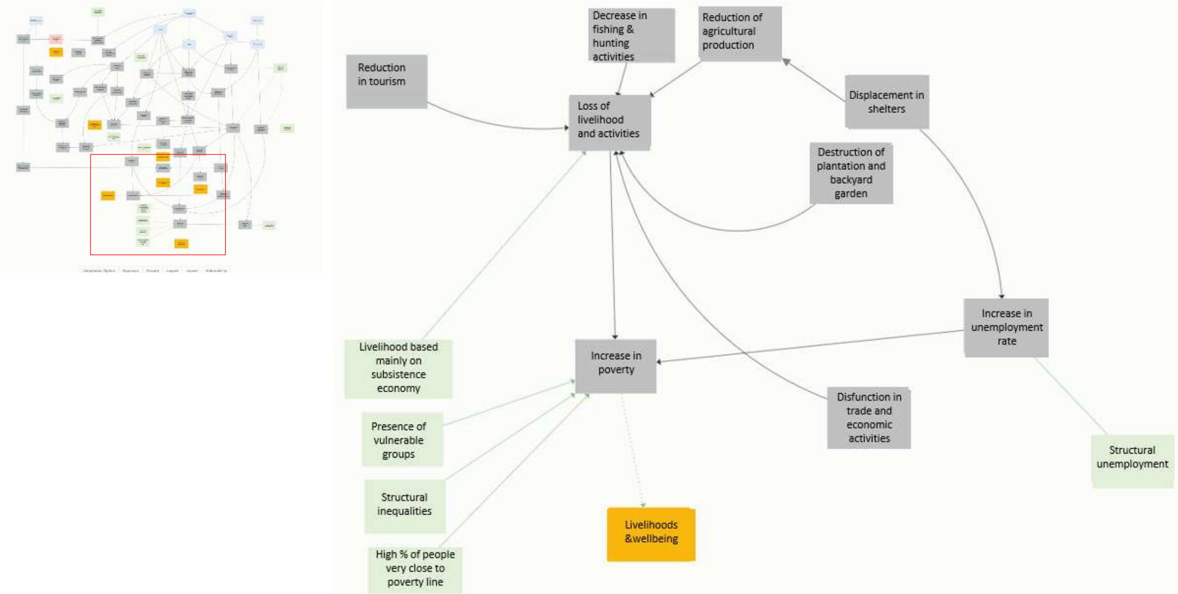

Figure 6.17 Long term impacts. See the link for the detailed impact chain

6.2.5 Impact chain- La Soufriére Volcanic Eruption, focus on waste management & health / sanitary sector (Learning Case Study)

The volcanic eruption placed significant pressure on both the waste management and health sectors. Prior to the eruption, the health sector was already facing challenges due to the increased demand for services caused by the spread of COVID-19. This surge in demand strained financial and human resources, as well as the availability of equipment and medication. The volcanic eruption further exacerbated these constraints, affecting resources and the availability of services in the health sector. Access to health services was delayed due to disruptions in the transportation system, and the closure of two district hospitals in high-risk areas reduced services availability.

People living in close to the volcano were relocated in the south of the island to prevent part any injuries or causality. The relocation of people increased population density in that region, heightening the risk of diseases and infections spread, and increased the pressure for water demand (PAHOb, 2021b).

The majority of displaced individuals were hosted in government-led shelters, but this gathering posed an increased risk of infection and disease transmission (Government of Saint Vincent and the Grenadines, 2021a). To prevent COVID-19 outbreaks in shelters, specific protocols and management measures were implemented, including increased use of personal protective equipment (IFRC, 2022). However, optimal sanitary conditions were not always ensured in the shelters. The disruption of the water supply system due to the eruption caused water shortages, leading to decreased personal hygiene. Furthermore, only a small percentage of shelters had enough running water to meet the needs of the occupants, leading to use of clear water and sea water for personal hygene(PAHO, 2021b).

The living conditions in shelters were even more difficult for women and girls that resulted highly exposed to gender- based violence. Several cases of sexual violence and gender-based violence were reported in shelters increasing the risk of spreading sexual reproductive disease and causing important traumas in victims (Government of Saint Vincent and the Grenadines, 2021a).

To improve the sanitary conditions in shelters thousands of water bottles, tanks, personal protective equipment, and hygiene kits were distributed to the population. All these items increased the amount of trash produced by the shelters that often were not equipped with a proper waste collection system (Miller et al., 2022). The amount of waste produced by relief-related items was identified as “the emergency after the emergency” by one of the coordinators of camps interviewed for the emergency assessment report.

The management of waste was identified as a huge issue not only within the emergency camps but on the overall islands. Waste collection system was suspended in several areas of the island, creating risk of disease, increasing the risk of soil and water contamination as well as of illegal dumping.

The majority of waste was produced by debris and boulders resulting from damages to buildings and infrastructures. The regular waste collection and management system experienced several difficulties in handling the amount of waste produced by the eruption, leading to the reach the maximum capacity of the few landfills available in the island (Miller et al., 2022)

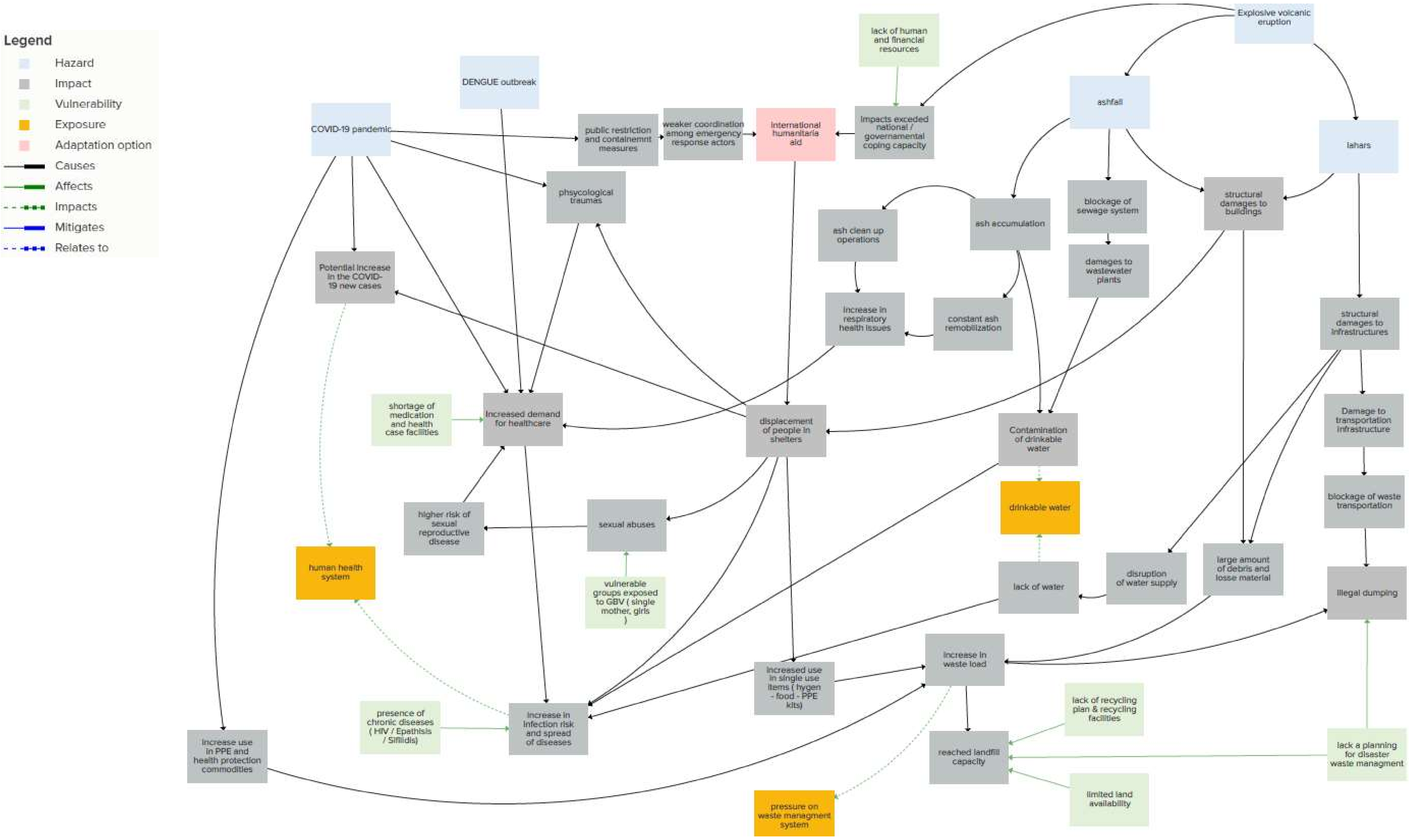

Figure 6.18 Detailed impact chain on interconnections between health and waste management sector. See this link for the detailed impact cha

7 Alps Application Case Study

The Alpine Application Case Study focuses on the impact of the interruption of cross-border transportation by different hazards in a mountainous environment, such as extreme wind, floods, rockfall, mudflow, landslides and snow avalanches within the Brenner Corridor reaching from Kufstein (Austria) to Bolzano (Italy). The Brenner Corridor marks one of the key transit routes connecting southern and northern Europe. Each year more than 10 million cars and 2 million trucks pass the corridor. It needs to be stressed that the Corridor comprises not only the Brenner highway itself but also municipal roads and railway tracks.

7.1 Participatory workshop summary

Within the Application Case Study Alps, two stakeholder workshops were organized within the first months of the project. Their overarching aim was to build up a trustful relationship with the stakeholders and the PARATUS team as well as between the different stakeholders. Additionally, the focus was to get to know the project partners and their expertise, the PARATUS project itself as well as the planned methodological approaches and its planned impacts, e.g., the user-centred platform. The workshops were held within the core area of interest of the Application Case Study, the Brenner-Corridor in Tyrol/Austria (Workshop 1) and in Bolzano/Italy (Workshop 2).

Most importantly, the focus was to give space and listen to the needs, requirements of the stakeholders and how they want to be involved, how they can contribute and what they expect form PARATUS. Additionally, the goal was to develop a mutual understanding between partners and stakeholders regarding the development of a multi hazard risk platform.

During the workshops, past hazards and how the stakeholders perceived and processed it and reacted on these situations, as well as future scenarios were discussed. Furthermore, the origin and direct and indirect impacts of these hazards were considered and recalled. From this recollection and knowledge from past events in the Application Case Studies, first exemplary impact chains were created, which visually represent the consequences and effects of hazard events. These impact chains are displayed and explained in detail in section 7.2. For a more detailed overview of the workshops, e.g., the selection of stakeholders, the methods applied in the workshops and the outcomes, we refer to Deliverable 6.2. In the following, the two mentioned workshops are briefly summarized.

Workshop 1, in Pfons, Matrei am Brenner, Austria with around 25 participants, was structured into 2 days (2.-3. March 2023), discussing in different group settings with different participatory methods, past and future events, to identify challenges and how to cope with them for the region.

The first day gave an overview of the PARATUS partners and the project. The focus of the workshop was to get to know the present key stakeholders working in the area of interest and gave them the opportunity to present their experience and share and exchange knowledge. Later, participants were split up into four focus groups with two moderators, each discussing past hazard events in the Brenner Corridor.

The second day continued presenting and discussing the idea of a co-developed multi risk platform and future plans were formulated. Interests of the stakeholders were collected as well as their wishes and needs. Further, the stakeholders also shared ideas how they can support PARATUS with data or their expertise in various ways. The workshop concluded with an excursion around the area of interest, along the Brenner Corridor which was of great importance to get a notion of the challenges and hot spots in the Application Case Study Alps.

Workshop 2, in Bolzano, Italy, with 5 participants was held on one day (10. May 2023), presenting outcomes from the first workshop and discussing these with the stakeholders from the Italian side. In the first session, hazard events occurring along the Brenner Corridor and concerns of the stakeholders were collected. Later on, these topics were put into context and structured in preliminary impact chains. The workshop was important in the process of adding further details to the preliminary impact chains.

7.2 Impact chain methodology

Both workshops were crucial as a starting point in developing the first draft of impact chains and the decision on which past and possible future events will be further elaborated.
The aim of the first session was to discuss past events in smaller groups and to work out risk pathways. Prepared questions guided the discussion of each group to create initial connections between hazards, impacts and adaptation measures. Session two concentrated on future challenges and scenarios. Before continuing the group work the general concept of impact chains was presented. This enabled the groups to put the previously identified hazards and impacts into context. The stakeholder meetings enabled the identification of certain key risks connected to natural and systemic hazards in the Brenner Corridor. These comprise for example:

- Heavy traffic,
- straining the infrastructure (increased truck load and frequency over the past decades and also bridges are in strong need of renovation),
- forest health (incl. fires, bark beetle) and
- blocking partially the road system.

Next to many natural hazards mentioned by the stakeholders also technological and anthropogenic hazards were mentioned. One example here is cyber criminality which was mentioned as one of the new hazards to infrastructure, as well as the general interconnectedness of processes leading to secondary hazards.

Subsequently to the workshops, the results were analysed, synergies and connections compiled to present 4 exemplary impact chains for the alpine application case study. Two impact chains focus on past flood events, therefore on the hazard aspect. One impact chain concentrates on the specific processes of slow-moving landslides and one impact chains addresses the future scenarios of a complete blockage of the Brenner Corridor.

7.3 Impact Chain - Alps flooding; 2002 (Learning case study)

The impact chain *Alps flooding 2002* identifies the risk pathway of a meteorological situation with heavy rainfall events amongst other things and leading to secondary compounding events within the Alps. The year 2002 was not only marked by drought conditions lasting since 1999 but also by multiple flooding’s exceeding the 50- and 100-year flood return period (Godina et al. 2003). High amounts of precipitation were mainly caused by weather systems comparable to Vb low pressure systems, transporting moist air masses from the Mediterranean to central Europe. The spring and summer of 2002 was characterized by low pressure systems leading to prolonged rain but also heavy rainfall events which subsequently led to flooding events in different parts of central Europe.

In March 2002 mostly north-eastern Austria and Tirol experienced extreme precipitation while the south was suffering from a prolonged drought. The concentration of the extreme precipitation in a short period of time together with a rise of temperature leading to snow melt led to some streams overflowing their banks. Due to the naturally reduced water absorption capacity of vegetation in this early period of the year, large parts of the water could not infiltrate but was transported as surface run off. Further contributing to the already high-water levels in streams and rivers. Strong convective precipitation events in spring caused mudflows and spatially restricted flooding. Generally, above average precipitation was recorded, often concentrated on just a few hours.

Also in August 2002 above average precipitation was measured, leading to flooding's in northern Austria (Figure 7.1). The rapid rise of water and overland flow reduced the slope stability and triggered multiple landslides. These natural events led to considerable damage to infrastructure, but also long term affects, such as crop failure and subsequently political changes. Some parties could gain popularity due to the partly miss managed flood disaster management.

Summing up, especially the preceding drought conditions but also warmer weather situations leading to snow melt and the lower vegetation in early spring increased the vulnerability of the area of extensive floods. The cascading events of the extreme precipitation impacted not just physical structures, such as buildings, roads and but also socio-political systems.

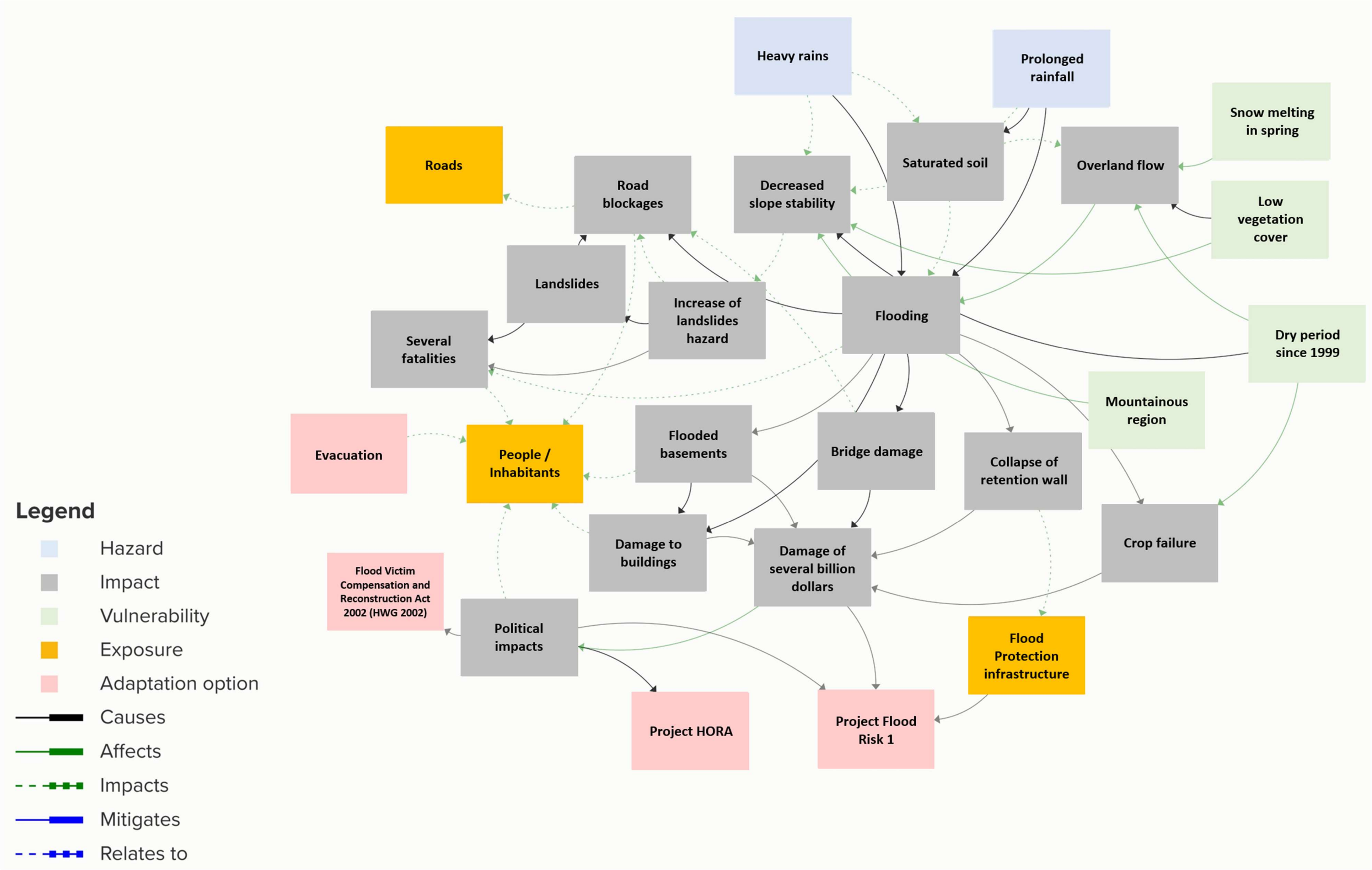

Figure 7.1 Impact chain of the 2002 flood event in the Alps. See this link for detailed impact chain

7.4 Impact Chain - Alps flooding; 2005 (Learning case study)

While western parts of Europe experienced extreme forest fires, especially the middle and eastern parts of Europe endured extreme rainfall with partly more than 200 mm in 24 hours. The low-pressure system over the Adriatic Sea between 20. – 23. August 2005 resulted in flooding in central Europe and parts of the Danube catchment (Figure 7.2).

Similar to the flood in 2002, preceding weather conditions laid the basis for the flood events. A similar frontal system, moving to the northeast over eastern Austria, was already observed a week prior. The precipitation as such was not unusual and, in many parts, did not exceed recorded above average values (Rudolf et al. 2006). Rather the combination of multiple events, in this case the continuous precipitation, with a long-wet summer period, saturated soils as well as the partly convective heavy precipitation for a few days triggered the destructive flood. Additionally, the snowline increased from 2000 m to above 3000 m, which meant that most precipitation fell in liquid form. Apart from the direct run off, no old snow fields could retain the precipitation. Especially in the high orographic Alps, strong precipitation can cause water to accumulate quickly in the narrow valley bottoms and on the way down the slopes, has the potential to erode material or activate mudflows.

Human interferences such as buildings in flood plains and changes in the river morphology most certainly enhanced the impact of this destructive flood. The results were a never before recorded discharge value of 1525 m^3/s (23.08.2005) at the Inn gauging station (mean annual discharge 718 m^3/s) (Hydro Online).

One adaptation strategy, storage dams, that can retain millions of cubic meters during a flood, might on the other hand pose a vulnerability. A common practise is to divert small creeks from their original flow path into other valleys via tunnel systems to supply water a there located reservoir. Therefore, the discharge regime in the original creek bed downstream of the diversion is modified. This leads to a discharge decrease and an increase of accumulated material. In case of an extreme event, these creeks are more likely supply transport material that has accumulated and generate higher erosive forces.

Further hazards triggered due to the continuous heavy precipitation and rising water levels are as seen in the Impact Chain, landslides. Some villages were cut off any supply due to road blockages or the erosion of roads. Houses, roads, and industrial areas were damaged or destroyed and many areas experienced blackouts and a complete failure of other critical infrastructure such as sewage and freshwater systems.

First and second responders were hindered in arriving at sites of deployment due to missing infrastructure. The event led to some areas adjacent to the Brenner Corridor being blocked completely for some time due to high water levels. Other areas were cut completely off supply, such as the Paznauntal. About one third of all the roads were destroyed in this valley (ORF.at, 2019). Due to high Inn water level, also ground water had to be pumped away continuously at the clinic and University of Innsbruck.

Austria was most affected in the western states. Relatively, more damage in small areas compared to 2002 with overall 700 Mio US$ damage, but overall, 2002 was affecting a larger area. Further west, Switzerland experienced one of the most dramatic disasters events with 6 fatalities and 2100 Mio US$ damage. Even through the German disaster management changed certain procedures since the 1999 flood, also here a damage of 220 Mio US$ was noted (Kron, 2005). However, Bavaria had a 200 – 500 yearly event. Adaptation measures were partly still missing 10 years after the event occurred (meinbezirk.at, 2015).

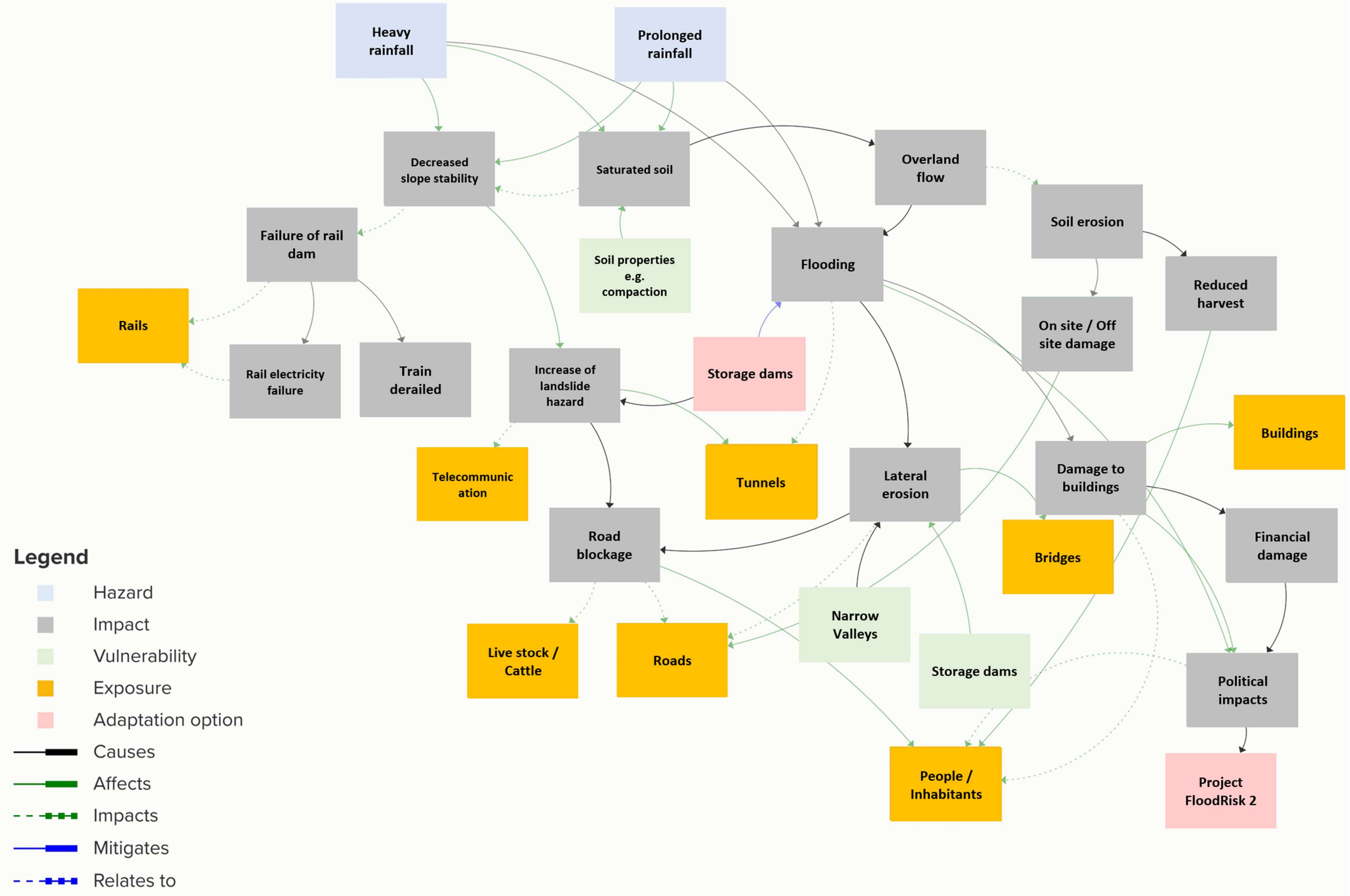

Figure 7.2 Impact chain of the 2005 flood event in the Alps. See this link for detailed impact chain

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7.5 Impact Chain - Landslide Observatory Lower Austria (Learning case study)

Similar to the paradigm of PARATUS, “Looking back and ahead” the learning case study in Lower Austria has been investigated thoroughly starting from historical events, to establish a monitoring system and to analyse the process of slow-moving landslides. The landslide observatory includes three sites, situated transitional in the Flysch and Klippen zone in Lower Austria.

The understanding of slow-moving landslides is a challenging task due to the high variability of many predisposing and finally triggering mechanisms. Looking ahead, the non-linearity of sliding processes is further aggravated due to global environmental change and therefore here presented in a simplified scenario impact chain (Figure 7.3). The impact chain is based on extensive field research by the ENGAGE working Group of the University of Vienna. One specific site of the landslide observatory in Lower Austria, the Hofermühle landslide is visualized in the IC. This landslide is located in Konradsheim, a district of the Lower Austrian statuary town of Waidhofen an der Ybbs. Find more information on the monitoring which is embedded in the NoeSLIDE project at this link. Here the possible transition processes of a slow-moving landslide to a rapid mudflow is visualized. In 2013 the Hofermühle landslide abruptly changed from slow moving, to a rapid mudflow. The learning site primary focuses on the process understanding, not on a specific exposed system. However, understanding the processes on the location will enable the development of general guidelines for best practice to study slopes susceptible to sliding and possibly harming society.

The past has shown that prolonged and high intensity rainfalls can accelerate slope movement. This can damage road infrastructure and arable land. Also, the factor of safety, describing the stability of the slope can be reduced due to open scarps and missing vegetation. However, especially slow-moving landslides are influenced by many predisposing factors, forming vulnerabilities. Long lasting heavy rainfall and rapid snow melt might be the trigger, but the root cause of the slope mobilization is much more complex. The slope is physically influenced by lithological and soil settings. The weathered rock, apparent at the Hofermühle slide shows generally a low stability, enabling seepage water routing through the sedimentary rocks. Also, exposition and aspect (slope inclination), as well as the setting of lithological layers influences stability e.g., through water rooting. Here the unit layers are dipping west to northwest with 35°, perpendicular to the slope inclination, which can cause further instability. In the flysch zone of lower Austria even moderate slope inclination can cause a higher susceptibility (Petschko et al. 2012). Vegetation can increase the stability of the slope. At the Hofermühle landslide the majority of unstable material is located below pastureland. The mudflow in 2013 on the other hand originated in the more vegetated creek. This also indicates the presence of multiple subsystems, not just one landslide body.

Next to natural physical predispositions, anthropogenic activities might be the most dominant influence on slope vulnerabilities (Crozier 2010; Damm & Klose 2015). Even through the Hofermühle landslide is close to infrastructure and used as pastureland, the rapid mudflow originated in the more natural creek, retrogressively eroding upslope. Surface incisions might increase the vulnerability to further sliding. Quantifying each vulnerability remains however challenging. The IC for the landslide observatory does not concentrate solely on exposed systems, rather on the process itself and the risk pathway from predispositions, triggers to impacts (see Fig. 7.3). This shall give an overview of involved processes, direct and indirect leading to the rapid acceleration of the slide. Activated in 2011, the slide was further mobilized due to heavy precipitation on the 19.04.2013. Water saturated material flowed down slope with 20 m/h and also further movement was observed in the upper slope body between 2014 and 2015. No significant movement was recorded in the past years. Nonetheless, slides generally tend to restore an equilibrium in the unstable mass, through further movement over time.

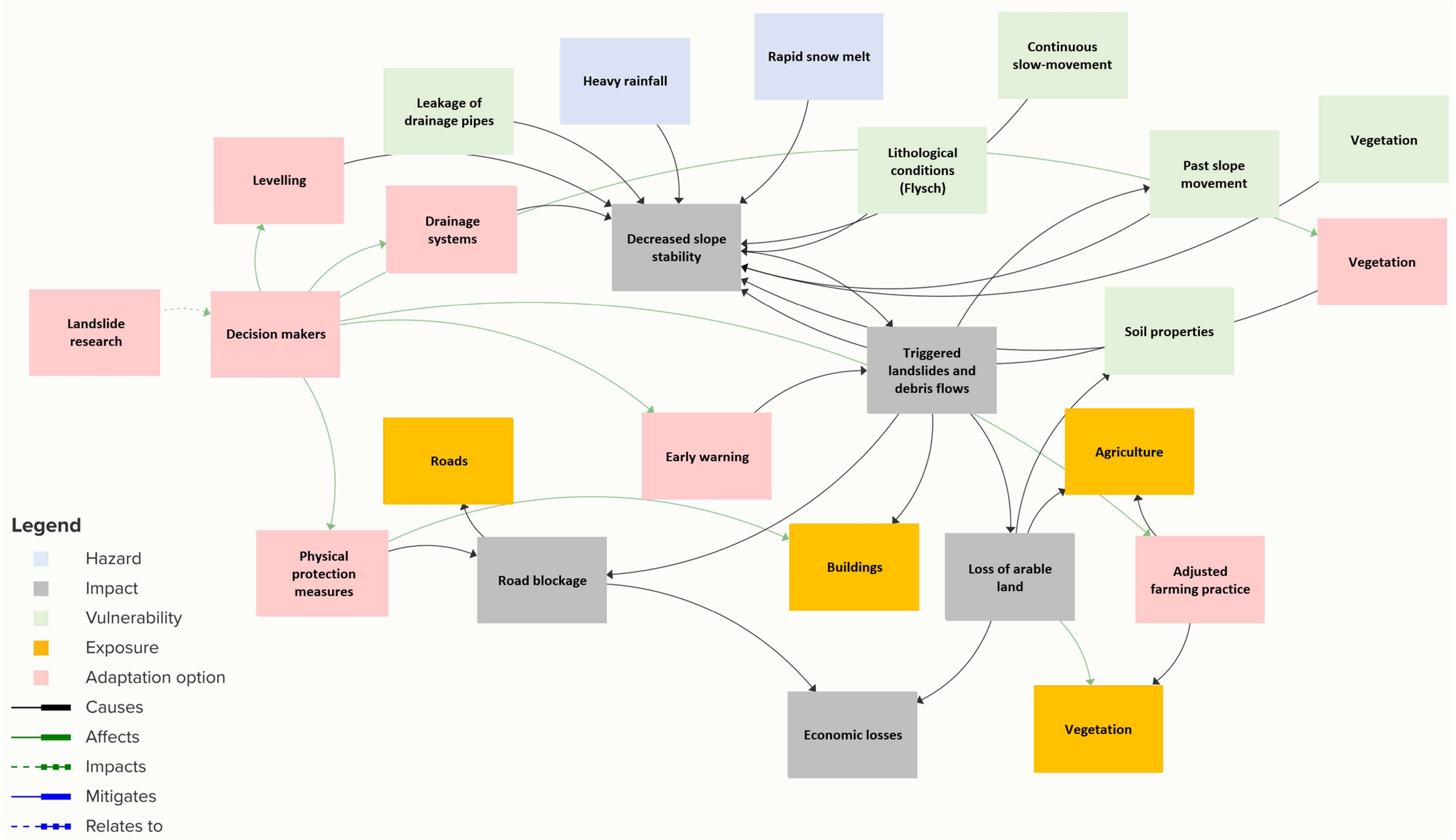

Figure 7.3 Impact chain of the Learning Case Study Landslide Observatory Lower Austria. See this link for detailed impact chain.

7.6 Impact Chain- Alps scenario of Brenner Corridor blocked (Application case study)

A look into the future shows that especially mountainous regions are expected to warm up much faster than the global average and are one of the hotspot regions affected by climate change. In addition, settlements in the alpine valleys are becoming denser and transit traffic has increased steadily over the last 40 years (Statista.com). Therefore, increasing the number of elements at risk. Especially in the stakeholder workshops, concerns were expressed, about what will happen if the Brenner transit route is closed. Hence, the outcome from the different group sessions with the most striking overlaps were combined to one impact chain. This 4th IC collects these concerns mentioned by the stakeholders regarding future scenarios along the Brenner Corridor.

The IC shows the connection of events, impacts and the vulnerabilities close to the highway in the Wipp valley, with regard to the specific scenario of a highway blockage. Multiple sectors are investigated The Brenner highway is the most important transit route crossing the Austrian Alps with 2,38 Million trucks crossing the Brenner Pass in 2020 (Statista.com). It is not just important for transit but is also a densely populated valley with a steep natural relief.
Past events, as shown in the past Impact Chains (Figures 7.1 & 7.2) partly blocked transit traffic and caused next to flooding’s multiple cascading and compounding secondary hazards as well as impact such as mudflows. The successive increase in extreme events and future models for more extreme weather events suggest that a possible blockage of the whole route could impact on many different sectors and trigger far reaching consequences.
Possible hazards identified are next to natural origin also anthropogenic caused. Cyber Criminality, a raised concern by stakeholders since more and more technology is connected to external services. But also spills due to transport accidents can cause a direct environmental impact with far reaching consequences for road blockage.

Natural slow onset processes as the continuous decrease of water availability in the past years, combined with rapid local convective precipitation events successively can reduce the protection capacity of forests. Forests formerly able to protect roads or settlements from smaller rockfalls or avalanches are now and, in the future, shifting towards becoming a hazard by itself due to deadwood accumulating and barren slopes. In the context of climate change and increasing temperatures also the likelihood of forest fires increases. Areas affected by forest fires are prone to erosion and potential landslides in case a heavy rainfall event occurs. Currently unclear and investigated is how the protective ability of forests changes when dead wood is kept in place on the slopes (Teich et al. 2022). One often mentioned and illustrated problem is quick heavy snow events. As such this would not impact over all traffic. However, due to non-compliance of areas restricted for trucks to overtake, whole road parts are blocked since snow ploughs are not able to pass the traffic jams. Especially in spring and summer, an increase of wildfires has been reported and is assumed to become more severe. Other vulnerabilities identified are concerned with communication e.g., in-between Austrian and Italian counterparts and the just in-time production. A delay of a few days can already cause problems for companies rather far away from the Brenner Corridor in southern or northern Europe.
This impact chain (Figure 7.4) gives just a glimpse on the overall variety of processes and events able to completely block the Brenner Corridor including adjacent systems impacted by a blockage.

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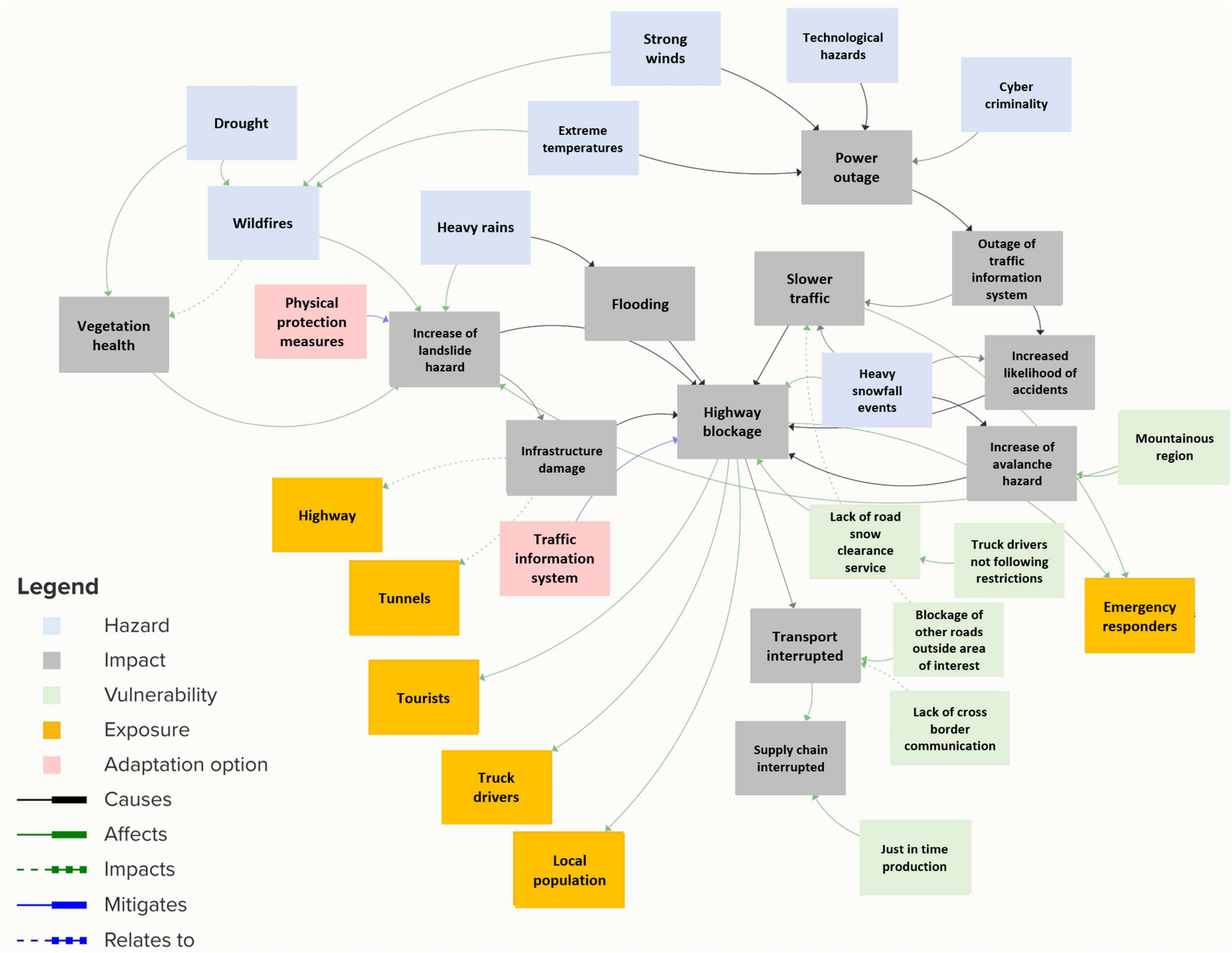

Figure 7.4 Impact chain of a future scenario of a highway blockage in the alpine Brenner Corridor. See this link for detailed impact chain.

8 Use of Impact Chains in the VISESS/PARATUS Summer School

The Summer School, titled "Analysing Changing Impact of Compounding and Multi-Hazard Events," was organised under the framework of the Vienna International School of Earth and Space Sciences (VISESS) PhD-program, in collaboration with PARATUS partners, in particular by Prof. Cees van Westen (University of Twente), with contributions from Prof. Thomas Glade (UNIVIE), Dr. Tatiana Ermolieva (IIASA), Dr. Philipp Marr (UNIVIE), Dr. Michalina Kulakowska (CRS) and Silvia Cocuccioni (EURAC). It took place from 10th to 14th July 2023 in the University of Vienna.

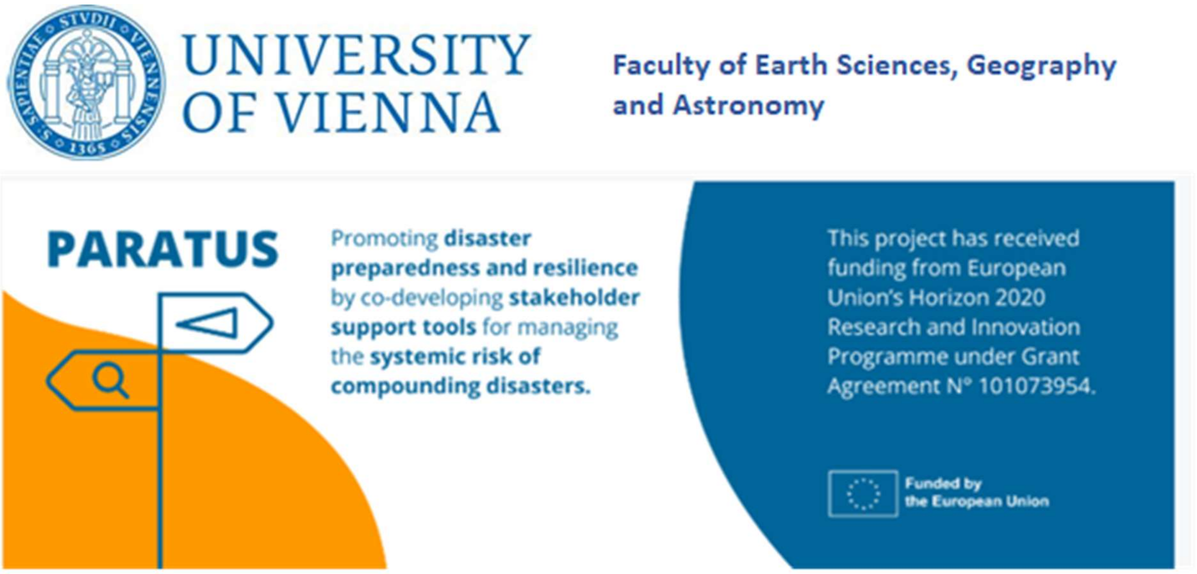

Figure 8.1 Information on the VISES/PARATUS Summer School.

The Summer School strongly involved young researchers from the University of Vienna and external students. It had a total of 11 participants from the University of Vienna, IIASA, and São Paulo State University, Brasil. To strengthen the connection of the VISESS PhD-program to international networks, the remaining participant places were granted to other students from the PARATUS project.

The program delved into the intricacies of hazard interactions, exposure, vulnerability, and the direct and indirect impacts they produce across various sectors. The Summer School had a strong practical focus, utilizing the same four application case studies as the PARATUS project, plus an additional international one (Pakistan). Participants had the opportunity to explore and develop from scratch complex impact chains within these regions, also exploring the quantification (and modelling) of their components (Figure 8.2).

Figure 8.2. The students at the Summer School brainstorming on the different Impact Chain components

By working on PARATUS application case studies, the Summer School provided an immersive learning experience where young researchers gained practical insights into the complex dynamics of compounding and multi-hazard events and their consequences on communities and critical infrastructures. The link with the PARATUS project provided local expertise on the different application case studies as well as data to practically apply different methodologies and tools.

8.1 Impact chains resulting from the Summer School

Impact Chains were developed for each application case study; some examples are reported below.

8.1.1 Bucharest Case Study

The group working on the Bucharest Application case study focussed on a specific scenario: the impact of an earthquake similar to the one in 1977 (7.4 Mw) occurring today. This therefore had a similar focus as the PARATUS Learning Case Study (see Chapter 5.4). The impact of such event will be multifaceted and severe, with important implications for Disaster Management. The following impacts were pinpointed and connected in an Impact Chain (see Figure 8.3):

- Damage to hospital buildings resulting from earthquake and subsequent fire
- Deaths and injuries due to building collapse, unfunctional medical equipment, panic
- Direct and indirect structural and functional losses (roads and lifelines, with major power outages)
- Road blockages
- Failure of emergency management system
- Communication problems

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- Delayed response
- Economic losses and implications: costs for retrofitting, financial support

Consequently, if a 7.4 Mw earthquake (similar to the one in 1977) will shake Bucharest, the human casualties and the amount of damage are likely to be larger than in the past – but it would depend on the timing of the earthquake.

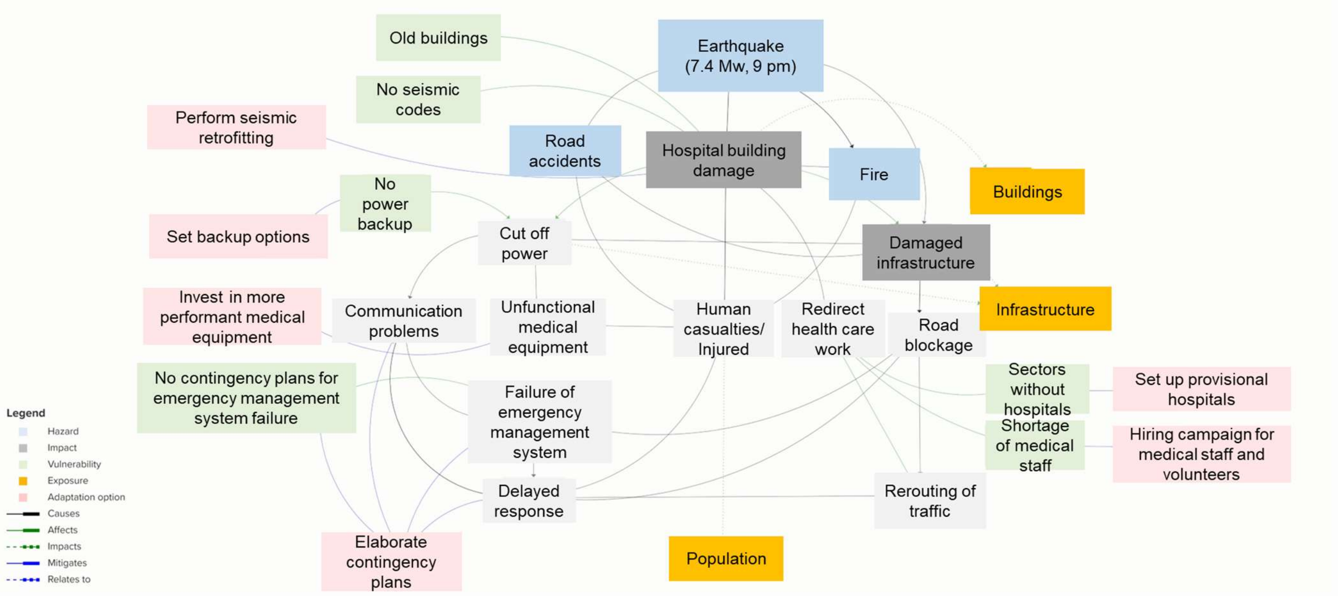

Figure 8.3 Impact chain illustrating the impacts of an earthquake similar to the one which happened in 1977 (7.4 Mw) occurring today in Bucharest.

Tgroup also edited the IC describing different scenarios. Firstly, they investigated the impacts of a 7.4 Mw earthquake if this would occur in Bucharest during a pandemic wave (Figure 8.4). This would result in the collapse of the local medical system, leading to a real disaster scenario. Secondly, they adapted the IC highlighting the impacts which would occur if the 7.4 Mw earthquake affecting Bucharest would trigger a flood by breaking the Lacul Morii dam (Figure 8.5). In this case, the impact of the medical units in proximity of the lake would be tremendous.

Constructing impact chains on different scenarios helped to explore the complexity of multi-hazard risk and represents a cornerstone of improved Disaster Risk Management.

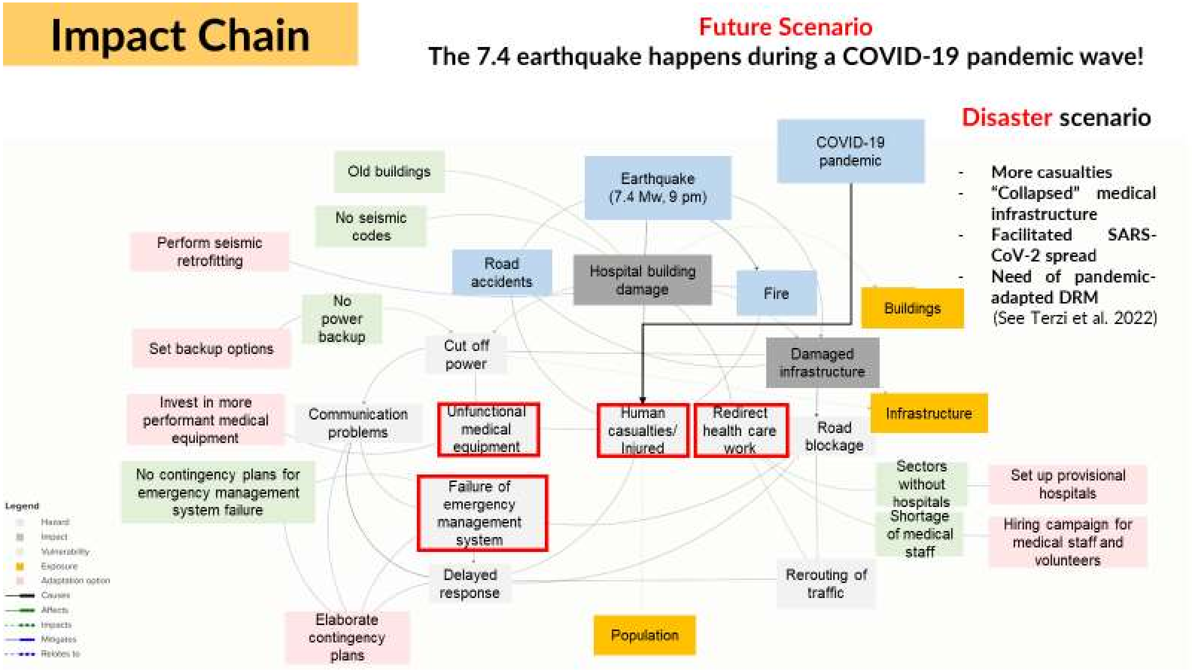

Figure 8.4. Impact chain illustrating the impacts of an earthquake similar to the one in 1977 (7.4 Mw) occurring in Bucharest during a pandemic wave .

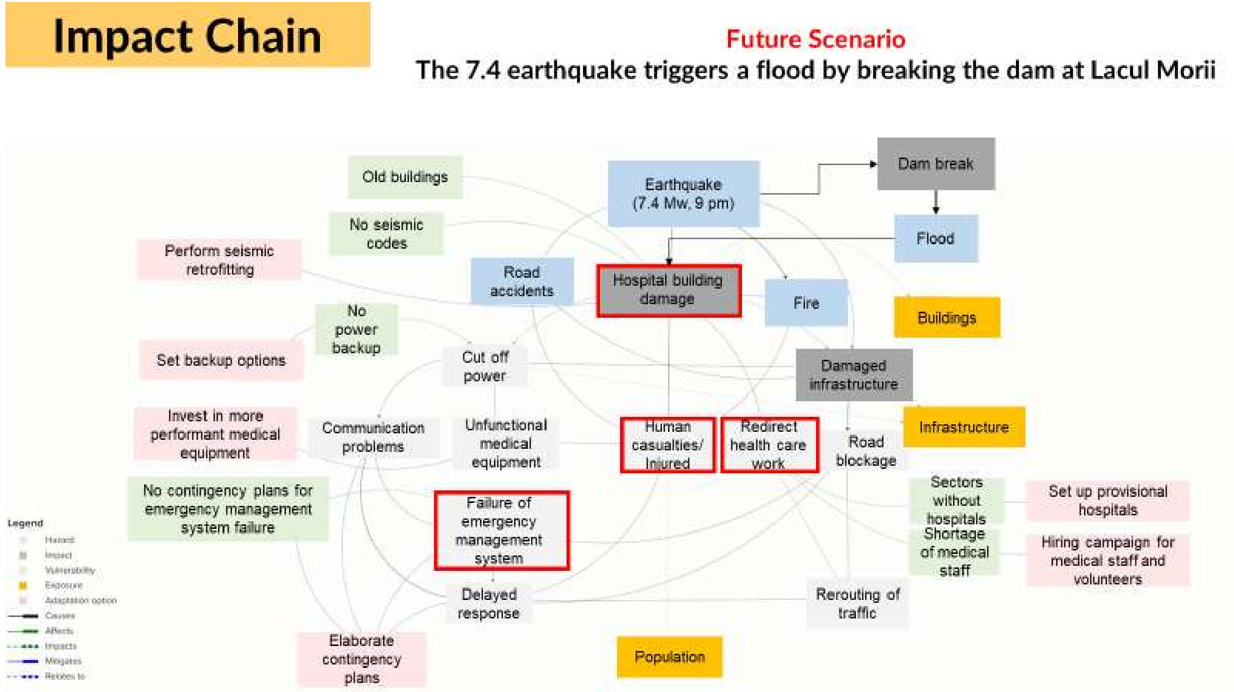

Figure 8.5 Impact chain illustrating the impacts of an earthquake similar to the one in 1977 (7.4 Mw) occurring in Bucharest and causing the breaking of the Lacul Morii dam

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8.1.2 Alps Case Study

In the Alps Case Study group, the Impact Chain work (Figure 8.6) focussed on the direct impacts of extreme precipitations on the highway and on indirect impacts subsequentially generating from these. Differently from the PARATUS Application Case Study, the elements of the IC where placed accordingly to their potential occurrence in time where T_0 is the actual hazardous event, T_1 the subsequent hazards or impact directly caused by the initial hazards, T_2 the impacts resulting from those etc.

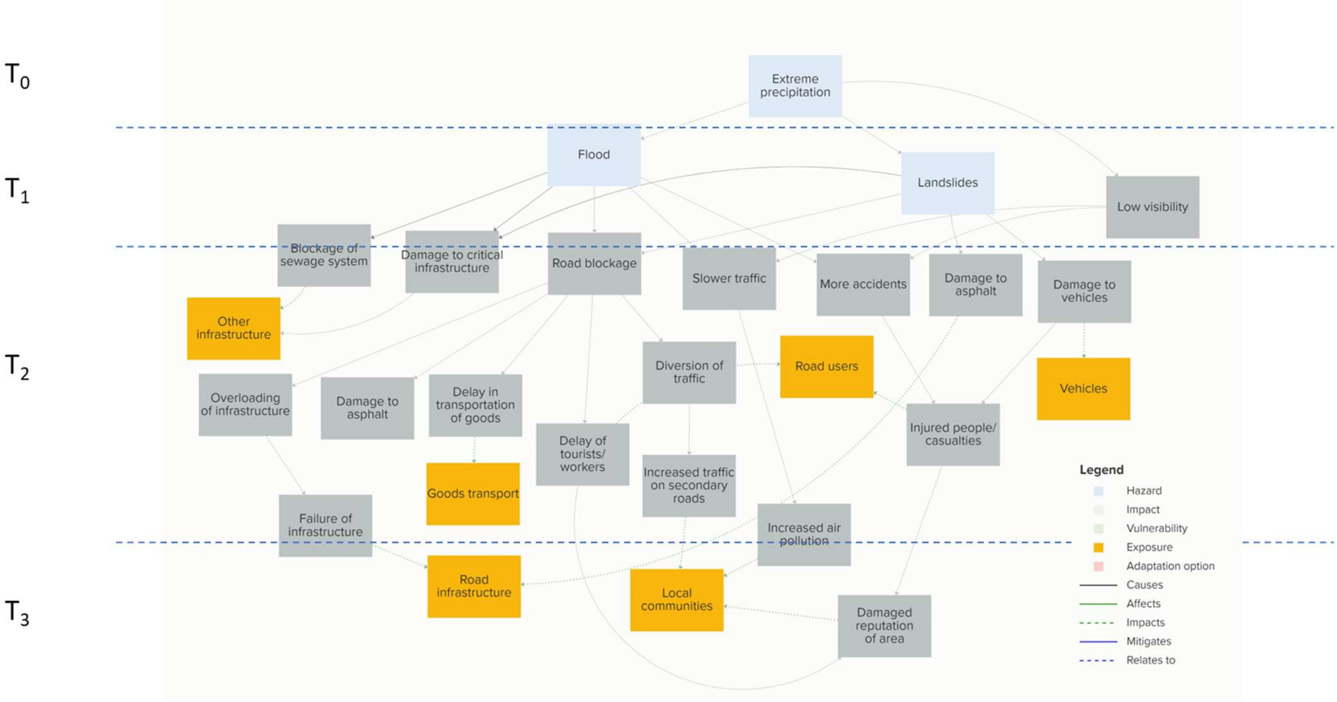

Figure 8.6 Impact Chain focussing on the Impact of extreme precipitation on the Brenner highway.

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9 Discussion and Conclusions

Impact chains are a natural solution for application-oriented risk conceptualization. They are a powerful tool to elicit knowledge from experts and to integrate knowledge from disparate sources, accommodating quantitative and qualitative components. The application of specific guidelines for the development of ICs can foster standardization though the adoption of a common language and a visualization structure. ICs can therefore be adopted as a basic conceptual tool to support quantitative risk analysis.

The Impact Chains developed at this stage of the project, show different degrees of complexity. The more we try to account for the reality of processes and factors which are relevant, the more complex is its representation. This complexity is difficult to be managed mostly because it translates into a visualization problem. Interactive tools (such as KUMU) can help the process, but relevance of factors and a proper synthesis is paramount to obtain significant representations.

Complexity could be better addressed also by using a different conceptual approach where ICs define a knowledge engineering tool. Taxonomies and Ontologies are a way to systematically encode the knowledge and information in an Impact Chain through a structured and semantic representation. Currently research activity is focusing on developing semantic ICs and using it to provide interactive exploration of the different factors. This also allows advanced querying of information and knowledge from a back-end system.

The ICs presented in this report will be improved by better defining and describing the different elements and connections which constitute them. This will be carried out using a mixed-method approach. Some components will be calculated quantitatively, in case of available data and modelling capacities (e.g. through RiskChanges). Other elements can be further described with the support of further stakeholder inputs. Moreover, new ICs will also be developed for both Application and Learning Case Studies. Further work on the ICs will be presented in D.1.2. which will have a stronger focus on Learning Case Studies.

Participatory approaches as applied in the PARATUS project are relevant in identifying direct damages, developing disaster narratives, and sensing broader impacts; however, they fall short of conveying economy-wide impacts of natural hazards. This is the case because economic impacts are understood on the sectoral level, such as industry, agriculture, finance, transportation, and thus come on a more aggregate level than ICs described in this report. While incorporating such economic impacts on sectoral level falls outside the scope of this report, we outline important issues related to economic impacts that will be more relevant at the next stages of building meaningful ICs.

Two broad types of challenges are identified that relate to the incorporation of economic damage into ICs. First, is combining physical and socio-economic aspects, and second is impact quantification.

On the first account, three issues arise: a) translating direct physical damages to natural and built environments into direct economic damages to productive sectors, that include businesses, public bodies and any other economic actors in the disaster area; b) identifying those elements of ICs that are of importance for identifying wider economic impacts on the national, international or even global levels (example of production shortages in local computer chip production had effects on global markets for electronic equipment and appliances); c) translating direct economic damages to business interruption (loss of production flows within the disaster area), and indirect losses to businesses and sectors outside the disaster area.

Second challenge relates to the quantification of impacts, where 6 major issues arise: a) quantification of higher-order economic damages requires both the presence of quality statistical data and inference, i.e.

economic modelling; b) for different types of economies and different types of impacts, different types of models are required (examples are tourism-reliant island economies vs industrialized western economies, or identification of transportation breakdown impacts on an economy vs understanding damages to productive sectors); c) different processes of economic loss proliferation caused by different natural hazards (hydrological vs climatological; acute vs slow onset events); d) trade-off between the 'linearity' of impact chain representation compared to the economy-wide circular flow approach in economic modelling that takes into account all inter-sectoral relationships; e) specification of spatial and temporal scales for impact chains, including recovery and disaster preparedness; f) aggregation level for economic losses, and indirect losses in particular, that is often more coarse than developed event impact chains, similar to those described in this report.

Other issues may relate to a broader socio-economic context of disasters, where underlying vulnerabilities become exacerbated, triggering non-trivial societal changes. Such factors may include high levels of social inequalities and segregation, issues of public health related to physical and mental health aspects, domestic and international migration, and many others. These aspects fall outside the scope of current report, however, may proliferate deeper into the socio-economic fabric in the aftermath of a disaster, and trigger the emergence of systemic risks. These will be discussed in the later stages of the project.

In the following steps of the project, ICs will be implemented in the **PARATUS platform** (see Deliverable 4.1 for more details on the Platform). The Platform will consist of two main components: an information service that provides static information and simulation service, and a dynamic component where stakeholders can interactively work with the tools in the platform. The ICs will be a central part of the PARATUS platform and included in both components.

In particular, the ICs developed within WP1, including those presented in this deliverable, will be consolidated in a **WIKI** system which will allow to:

- Collect, consult and display the impact chains related historical events in an interactive manner;
- Describe the single components of the impact chain and the connections using metadata (similarly to Kumu);
- Determine which components of the impact chain can be quantified;
- Use the library of impact chains as the starting point for generating new impact chains;
- Make a link between the impact chains component and the web-based calculation and simulation.

In the future, this platform will enable users to explore Impact Chains and their components with ease and efficiency. When data becomes available to support individual components, users will have the option to view and analyze it, including the ability to display maps or graphs for better comprehension. The platform will offer features to filter elements based on whether they are visually represented and backed by data or described solely through basic features and metadata (e.g., source, relevance, time range, etc.).

Furthermore, users will be able to leverage this tool to query and filter existing knowledge related to Impact Chains. They will have the flexibility to select specific sectors or hazards to refine their search for Impact Chains or focus on particular segments within complex Impact Chains.

With these capabilities, the platform aims to be a valuable resource, empowering users to gain deeper insights into Impact Chains and related information in a user-friendly and efficient manner.

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11 Annex I

PARATUS ISTANBUL STAKEHOLDER WORKSHOP- 1 June 2023

The participatory workshop that brought together external stakeholders was held at the Istanbul Metropolitan Municipality (IMM) facility of ''Dr. Mimar Kadir Topbaş Gösteri ve Sanat Merkezi, Yenikapı'' on June 1st, 2023, between 10:00 – 17:00. The meeting was attended by directors and affiliates of IMM as well as representatives of LoS stakeholders, universities, central governmental institutions, district municipalities and NGO's, with a total of about 87 participants. Prior to the meeting, a 41-page Turkish translated document was prepared and distributed to the attendees in hard copy, outlining the PARATUS project's aim and focus and output of the kick-off meeting.

The meeting began with the welcome speech of Özlem TUT, Director of Earthquake Risk Management and Urban Improvement Department. Deputy of General Secretary of the IMM, Buğra Gökce, gave a speech on the projects of Istanbul and emphasized the challenges that city is facing to. Afterwards, Cees van Westen, PARATUS Coordinator, presented the scope and focus of PARATUS Project and introduced the application case studies. The following speech of the welcome session was from Seda Kundak, Istanbul Case Study Leader at ITU, who gave general information about the workshop and shared the output of the previous meeting. The final presentation was given by Rahmi Hızır, Istanbul Urbanization Workshop Branch Director, which was on the evaluation of earthquake performance of housing stock in the light of Kahramanmaraş earthquakes. Throughout the meeting, common speeches and explanations were translated into English for foreign and online international participants via the Teams platform.

Agenda

Dr. Mimar Kadir Topbaş Gösteri ve Sanat Merkezi, Yenikapı, Fatih, İstanbul

09:45	Registration
10:00	Welcome speeches
10:10	Presentations of the PARATUS Project
	Prof. Cees VAN WESTEN – *PARATUS Project*
	Assoc.Prof. Seda KUNDAK – *PARATUS İstanbul*
	Rahmi HIZIR - Evaluation of earthquake performance of housing stock in the light of Kahramanmaraş 2023 Earthquakes
10:45	Break
11:00	Session 1: Impact Chain of disasters
12:30	Lunch Break
13:30	2023 Kahramanmaraş Earthquakes
	Assoc.Prof. Çağlar GÖKSU – Field Observations from February 2023 Türkiye Earthquakes and Suggestions for Reduction of Future Losses
	Assoc.Prof. Ahmet Atıl AŞICI – The Economic Consequences of Kahramanmaraş Earthquakes
	Assoc.Prof. Kerem Yavuz ARSLANLI – Analysis of Affordability and Turkish Housing Market after 2023 Maraş Earthquakes
14:00	Session 2: İstanbul earthquake
15:30	Break
15:45	Session 3: Presentations
17:00	Closure