An Impact Chain-based exploration of multi-hazard vulnerability dynamics. The multi-hazard of floods and the COVID-19 pandemic in Romania

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Abstract. In light of the increased frequency of multi-hazards, the dynamics of vulnerability across time, space, and different hazards emerges as an intriguing but challenging research topic. Within multi-hazard contexts~~s~~, both the impacts of hazards and the mitigation strategies can augment vulnerabilities, adding layers to the complexity of multi-risk assessments. Delving into these interactions~~intricacies~~, this study aims to~~-~~ analyse new connections in rising vulnerability that result from impacts and adaptation options, as well as their implications, putting under the magnifying glass the co-occurrent powerful river flood events and the COVID-19 pandemic in Romania, taking as references 2020 and 2021. The proposed framework relies on an Impact Chain that was enhanced to include new elements (i.e., augmented vulnerabilities and derived impacts) and links (i.e., connections that describe the augmentation of vulnerability); which were also used to rank the vulnerabilities based on their augmentation. The Impact Chain draws on various data and information sources, including scientific literature, the feedback of first responders, reports, legislative documents, official press releases, and news reports. This research work makes a significant contribution to the field of DRR by broadening the purpose of the Impact Chain, transforming it into a first-hand, semi-qualitative tool for analysing vulnerability dynamics.

1 Introduction

In the field of Disaster Risk Reduction (DRR), the co-occurrence of natural hazards of various types and magnitudes amid the COVID-19 pandemic has increased attention to potential synergies and asynergies between pandemics and other hazards (Terzi et al. 2022). Even before the pandemic, multi-hazard analysis switched its focus from analysing all the hazards that can affect an area in a given period of time, which is often called multilayer single hazard analysis (Gill and Malamud 2014) or "all-hazards-at-place approach" (Hewitt and Burton 1971), to analysing the interactions between the hazards that overlap in time and space (De Angeli et al. 2022). This shift was supported by the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR 2015) and the Paris Agreement (UN 2015).

The interactions between the COVID-19 pandemic and co-occurrent natural hazards add layers of complexity to analysing vulnerability dynamics and constructing Disaster Risk Management (DRM) models that factor in this dynamics. One of the complications arises from the necessity to adjust traditional natural hazard management approaches to the new pandemic conditions, with implications for both the impacts and the adaptation options that can increase vulnerability. Scientific literature provides several examples (Andrews 2020, Majumdar and Dasgupta 2020, UNDRR 2020, Kassegn and Endris 2021, Mangubhai et al. 2021, Mishra et al. 2021, Patwary and Rodriguez-Morales 2021, Pramanik et al. 2021, Izumi and Shaw 2022) that point out failures of hazard management, which stem from the fact that standard operational procedures were not adapted to pandemic conditions, or from the fact that the efforts of tilting the SARS-CoV-2 infection curve were not adapted to fit hazard management practices. In recent years, these misfits gained traction in the field of DRM, being debated by numerous scientists (Frausto-Martínez et al. 2020, Quigley et al. 2020, Potutan and Arakida 2021, Albulescu et al. 2022, Hariri-Ardebili et al. 2022). A counterexample is given by Mavroulis et al. (2022), who present pandemic-adapted practices of emergency response focusing on the cases of the earthquakes that hit different regions of Greece in 2020 and 2021.

This collection of negative and positive examples motivates the need for an in-depth understanding of the interplay of different hazards and of the spatial-temporal changes in exposure, vulnerability, and adaptation. It is only by gaining a profound understanding of these matters, that we can develop new DRM models that account for pandemic conditions and acknowledge that all systems have limited and variable capacity (Terzi et al. 2022), followed by improved multi-risk management (Potutan and Arakida 2020, UNDRR 2020, Ashraf 2021, Ishiwatari et al. 2020).

Up to date, scientific works on the interactions between natural hazards and the COVID-19 pandemic have primarily revolved around reporting observations, overlooking the effects on the dynamics of vulnerability. Many examples (e.g., Andrews 2020, Majumdar and Dasgupta 2020, UNDRR 2020, Kassegn and Endris 2021, Mangubhai et al. 2021, Mishra et al. 2021, Patwary and Rodriguez-Morales 2021, Pramanik et al. 2021, Izumi and Shaw 2022) pertain to hydro-climatic hazardous events amid the pandemic, offering only factual documentation on their interactions. Narrowing down to the flood hazard, the compounded impacts of flood events and the pandemic are largely unknown and have been described only tangentially or in short (Simonovic et al. 2020, Patwary and Rodriguez-Morales 2021, Pramanik et al. 2021, Turay 2022), although the pandemic can augment typical health-related flood impacts (e.g., injuries, gastric problems stemming from water contamination, increased stress and/or anxiety) (Simonovic et al. 2020). Instead, more literature is available on the potential effects of flood events on the dynamics of COVID-19 cases (Frausto-Martínez et al. 2020, Mavroulis et al. 2021a, b, Albulescu 2023). What is more, the augmentation or attenuation of vulnerability conditions by previous hazard impacts (be they floods, pandemics, or other hazards) was not considered in any case study and has only been documented related to long-term processes (de Ruiter and van Loon 2022).

Given the increased frequency of co-occurrent or cascading hazards in the last years, the key position of vulnerability in multi-risk analysis has become more apparent, mainly due to the fact that the impact of multiple hazards and adaptive strategies have reshaped its spatial and temporal dynamics. This also raises significant challenges for risk management while reinforcing vulnerability's role in portraying disasters as human constructs (de Ruiter and van Loon 2022). This study delves deeper into the changes in vulnerability under hazard-generated impacts, taking as a case study two co-occurrent, independent hazards (i.e., floods and the COVID-19 pandemic) that severely affected Romania. At the outset, it is necessary to clarify the role of impacts resulting from multiple hazards in shaping vulnerability, with illustrative arguments from the recent literature. These instances bring to light a notable research gap that requires investigation, as detailed in the following.

Hazards generate various impacts on exposed elements with certain vulnerability levels. A particular impact has the potential to alter the vulnerability conditions that underlie another impact, whether it is caused by the same hazard or a different one. Another way to frame this issue is that the impact of a hazard changes vulnerability conditions before the recovery process reaches its end, with significant implications for the manifestation of a different hazard (de Ruiter et al. 2020). This is also mentioned by Mohammadi et al. (2023) in relation to the functionality of a system: "Additionally, events of any size, no matter how severe, that occur after a destructive event may result in the system's functionality being reduced because the system will be more vulnerable than it was prior to the big event, due to the damages that have been imposed by the first big event." The stated situation corresponds to the third type of dynamic vulnerability identified by de Ruiter and van Loon (2022), namely the changes in vulnerability during compounding disasters that are caused by a chain of events.

A particular situation is the one where the adaptation options or the structural measures implemented to reduce the risk associated with one hazard (de Ruiter et al. 2020) or the vulnerability to one hazard (Ward et al. 2020) have unwanted effects, increasing the risk associated with a second hazard and respectively, the vulnerability to another hazard, leading to asynergies (de Ruiter et al. 2020). This means that multi-risk analyses become even more convoluted and that they have to account for interactions that act as both causes and effects; which is a tall order for both researchers and decision-makers (Reichstein et al. 2021), but it is also essential to consider in the recovery phase of the DRM cycle (Mohammadi et al. 2023).

This study aims to address the research gap regarding the dynamics of vulnerability in a multi-hazard context by analysing the increases in vulnerability that stem from hazard impacts and adaptation options, taking as a case study the co-occurrent extreme river flood events and the COVID-19 pandemic in Romania in 2020 and 2021. The proposed methodological framework relies on an enhanced version of the initial Impact Chain developed within the Paratus Project (PARATUS Deliverable 1.1 202) to document the two-year unfolding of the two independent but co-occurrent hazards. This was upgraded to capture the shifts in vulnerability by enriching it with additional elements and connection types.

Impact Chains are conceptual models designed to visualise, document, and analyse the interconnections between hazards, vulnerability, and exposure that ultimately give rise to a specific risk (IPCC 2014b, Zebisch et al. 2017, UNDRR, 2022). In this study, we refined the model to focus on vulnerability dynamics in a multi-hazard context. Such efforts are vital for elaborating post-pandemic risk management plans that avoid inadvertently introducing additional sources of unforeseen vulnerability. Risk (or hazard) management can act on vulnerability conditions both ways (de Ruiter and van Loon 2022): producing desirable results (i.e., by decreasing vulnerability) or unwelcome outcomes (i.e., by augmenting vulnerability). In certain cases, the risk management of a hazard was responsible for increasing the risk associated with another hazard (Ward et al. 2020, de Ruiter et al. 2021a, b); and there are fair chances that this will happen again if the dynamics of vulnerability in multi-risk situations is not properly understood.

This research work makes a significant contribution to the field of DRR by broadening the original purpose of the Impact Chain, transforming it into a first-hand, semi-qualitative tool for analysing vulnerability. The focus is on advancing its application to analyse the effects of hazard impacts and mitigation measures on vulnerability. The conceptual framework dwells on the argument of Otto and Raju (2023), who highlight that climate change should not be entirely blamed for climate-related disasters and that vulnerability conditions must be factored in when analysing impactful events. Placing greater emphasis on the vulnerability component brings up the necessity of understanding its dynamics across time and space (de Ruiter and van Loon 2022), and even more in multi-hazard situations. This can be achieved by expanding the scope of Impact Chains to give visibility to such shifts in vulnerability, and further on, to diagnose past or present multi-hazard risk management, and predict potential crises, shortcomings of management approaches, and the transformation of certain vulnerabilities into drivers of vulnerability.

The third decade of the 21st century debuted with the COVID-19 pandemic, which has greatly impacted human communities worldwide, and brought major challenges for Disaster Risk Management (DRM). The pandemic acted as a powerful driver of societal change, making scientists and practitioners reconsider their approaches to health care management (Begun and Jiang 2020, Rawaf et al. 2020, Matenge et al. 2022), health systems resilience (Chua et al. 2020, Hariri-Ardebili 2020, Traverson et al. 2020, Haldane and Morgan 2021, Haldane et al. 2021), or resilience in general (Hariri-Ardebili et al. 2022), as well as multi-hazard risk management (Quigley et al. 2020, Potutan and Arakida 2020, Ali Maher 2021, Ashraf 2021, Kruczkiewicz et al. 2021, Simonovic et al. 2021, UNU-EHS 2021, Mavroulis et al. 2022, Terzi et al. 2022), and giving way to new economic challenges (Buheji et al. 2020, Kaye et al. 2020, Asare and Barfi 2021, Sikder et al. 2020, Younas and Kassim 2022).

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Given the increased frequency of co-occurrent or cascading hazards, vulnerability consolidated its key position in multi-risk analysis because the impact of multiple hazards and adaptive strategies reshaped its spatial and temporal dynamics. This raises significant challenges for risk management while reinforcing vulnerability's role in portraying disasters as human constructs (de Ruiter and van Loon 2022). This study delves deeper into the changes in vulnerability under hazard-generated impacts, taking as a case study two co-occurrent, independent hazards (i.e., floods and the COVID-19 pandemic) that severely affected Romania. At the outset, it is necessary to clarify the role of impacts resulting from multiple hazards in shaping vulnerability, with illustrative recent examples from the literature. These instances bring to light a notable research gap that requires investigation, as detailed in the following.

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This research work makes a significant contribution to the field of DRR by broadening the original purpose of the Impact Chain, transforming it into a first-hand, semi-qualitative tool for analysing vulnerability. The focus is on advancing its application to delve into the intricate multi-hazard impacts, along with their ramifications on vulnerability conditions. The conceptual framework dwells on the argument of Otto and Raju (2023), who highlight that climate change should not be entirely blamed for climate-related disasters and that vulnerability conditions must be factored in when analysing impactful events. Placing greater emphasis on the vulnerability component brings up the necessity of understanding its dynamics across

~~time and space (de Ruiter and van Loon 2022), and even more in multi-hazard situations. This can be achieved by expanding the scope of Impact Chains to give visibility to such shifts in vulnerability, and further on to diagnose past or present multi-hazard risk management, and to predict potential crises, shortcomings of management approaches, and the transformation of certain vulnerabilities into drivers of vulnerability.~~

2 Setting the scene

~~Floods, the COVID-19 pandemic, and heavy rainfall were considered primary hazards within the Impact Chain, but only the first two are analysed in this study due to their significant impacts. Other secondary hazards (e.g., strong wind, landslides) co-occurred with the other two, but their role was of lesser significance in the analysed multi-hazard context.~~

2.1. Flood risk ~~and hazard events~~ in Romania

Floods are among the most common and impactful natural hazards that affect Romania, causing significant damage throughout the country. The EM-DAT (2023) database includes 102 natural hazardous events that occurred in Romania in 1900-2023, of which flood events represent almost 52%. These floods resulted in more than 1700 deaths, more than 146600 homeless people, over 1.64 million affected people, and total estimated damages of about 8.69 billion dollars. This incomplete dataset, complemented by other European flood-related databases (e.g., HANZE v2.1 developed by Paprotny and Mengel 2023, Paprotny et al. 2023) ~~points out~~highlights the prominence of floods among the natural hazards that occur in the country of reference.

Usually, river floods follow a seasonal pattern, with the largest events occurring in the late spring months and early summer ~~months~~ due to the convergence of high rainfall amounts and snow melting in mountainous areas. This water input increases the discharge of ~~both~~ main rivers (e.g., the Danube, Siret, Prut, Olt, Mureș, and Argeș rivers) as well as~~nd~~ low-rank streams. The~~is~~ high level of flood hazard overlaps long-standing vulnerability conditions that are only partially discussed in the scientific literature (Constantin-Horia et al. 2009, Constantinescu et al. 2015, Vinke-de Kruijf et al. 2015, Peptenatu et al. 2020): deforestation, the extension of the residential areas and transport networks in floodplains and other flood-prone areas ~~because of~~favoured by inconsistent law enforcement, infrastructure-related failures (e.g., poor-performing, undersized urban sewage systems), and a reactive approach to flood management that neglects ~~the~~ preparedness ~~facts~~ and does not properly understand what salient recovery involves (Mohammadi et al. 2023). In fact, the most recent~~last~~ National Synthesis of the Flood Risk Management Plan (2023) still focuses on generic (i.e., forest and bridge-related measures, about 50%), structural methods (about 33%) to reduce the flood risk at the national scale and also includes confusions among~~between~~ risk-related terminology (e.g., exposure, hazard, vulnerability).

The significant flood hazard and vulnerability levels result in a high flood risk that materialises once every few years into very impactful flood events. The flood risk is addressed by the Flood Risk Management Plans elaborated for the 11 Basinal

Administrations that function at the county scale. On a national scale, flood risk management is coordinated by several organisations: the Ministry of Environment, Water and Forests, the National Administration of Romanian Water, and the National Institute of Hydrology~~,~~ and Water Management. These organisations are often criticised for their underperformance in managing flood risk by both scientists (Vinke-de Kruijf et al. 2015) and civil society; an attitude ~~which~~ that is justified by the wrecked aftermath of large flood events that were forecasted and communicated by hydrological warnings.

Flood ~~risk~~ occurrences and the quantification of their associated impacts are~~management is~~ not sufficiently documented in Romania, as evidenced by the absence of relevant official databases.~~demonstrated by the lack of databases regarding the occurrence and impacts of floods.~~ Such information has to be obtained from alternative sources, like weather and hydrological forecasts and news reports. The flood events taken under analysis in this paper were identified using the hydrological warnings issued by the National Institute of Hydrology~~,~~ and Water Management during 2020-2021, which were corroborated with information from a national news platform. Multiple news reports were used for the validation of each extracted piece of information.~~.~~

In 2020, there were five major flood events that imposed the evacuation of people, all in June (16th, 18th, 19th, 23rd, and 26th). In the subsequent year, there were eight~~8~~ such events, of which two occurred in May (13th, 18th), two in June (18th, 19th), and four in July (15th, 16th, 19th, 20th) (Albulescu 2023). In addition, flood events that did not involve evacuation procedures, but were still included in the Impact Chain, occurred in January, August, and December 2021. The 2020-2021 flood events resulted in seven human casualties (Meteo Romania 2020, 2021,~~), which is confirmed by the~~ HANZE v2.1 ~~(~~2023) ~~database~~. The spatial extent of the various impacts of the powerful river floods in 2020 and 2021 is presented in Figure 1~~, and detailed in the Results~~.

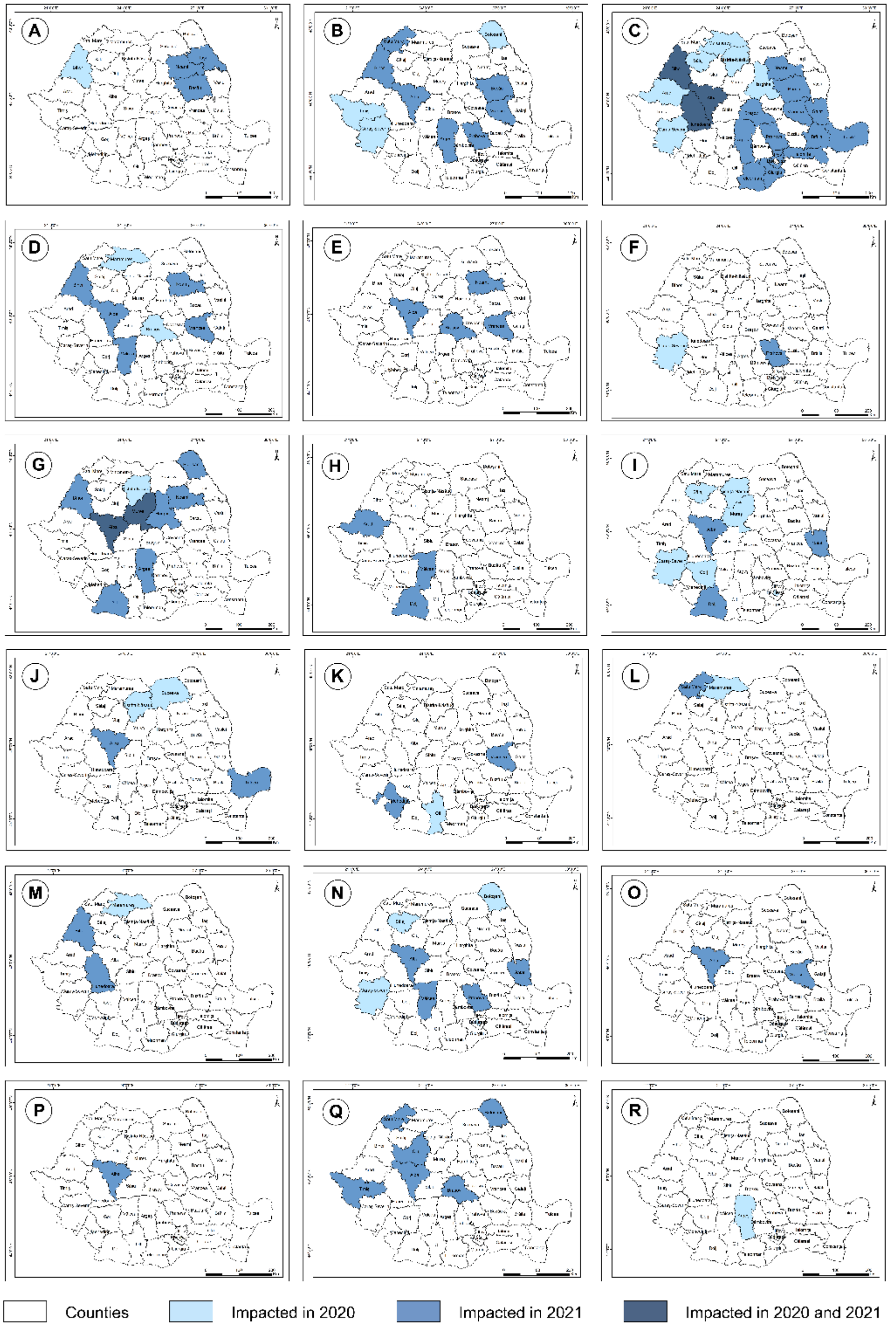

Figure 1: Spatial extent of the impacts of the extreme flood events that affected Romania in 2020 and/or 2021. Impacts: A – Human casualties, B – Displaced/(Self-) Evacuated people, C – Flooded/Damaged ~~househols~~households or houses, D – Damaged bridges, E – Isolated human communities, F – Railway transportation impairment, G – Damaged facilities/Cut off of electricity/gas/water supply, H – Sewage system overflow, I – Fallen trees, J – Landslides, K – River water contaminated with garbage, L – Dead/Missing animals, M – Flooded croplands, N – Damaged cars, O – Disrupted tourism activities, Q – Flooded business buildings, P – Flooded public buildings (including 1 hospital), R – ~~Distrupted~~Disrupted ambulance service

2.2. The COVID-19 pandemic in Romania

The first confirmed case of COVID-19 registered in Romania was recordedoccurred on the 26th of February 2020, and the first two deaths due to this disease occurred approximately a month later. Until the beginning of June 2023, more than 3.4 million cases of COVID-19 and over 68,000 deaths were registered in the country of interest, of which 53.07% and, respectively 86.09% can be traced back to the first two pandemic years (WHO Dashboard 2023). This human toll unfolded in five pandemic waves (Figure 2), of which the fourth one, starting in 2022, was the most aggressive.

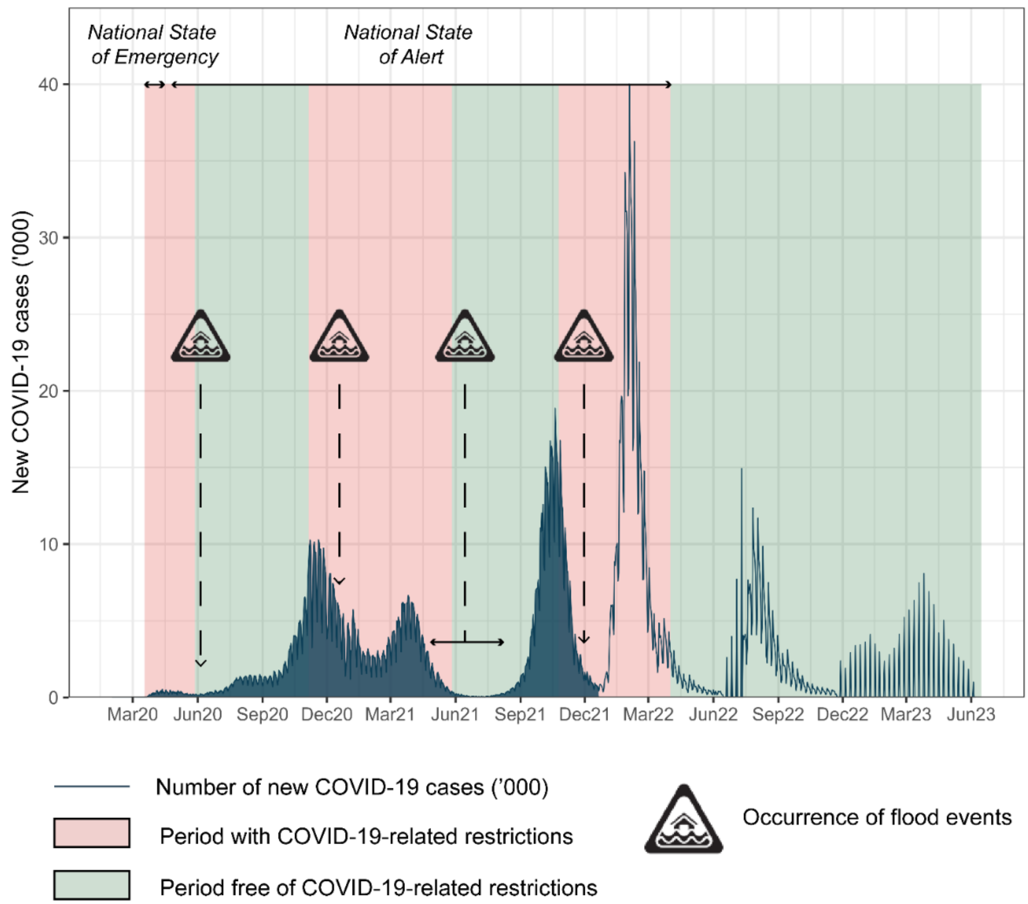

Figure 2: The dynamics of the new cases of COVID-19 in Romania with a highlight on 2020 and 2021, plotted against the periods with/without restrictions and the clusters of flood events (COVID-19 data source: WHO Dashboard 2023)

Like in many other countries, the pandemic waves in Romania followed a seasonal pattern that was conditioned by temperature and humidity (Mecenas et al. 2020). Figure 2 indicates that the same seasonal pattern was followed by the COVID-19-related restrictions. As an immediate response to the emergence of COVID-19 cases, at the end of March 2020, the Romanian

Government declared ~~the~~ National State of Emergency (Decree no. 195/2020) and imposed a lockdown~~, which was~~of increased severity~~e~~ compared to the ones implemented in other counties. This ended on the 15th of May 2020, and was followed by a two~~2~~-year National State of Alert during which periods free of restrictions – that overlapped the summer months, alternated with periods of circulation restrictions for citizens that aimed to tilt the SARS-CoV-2 infection curve – that were specific to the cold season (Figure 2).

Figure 2 shows that the flood events that occurred in June 2020 correspond to the beginning of a restriction-free period, which was followed by one with severe restrictions. The floods of January 2021 overlapped a period with restrictions for everyone~~,~~ when wearing face masks was mandatory, circulation was prohibited between 23 p.m. and 5 a.m., social gatherings were banned, and a large part of work was moved to the virtual environment. Towards May 2021, circulation restrictions were lifted only for vaccinated people, and it was not until the 26th of July that all COVID-19-related restrictions ceased. This~~; this~~ means that the flood events that happened on the 13th and 18th of May 2021 overlapped a period with restrictions for unvaccinated people and that the ones in June-August correspond to a restriction-free interval. The flood events of December 2021 occurred during a period of restrictions imposed on unvaccinated people.

3 Methodology

The proposed methodological framework aims to identify and analyse the augmentation in vulnerability conditions within a multi-hazard context. This framework dwells on Impact Chains as instruments for documentation, visualisation, organisation, and scientific inquiry, ultimately broadening their application to fit the objective of studying the dynamics of vulnerability – particularly the augmentation of vulnerability, and henceforth to turn them into diagnosis and prediction tools. With this addition, the documentary focus of the chain progresses to a more analytical stance, specifically geared towards identifying and tracking the transformation of specific vulnerabilities into drivers of vulnerability.

The next section presents two distinct workflows within the methodological framework (Figure 3): ~~Building~~ building the Impact Chain initially developed by the authors within the Paratus Project (PARATUS Deliverable 1.1 2023) – which was further strengthened by first responders' input and, secondly, its enhancement to account for vulnerability augmentation.

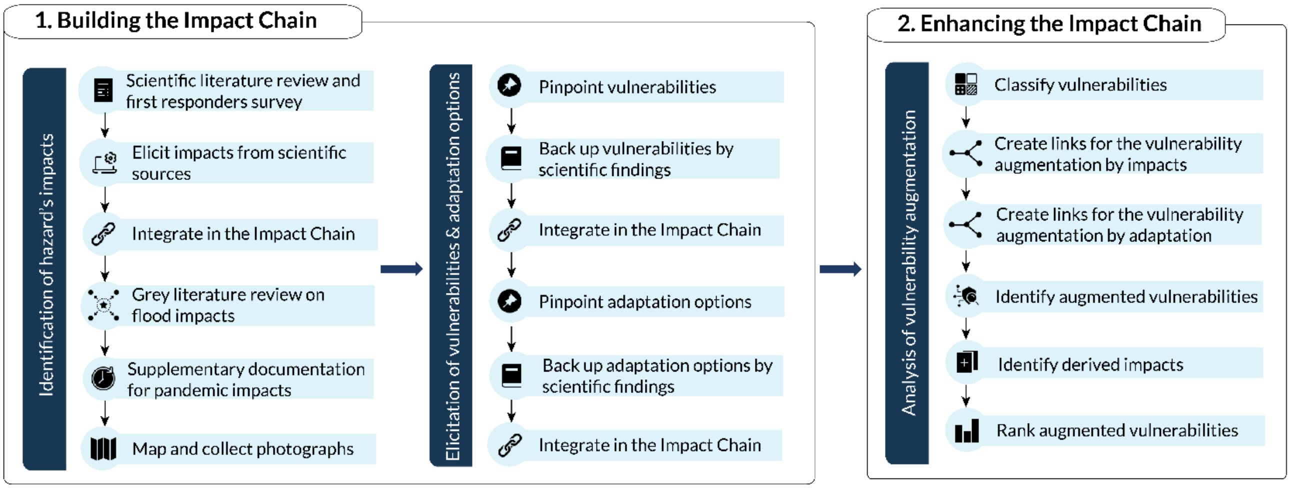

Figure 3: Methodological framework

3.1. Building the Impact Chain

Impact Chains represent conceptual models designed to facilitate the investigation of climate and disaster risk under a structured analysis framework for the risks associated with climate-related impacts (UNDRR 2022). They have been used for elicitation, conceptualisation, analysis, and information sharing purposes, as tools that explore and analyse the impacts of single hazards or multi-hazards specific to past or potential hazard events, following different operational frameworks (e.g., expert workshop, desktop analysis, machine-generated) and taking into consideration different spatial and temporal scopes (Pittore et al. 2023). There are numerous examples where Impact Chains were integrated into vulnerability or risk assessments specific to climatic aspects (Becker et al. 2014, Schneiderbauer et al. 2020, Zebisch et al. 2017, 2021, Menk et al. 2022).

In this paper, Impact Chains were used as models of cause and effect (Menk et al. 2022) that were upgraded to capture the augmentation of vulnerability by hazard impacts and~~or~~ adaptation options, with a limited participation of stakeholders (i.e., only integrating the feedback of first responders involved in flood emergency interventions). Unlike the scientific papers reviewed by Menk et al. (2022), this study does not integrate Impact Chains as tools for the assessment of vulnerability or risk pertaining to a climatic hazard, but broadens their scope to focus on vulnerability dynamics within a multi-hazard context that involves a hydrological hazard (i.e., flood) and an epidemiological one (i.e., the COVID-19 pandemic). This approach aligns with Zebisch et al. (2021) recommendation that the “relatively linear and sectorial approach of impact chains could be widened to impact webs, which would include feedback relations and cross-connections~~.~~”, which is also supported by Sparkes et al. (2023).

The structure of an Impact Chain includes elements that can be considered the fundamental units of a hazard-related context and the connections established between them. The~~se~~ elements can take the form of hazards, impacts, exposed elements, vulnerabilities, and adaptation options,~~–~~ defined according to the Sendai Framework Terminology on Disaster Risk Reduction (UNDRR 2017). Given the central role of impacts, vulnerabilities, and adaptation options in the proposed vulnerability augmentation framework, we consider that their meaning should be highlighted here. In this paper, impacts particularly refer to the negative effects of a hazardous event or a disaster, while vulnerability represents the "conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards" (UNDRR 2017). Adaptation options are measures meant to attenuate the negative impacts by addressing one or more vulnerabilities or impact mechanisms (IPCC 2014a). These elements~~y~~ are organised in a chain-resembling structure that relies on different connection types: causes, affects, relates to, impacts, and mitigates. Detailed guidelines on how such connections were established ~~structures were built~~ within the Paratus Project are provided by Pittore et al. (2023) and PARATUS Delivarable 1.1 (2023).~~.~~

Figure 3 illustrates a comprehensive breakdown of the construction of the Impact Chain through a combination of knowledge, data, and information extracted from a diverse range of sources: scientific papers, legislative documents, official press releases, reports, statistical datasets, and grey literature in the form of news reports (Figure 3). The Impact Chain was implemented in Kumu, which is a powerful mind mapping tool that allows for a variety of mapping settings (e.g., stakeholder, systems, social network, community asset, concept mapping), as well as import and export options (Kumu 2023). Floods, the COVID-19 pandemic, and heavy rainfall were considered primary hazards within the Impact Chain, but only the first two are analysed in this study due to their significant impacts. Other secondary hazards (e.g., strong wind, landslides) co-occurred with the other hazards~~two~~, but they were less impactful compared to the mentioned hazards ~~their role was of lesser significance~~ in the analysed multi-hazard context.

The first phase of the building process (Figure 3) relied on a literature review regarding the impacts of flood events and the pandemic, complemented by a ~~grey literature review~~supplementation of examples~~ that provided on-point examples~~ specific to the flood hazardous events in 2020-2021 collected from studying the grey literature. As part of the first review, the most prominent scientific databases (i.e., Web of Science, Google Scholar, ResearchGate, and PubMed) were searched for relevant papers using the following keywords: "Covid-19 pandemic Romania", "Covid-19 pandemic impact Romania", "Floods Romania 2020", "Floods Romania 2021". Next, during the exclusion phase, the titles and abstracts of the collected articles were analysed in order to select only the research works with a clearly defined and relevant aim, a thorough and methodologically validated analysis of the impacts of the hazards, and an adequate spatial and temporal focus. In the last phase of the literature review on impacts, content analysis was performed on the selected papers, and the relevant impacts were included in a database. The grey literature review was performed using a prominent online Romanian national news portal, Digi24 (2023). It was limited to the impact of~~ extreme~~ floods and did not include the impacts of the pandemic. Supplementary documentation was necessary to extract pandemic impacts~~These were extracted~~ from legislative documents (Decree no. 195/2020), official press releases (CCR 2022),~~ or~~ reports (WHO 2020b, HSRM 2021a, b, OECD 2021, CDC 2022, WHO

Dashboard 2023), and statistical datasets (Eurostat 2021). Next, the Kumu design for appropriate flood impacts was enriched with photographs and maps depicting the spatial distribution of impacts in 2020, 2021 or both, at the county or local scale.

The last two phases of the construction process focused on the elicitation of vulnerabilities and adaptation options under an expert knowledge-based approach. The identification of these elements was backed by scientific findings wherever possible in order to obtain a valid configuration of the chain (Figure 3).

An addition to the Impact Chain developed in the early stages of the Paratus Project (PARATUS Deliverable 1.1 2023) was to integrate the feedback of 595 first responders involved in flood management in 2021, focusing on aspects concerning preparedness, coordination, and experience, upon extracting them from the study of Fekete et al. (2023). Their perception of the problems encountered during flood-related emergency interventions, potential improvements, cooperation among volunteers, provision of information about the deployment, and flood-affected infrastructure served as a basis for eliciting a new set of vulnerabilities and adaptation options.

Regardless of their type, all elements and connections were integrated into Kumu with a short description, associated sources, and references. The Kumu design for appropriate flood impacts was enriched with photographs and maps depicting the spatial distribution of impacts in 2020, 2021 or both, at county or local scale. Cumulatively, the Impact Chain drew from 46 scientific papers (including one on the 595 feedback of first responders engaged in on-site flood management), one legislative document, one official press release, one Eurostat statistical dataset, 6 official reports, and 75 news reports. All the connections in the Impact Chain, regardless of their type or the elements they connect, were described and assigned values for the Sources or References parameters.

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3.2. Enhancing the Impact Chain

In the next phase, we extended the application of Impact Chains to explore the third type of vulnerability dynamics identified by de Ruiter and van Loon (2022), namely the changes in vulnerability conditions related to compounded hazards, or more accurately, the augmentation of vulnerability in a multi-hazard context. Elevating the Impact Chain from its above mentioned original purposes to a tool for analysing vulnerability dynamics representsed a pioneering research endeavour, standing out as an element of methodological novelty.

This broadening of the original application of the Impact Chain was done by 1) introducing new types of elements (i.e., augmented vulnerabilities, derived impacts), 21) establishing new types of connections between the impacts/adaptation options and vulnerabilities~~,~~ 2) introducing new types of elements (i.e., augmented vulnerabilities, derived impacts) based on these connections, and 3) ranking the vulnerabilities in the Impact Chain based on their augmentation. These steps were implemented to construct an enhanced Impact Chain, building on the previous version that documented the unfolding of the selected co-occurrent hazards in Romania in 2020-2021.

To set the stage for the implementation of the vulnerability augmentation framework, an in-depth analysis of the vulnerabilities in the Impact Chain was performed. The vulnerabilities were classified according to their related hazards, types, spatial scales, and links to specific adaptation option(s). This classification provided a better understanding of the contribution of vulnerabilities to the manifestation of flood and COVID-19 pandemic impacts.

~~The first step was to perform an in-depth analysis of the vulnerabilities in the Impact Chain. The vulnerabilities were grouped according to their related hazard, type, spatial scale, and links to specific adaptation option(s). This classification provided a better understanding of the contribution of vulnerabilities to the manifestation of flood and COVID-19 pandemic impacts.~~

Further on, the Impact Chain was enhanced by identifying new connection types between the impacts/adaptation options and the vulnerabilities (Figure 4), drawing from the types of maladaptation to climate change and their implications on vulnerability proposed by Schipper (2020). The three types of maladaptation in question (i.e., rebounding vulnerability, shifting vulnerability, and creating negative externalities) were tailored to suit the multi-hazard context and complemented by a new connection type also relevant to the Impact Chain (i.e., deepens~~sing~~ vulnerability). These new connections account for the augmentation of a vulnerability by a given impact or adaptation option in a way that could not have been prevented or precluded. The new links are defined as:

- Deepens (vulnerability): the augmentation of a vulnerability by an impact, both relating to the same hazard;
- Shifts (vulnerability): the augmentation of a vulnerability to a certain hazard by an impact caused by a different hazard;
- Rebounds (vulnerability): the augmentation of a vulnerability by an adaptive option that aimed to attenuate an impact or vulnerability affecting a certain group/system, but ended up increasing a vulnerability of that same exposed element;
- Creates negative externalities: the augmentation of a vulnerability by an adaptive option that has adverse effects on anyone who was not targeted by it (Schipper 2020).

To set up the new connections, each impact was studied from the perspective question of "Which vulnerability can be augmented by this impact?". The adaptation options were also scanned according to the same ~~adapted~~ adjusted question, with the goal of identifying possible unwanted effects of measures intended to lessen certain vulnerability conditions, as reported by de Ruiter et al. (2021a, b). The vulnerabilities that were connected with impacts and/or adaptation options through the above said new links that express vulnerability augmentation were transformed into elements called augmented vulnerabilities.

A noteworthy situation that emerged from the experience-based feedback of first responders is the one where certain vulnerabilities that influence the manifestation of impacts can also slow down or obstruct the implementation of adaptation options. Such instances were marked by a new type of connection called “slows down/obstructs”, established between vulnerabilities and adaptation options.

Within the new conceptual framework of the enhanced Impact Chain (Figure 4), certain ~~augmented~~ vulnerabilities, upon augmentation by an impact, ~~stand out~~can also act ~~also~~ as impacts that further on deepen the very impact that increased the vulnerability in the first place. This process represents a positive feedback loop, where the initial impact augments a vulnerability that can be viewed afterwards as a (derived) impact that will reinforce the first impact in the future. Such augmented vulnerabilities that also act as impacts were introduced in the ~~enhanced Impact Chain~~enhanced Impact Chain as derived impacts and linked to the vulnerability element that they share their name with by “relates to” connections. These “relates to” links are not visible within the enhanced Impact Chain in Kumu in order to reduce the visual strain. Subsequently, the derived impacts were linked with the impact that ~~augmented~~ deepened/shifted the corresponding vulnerability by a newly introduced type of connection ~~named~~ referred to as “sharpens” (Figure 4). These “sharpens” connections convey the message that the augmented vulnerability will intensify~~reflects back on~~ the impact that initially ~~increased it~~augmented the vulnerability, ~~making it even more prominent than in the beginning~~rendering this impact more prominent than before.

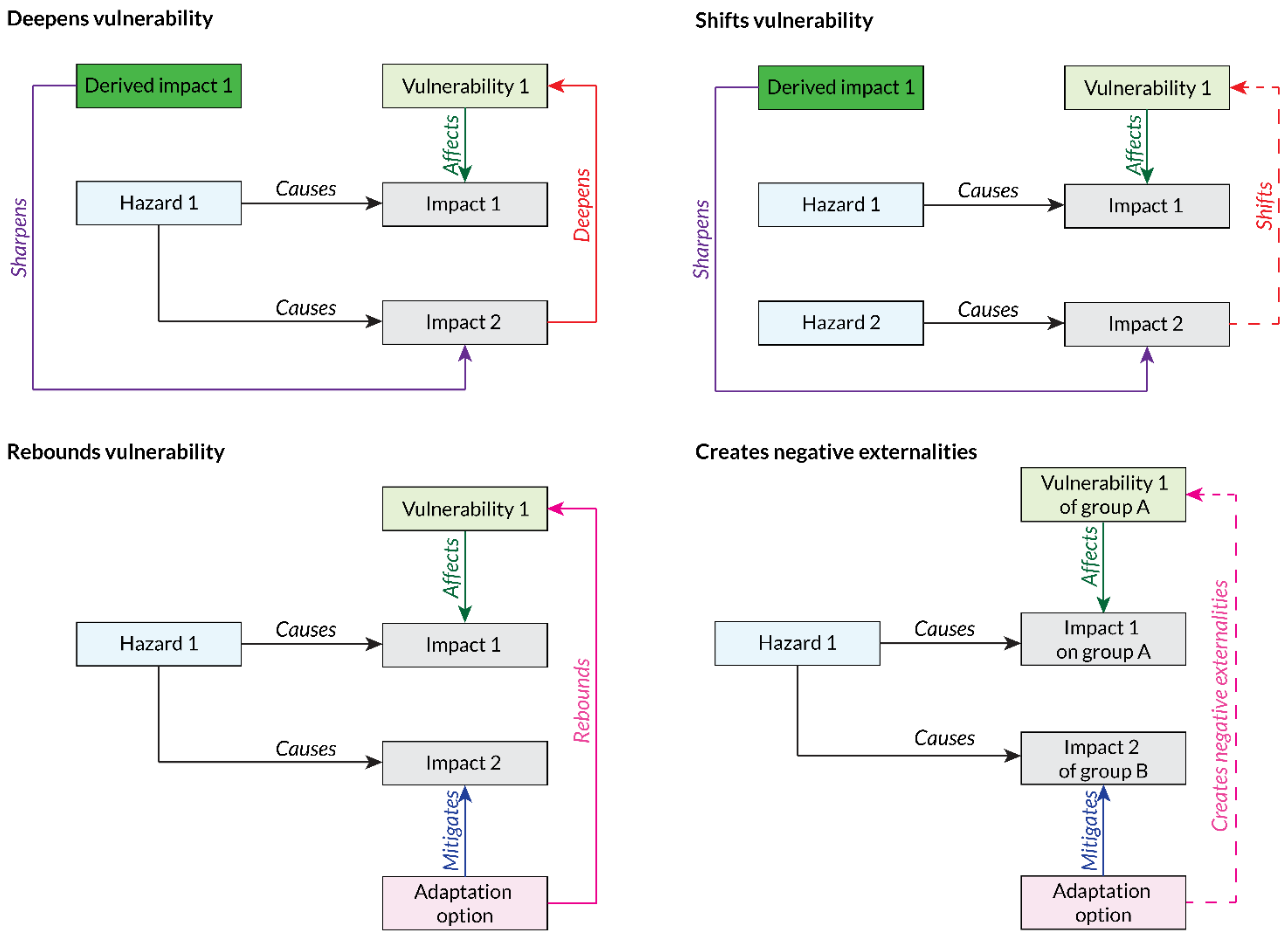

Figure 4: Conceptual framework of the new elements and links of the enhanced Impact Chain

The ranking of the vulnerabilities based on their augmentation relied on the number of augmentation connections from impacts to vulnerability (i.e., deepens, shifts) and on the number of augmentation connections from adaptation options to vulnerability (i.e., rebounds, creates negative externalities). These were computed for each of the 26 vulnerabilities in the enhanced Impact Chain and subsequently checked for Pearson correlation. The absence of correlation allowed for the computation of the Z-score. Augmented vulnerabilities were transformed into z-scores based on the number of augmentation links they ~~generate~~collect, showing the relationship of the values in terms of distance to the mean of the distribution. The basic principle we have assumed was that the further away from the mean of the distribution, the more outstanding~~-~~/~~-~~augmented that vulnerability is. ~~-~~Next, two rankings of the vulnerabilities were calculated based on the Z-scores of the augmentation connections of impact-vulnerability and adaptation option-vulnerability. The final ranking was computed using a~~n~~ statistically weighted approach~~,~~ by attributing the impact-vulnerability connections a weight of 70% and the adaptation option-vulnerability connections a weight of 30%. The rationale behind the assigned weights lies in the fact that impacts augment vulnerabilities to a greater extent than adaptation options do, at a ratio of 54~~3.84~~% augmentation by impacts vs. ~~3.84~~4% augmentation by adaptation options, while ~~the remaining~~ 12~~1.53~~% is attributable to both impacts and adaptation options combined. The ascending order of the final ranking showed the extent to which the vulnerabilities were ~~overall~~ augmented overall, from the most to the least augmented.

4 Results

This section focuses on the augmentation of vulnerability stemming from ~~certain~~ flood ~~or~~ and pandemic impacts and ~~of~~ the adaptation options implemented to mitigate vulnerabilities and/or impacts. It starts with a~~the~~ classification of all vulnerabilities in the Impact Chain, followed by details on the augmented ones and on the vulnerabilities that also act as derived impacts. Finally, we rank the amplified vulnerabilities to identify those most significantly affected.

The intricate configuration of the Impact Chain does not allow for a proper visualisation within this paper, but it can be accessed online on the Kumu platform.

4.1. Classification of vulnerabilities

The enhanced Impact Chain includes 26 vulnerabilities upon integrating the perception of first responders. More than half (58~~7.7~~%%) of these vulnerabilities were related to flood events, 23~~.1~~% pertained to both hazards, and 19~~.2~~% of them to the pandemic (Table 1). Most of the vulnerabilities contribute to prominent ~~multi-hazard~~ flood impacts such as the flooded/damaged houses or households, the flooded/damaged/blocked roads, the displaced/(self-) evacuated people, or multi-hazard impacts, like increased stress or anxiety, and the potential increase in COVID-19 new cases.

~~The v~~Vulnerabilities were grouped according to their type, as described in Appendix A. More than a third (35~~4.6%~~%) of them stemmed from failures of emergency management, while 19~~.2~~%~~ of them~~ derive from failures of territorial planning or of medical management (Table 1). At the same time, the number of vulnerabilities associated with the coping capacity (15~~.4~~%) or infrastructure (12~~1.5~~%) was rather low. It should be highlighted that this is a simple classification, and that the range of vulnerabilities is more nuanced, including governance-related vulnerabilities (e.g., improper governance structure for effective flood management, flood management not adapted to the COVID-19 context, ineffective institutional communication) or development-related vulnerabilities (e.g., development of inhabited areas in flood-prone areas, development of infrastructure in flood prone areas, poverty, depleted capacity due to seasonal patterns of hazards, low quality construction materials, ineffective sewage system). In terms of spatial scale, most vulnerabilities were identified at the local level~~scale~~ (69~~.2~~%), and only 23~~.1~~% were specific to the entire country (i.e., national scale) (Table 1).

Table 1. Number and proportion of vulnerabilities by A. hazard, B. type, and C. spatial scale in the Enhanced Impact Chain

A. Vulnerabilities by hazard		
Hazard	**Number**	**Proportion (%)**
COVID-19 pandemic	5	19.2
Floods	15	57.5
Floods, COVID-19 pandemic	6	23.1
B. Vulnerabilities by type		
Type	**Number**	**Proportion (%)**
Vulnerabilities related to infrastructure	3	11.5
Vulnerabilities related to coping capacity	4	15.4
Vulnerabilities related to territorial planning	5	19.2
Vulnerabilities related to medical management	5	19.2
Vulnerabilities related to emergency management	9	34.6
C. Vulnerabilities by scale		
Scale	**Number**	**Proportion (%)**
Individual	1	3.85
Local	18	69.2
Regional	1	3.85
National	6	23.1

~~When it comes to adaptation options, only~~Only a third ~~30.76%~~ of the vulnerabilities were mitigated by ~~such elements~~adaptation options, 3 of them related to the COVID-19 pandemic (i.e., low-performance medical system, insufficient medical personnel, insufficient ICU capacity), the other 3 to both hazards (i.e., flood management not adapted to the COVID-19 context, ineffective institutional communication, uncooperative population), and the rest to floods (i.e., improper mapping and visualisation of affected areas, lack of equipment for first responders).

The 31~~0~~% rate of mitigated vulnerabilities shows that most of the adaptation options targeted impacts, which means that they produced short-term positive change, addressing only to a limited extent the causes of the medical crisis and the multi-hazard vulnerabilities, and even to a lesser extent the flood vulnerabilities. The adaptation options that mitigated vulnerabilities related to the COVID-19 pandemic were the most numerous: 4 in the case of insufficient ICU capacity, 3 in the case of insufficient medical personnel, and 2 in the case of the low-performance medical system. The main adaptation options related to the support ~~from other~~provided by other states (~~e.g.,~~ in terms of medical equipment and staff), the transfer of COVID-19 patients to other countries, the establishment of new modular hospitals, and the hiring of additional medical personnel; ~~—~~ all ~~of which allowed~~ allowing the fight against the pandemic to continue.

All ~~of ~~the other mitigated vulnerabilities were addressed by a single adaptation option, showing a unilateral approach. In the case of floods, several ~~both ~~vulnerabilities were mitigated by an "umbrella" adaptation option that includes various actions specific to each context, namely the great capacity of first responders to develop creative solutions in crisis and cope with new challenges. With few exceptions (e.g., RO-Alert SMS messages and hydrological warnings, which are part of early warning systems), most of these flood-related adaptations focused on alleviating the "symptoms" of the local crisis and did not address its root causes. For instance, during the flood event on the 18th of June 2020, river banks were heightened by firefighters with sand bags to prevent ~~the ~~water from reaching the houses in proximity ~~at ~~in two settlements in Caraș-Severin County. Other examples of short-term, recovery-related adaptation options are the removal of fallen trees from streets/roads or~~-~~ flood water from households~~, or~~ buildings, or roads.

4.2. Statistical overview of augmented vulnerabilities and augmentation links

To identify the augmented vulnerabilities, 41 new connections (Appendix B) that express different forms of vulnerability augmentation were established between the impacts that would potentially generate increases in vulnerability (i.e., deepens or shifts vulnerability links) or from the adaptation options with this effect (i.e., rebounds vulnerability or creates negative externalities connections), under an expert-based approach.

In the enhanced Impact Chain, 18 (69~~.23~~%) out of 26 vulnerabilities were augmented, some of them more than once by different impacts or adaptation options: 14 (54~~3.84~~%) were augmented by hazard impacts, 1 (~~3.8~~4%) was augmented by solely adaptation options, and 3 (12~~1.53~~%) by both impacts and adaptation options. The vulnerabilities that increased because of both elements are: the uncooperative population, flood management not adapted to COVID-19 conditions, and shallow implementation of preventive measures.

The distribution of augmented vulnerabilities among the hazards is unbalanced: half of them~~ augmented vulnerabilities ~~ are specific to floods, 28~~7.77~~% to the COVID-19 pandemic, and 22~~.22~~% to both hazards. Also, the augmented vulnerabilities related to medical or emergency management account for 67~~6.66~~% of the total, and the other 3 categories (i.e., vulnerabilities related to coping capacity, infrastructure, or territorial planning) each account for less than 20%. Most augmented vulnerabilities manifest at the local scale (67~~6.66~~%), and 22~~.22~~% of them at the national level. Almost all vulnerabilities that were mitigated by adaptation options were also augmented either by hazard impacts (i.e., lack of equipment for first responders, improper mapping and visualisation of affected areas, low-performance medical system, insufficient medical personnel, insufficient ICU capacity), or both impacts and adaptation options (i.e., uncooperative population). The only mitigated vulnerability that was not also augmented was the ineffectiveness of institutional communication.

Almost half (49~~8.8~~%) of the new augmentation connections convey a deepening effect on vulnerability elements, and more than a third (37~~6.6~~%) augment vulnerability by shifting it from one hazard to the other (Figure 5). The increases in vulnerability caused by adaptation options total about 15~~4.64~~%, with equal unwelcome effects (7~~.32~~%) resulting from rebounding vulnerability and creating negative externalities. The details on the augmentation of certain vulnerabilities by impacts or adaptation options are provided in Appendix B.

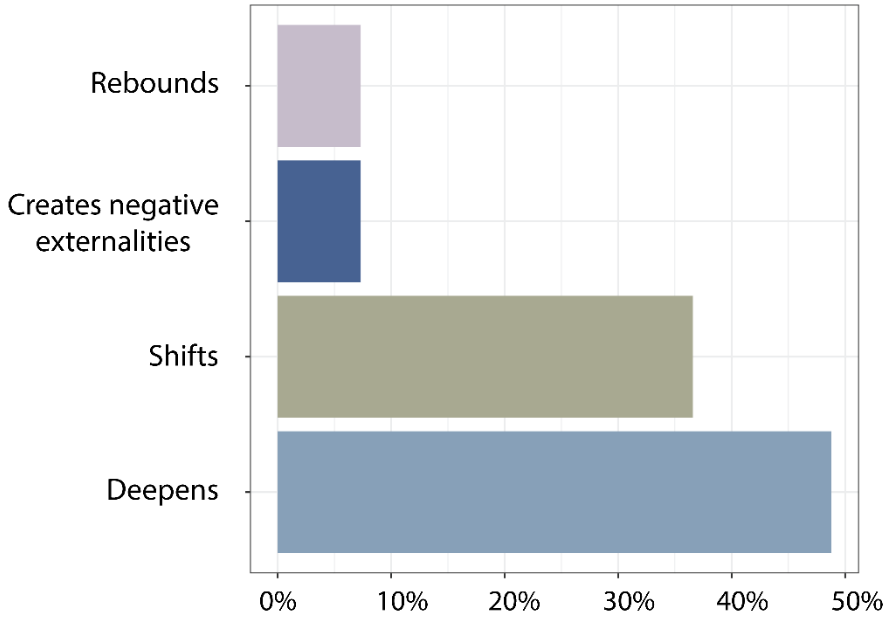

Figure 5: Proportion of vulnerability augmentation connections in the enhanced Impact Chain

4.3. Derived impacts

When augmented, certain vulnerabilities can ~~act like~~function similarly to impacts, ~~and reinfor~~reinforcing~~ee~~ the very impact that initially increased the vulnerability ~~in the first place~~, forming a positive loop feedback composed of "deepens/shifts" links and "sharpens" links. Such augmented vulnerabilities with double status were ~~doubled~~ duplicated in the enhanced Impact Chain and ~~called~~ labelled as "derived impacts", as detailed in Appendix B. Some vulnerabilities underwent multiple transformations into derived impacts because they acted as (derived impacts) in relation to more than one augmentation-generator impact (Figure 6). This resulted~~, resulting~~ in a larger number of cases where the augmentation of a vulnerability created a derived impacts (15 cases)~~,~~ compared to the number of actual derived impacts (9) in the chain. ~~The explanation lies in the fact that multiple impacts can augment the same vulnerability, creating also a derived impact that reinforce the impact that generated the augmentation.~~ The vulnerabilities that also act as derived impacts were~~:~~: low-performance medical system (reinforced as a derived impact 3 times), insufficient medical personnel (3 times), insufficient COVID-19 testing capacity (2 times), uncooperative population (2 times) (Figure 6). On the other hand, the vulnerability called households at short distance from the river, insufficient/ineffective hard engineering infrastructure/measures, improper mapping and visualisation of affected areas, lack of equipment for first responders (including protective gear), and work overload on first responders were transformed into derived impacts only once.

Of the vulnerabilities that also act as derived impacts, 45~~4.44~~% pertain to floods, 33~~.33~~% to the pandemic, and 22~~.22~~% to both hazards. More than half (60%) of the derived impacts are associated with "deepens" connections, suggesting that the augmentation of the vulnerabilities and their subsequent reinforcement as derived impacts are mostly related to the same hazard. All the identified derived impacts are detailed in Appendix B, with the focus in this section limited to the most significant ones (Figure 6).

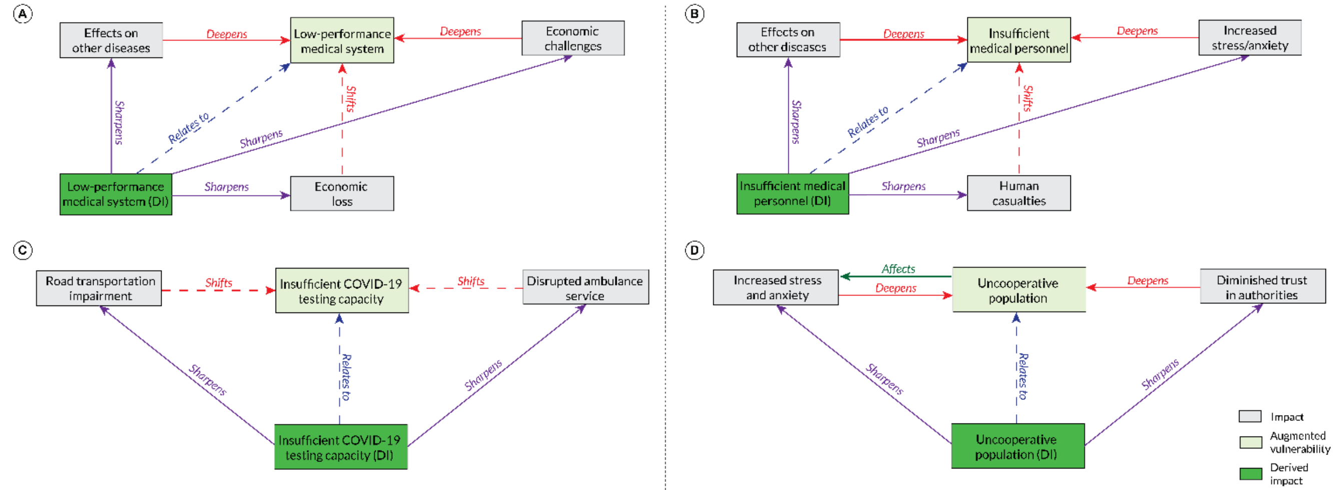

Figure 6. The augmented vulnerabilities that function as derived Impacts (DI) more than once linked through sharpens connections to the impacts that generated the augmentation

The augmentation of the low-performance medical system was caused by the effects of the pandemic on other diseases, the economic loss caused by both floods and the pandemic, and the economic challenges brought by the pandemic (Appendix B, Figure 6A)~~(Appendix B)~~. In the first instance, the COVID-19 pandemic delayed the provision of treatment for certain diseases (Cucu et al. 2021, Dionisie et al. 2022, Barbos et al. 2023), or accelerated the progression of diseases like kidney pathology (Trifanescu et al. 2022, Mureșan et al. 2022, Tudora et al. 2023). These circumstances exerted additional strain on the already suboptimal medical system, contributing to the exacerbation of other health issues. In addition, the economic loss and the pandemic-related economic challenges have the potential to perpetuate the underfunding of the medical system, with negative effects on its performance. In return, the underperforming medical system is a cause of both economic loss (due to treatment delays and shortages of medical and human resources) and economic challenges stemming from its coping ineffectiveness.

The augmentation of insufficient medical personnel was linked to impacts like human casualties, the effects of the pandemic on other diseases, and increased stress or anxiety (Appendix B, Figure 6B). The victims of COVID-19 included healthcare staff that became infected with the virus while attending to COVID-19 patients, which deepened the shortage of personnel and subsequently significantly altered their capacity to provide life-saving healthcare to the thousands of patients in need, therefore increasing the human death toll. Similarly, the surge in workload for medical personnel, resulting from aggravated diseases against the COVID-19 pandemic, limited the availability of healthcare staff dedicated to tending to COVID-19 patients. Consequently, the insufficient number of healthcare personnel negatively affected the development of certain diseases, as timely and appropriate treatment was not administered. Lastly, the increased stress/anxiety temporarily affected the mental health and wellbeing of the medical staff, necessitating ~~temporary~~ breaks in their duties. The temporary unavailability of their colleagues heightened the stress/anxiety levels among the remaining healthcare professionals, as well as among the general public, who was aware of the scarcity of medical human resources during critical times.

The insufficient COVID-19 testing capacity was augmented by the road transportation impairment resulting from floods and also by the disrupted ambulance service (Appendix B, Figure 6C). During and immediately after floods, people were precluded from reaching COVID-19 testing centres, and ambulances were prevented from reaching the people who requested to be tested at home. Both of these obstructions limited the testing capacity. In return, the limited testing capacity at the local scale forced the people to undertake road journeys to the available testing centres located in other settlements, sometimes at great distances, resulting in traffic jams in numerous places and occasions.

In the analysed multi-hazard case study, the population became even more uncooperative because of the diminished trust in authorities and the increased stress/anxiety associated with both floods and the pandemic (Appendix B, Figure 6D). The lessened credibility of authorities can be traced back to ~~the~~ faulty pandemic management and the lockdown imposed in March-May 2020 (Džakula et al. 2022), and also to the economic problems resulting from both hazards. This increased reluctance to collaborate with first responders and authorities also undermined trust in authorities, establishing a positive feedback loop. Amid flood-related interventions, the escalation of stress or anxiety levels can make people fearful and less willing to collaborate with first responders, hindering rescue or evacuation operations. Conversely, this reluctant attitude of the population and the associated difficulties can increase the stress/anxiety of first responders on duty.

4.4. Ranking of augmented vulnerabilities

The last part of the analysis is dedicated to the ranking of augmented vulnerabilities under the proposed statistical approach, with the goal of pinpointing those vulnerabilities expected to experience the most substantial increase. By building augmentation links between impacts and vulnerabilities (i.e., deepens, shifts) and between adaptation options and vulnerabilities (i.e., rebounds, creates negative externalities), we can identify which vulnerabilities are expected to increase in the future and because of what causes. The increase in vulnerability refers to those levels of vulnerability that are expected to be higher in the future, providing the next hazardous events will lead to similar impacts, and that similar adaptation options will be implemented to mitigate those vulnerabilities.

This ranking, along with the corresponding computational values, ~~are~~ is depicted in Table 2. The top 3 augmented vulnerabilities were: the uncooperative population, the low-performance medical system, and flood management not adapted to the COVID-19 context. The first and third are multi-hazard vulnerabilities that correspond to both floods and the pandemic, while the low-performance medical system is specific to the pandemic. In terms of type, the most augmented vulnerability relates to coping deficiencies, while the next two pertain either to medical ~~management~~ or emergency management failures. As for the scale of manifestation, the uncooperative population is a local-level vulnerability, while the other two manifest at a broader, national scale.

The above ~~said~~ -mentionedvulnerabilities were followed by other management-related vulnerabilities, like the insufficient medical personnel, the lack of equipment for first responders, the shallow implementation of preventive measures, the insufficient COVID-19 testing capacity or ICU capacity, and the work overload on first responders, most of them relating to the COVID-19 pandemic (Table 2). The least augmented vulnerabilities are specific to the flood hazard (i.e., defective coordination of first responders from multiple counties, deforestation, households at short distance from the river, etc.).

When looking at the augmentation produced by impacts, the ranking resembles the final one (Table 2), which is expected due to the 70% weight of the impacts-vulnerability augmentation connections. The difference is that the flood management not adapted to the COVID-19 context, the insufficient medical personnel, and lack of equipment for first responders were augmented by impacts to equal extents, which also holds true for the next four vulnerabilities (Table 2). On the other hand, the vulnerabilities that were most augmented by adaptation options (to equal extents) were the shallow implementation of preventive measures and the absence of preparedness at individual level. In the ranking of augmented vulnerabilities by adaptation options, these were followed by the uncooperative population and flood management not adapted to the COVID-19 context, which both occupy the third place (Table 2). All ~~of~~ the other vulnerabilities were not augmented by adaptation options.

Although not augmented, ~~T~~the vulnerabilities at the bottom of Table 2 ~~were not augmented; however, they~~ bear the potential for escalation due to the fact that they were not addressed by any adaptation options: assets at short distance from river, depleted capacity due to seasonal patterns of hazards, development of ~~infrastructure or~~ inhabited areas or infrastructure in flood-prone areas, improper governance structure for effective flood management, ineffective sewage system, and low quality construction materials. Except for the depleted capacity due to seasonal patterns of hazards, all of these are specific to floods.

Table 2. Ranking of vulnerabilities based on their augmentation. I – Impact, V – Vulnerability, Ao – Adap~~a~~tation option

Vulnerability	No. of I-V augmentation connections	No. of Ao-V augmentation connections	Z-score I-V	Z-score Ao-V	Rank Z-score I-V	Rank Z-score Ao-V	Weighted rank	Final rank
Uncooperative population	5	1	2.640	1.310	1	3	0.8	1
Low-performance medical system	4	0	1.918	-0.393	2	5	1.45	2
Flood management not adapted to the COVID-19 context	3	1	1.195	1.310	3	3	1.5	3
Insufficient medical personnel	3	0	1.195	-0.393	3	5	1.8	4
Lack of equipment for first responders (including protective gear)	3	0	1.195	-0.393	3	5	1.8	4
Shallow implementation of preventive measures	2	2	0.472	3.014	6	1	2.25	6
Insufficient COVID-19 testing capacity	2	0	0.472	-0.393	6	5	2.85	7
Insufficient ICU capacity (e.g., no. of beds, ventilators, O2 supply)	2	0	0.472	-0.393	6	5	2.85	7
Work overload on first responders	2	0	0.472	-0.393	6	5	2.85	7
Improper mapping and visualisation of affected areas	2	0	0.472	-0.393	6	5	2.85	7
Defective coordination of first responders from multiple counties	1	0	-0.250	-0.393	11	5	4.6	11
Deforestation	1	0	-0.250	-0.393	11	5	4.6	11
Households at short distance from the river	1	0	-0.250	-0.393	11	5	4.6	11
Insufficient/ineffective hard engineering infrastructure/measures	1	0	-0.250	-0.393	11	5	4.6	11
Long shifts of first responders	1	0	-0.250	-0.393	11	5	4.6	11
Poverty, especially in uneducated/roma/migrant population	1	0	-0.250	-0.393	11	5	4.6	11
Significant psychological tension of first responders	1	0	-0.250	-0.393	11	5	4.6	11
Absence of preparedness at individual level	0	2	-0.973	3.014	18	1	6.45	18
Assets at short distance from river	0	0	-0.973	-0.393	18	5	7.05	19
Depleted capacity due to seasonal patterns of hazards	0	0	-0.973	-0.393	18	5	7.05	19
Development of infrastructure in flood prone areas	0	0	-0.973	-0.393	18	5	7.05	19
Development of inhabited areas in flood prone areas	0	0	-0.973	-0.393	18	5	7.05	19
Improper governance structure for effective flood management	0	0	-0.973	-0.393	18	5	7.05	19
Ineffective institutional communication	0	0	-0.973	-0.393	18	5	7.05	19

Ineffective sewage system	0	0	-0.973	-0.393	18	5	7.05	19
Low quality construction materials	0	0	-0.973	-0.393	18	5	7.05	19
Average (m)	1.346	0.231						
Standard deviation (SD)	1.384	0.587						

5 Discussion

The current study stands at the forefront of research, bringing into the spotlight the potential increase in vulnerability within the unprecedented co-occurrence of the COVID-19 pandemic and the multiple flood events that affected Romania in 2020-2021. The configuration of the Impact Chain shows a convoluted multi-hazard, where certain hazard impacts and adaptation options have an augmentation effect on underlying vulnerabilities. In return, some of the augmented vulnerabilities also act as derived impacts that reinforce the very impacts that increased vulnerability in the first place. In this sense, both hazards and what we do to mitigate them can be considered indirect generators of changes in vulnerability, with deep implications for how we approach multi-risk management.

In the presented case study, the enhanced Impact Chain shows that vulnerability is expected to increase based on the augmentation in different forms conveyed by the new links, as 69.23% of vulnerabilities were augmented either by impacts and/or backfiring adaptation options. Another expected path to increasing vulnerability is related to the limited range of adaptation options that address vulnerabilities, as only a third of them were addressed by any adaptation optionsmitigation measures. This means that 1) the unforeseen implications of impacts that act as vulnerability enhancers, 2) wrongful action intended to mitigate vulnerability and/or impacts, and 3) inaction can set the premises for increased vulnerability levels that will render multi-risk management more difficult (Figure 67).

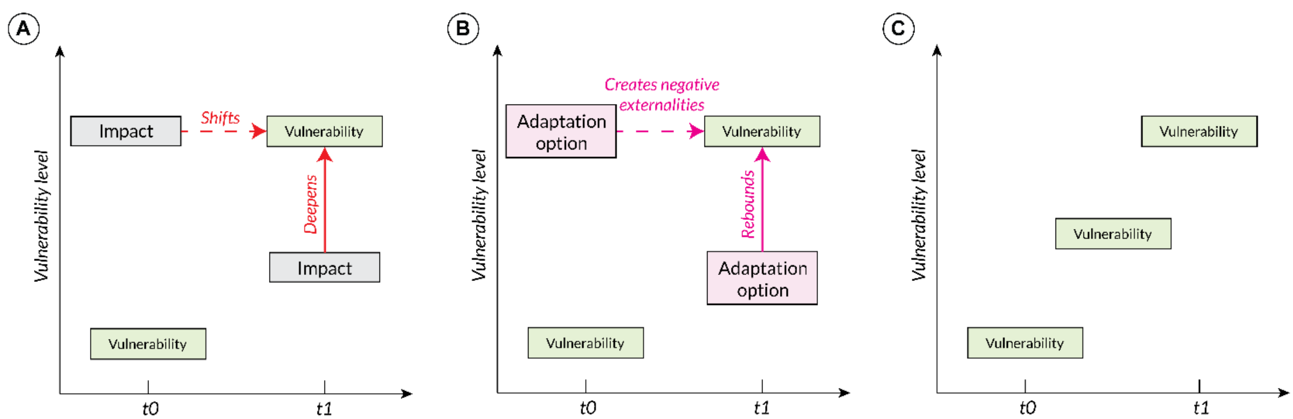

Figure 67: Conceptual paths of rising vulnerability: A – Augmentation of vulnerability resulting from hazard impacts, B – Augmentation of vulnerability resulting from misfiring adaptation options, C – Perpetuation of vulnerability due to inaction. t0 – Present moment, t1 – Future moment

5.1. Conceptual paths of rising vulnerability

The first conceptual path refers to the impacts of the flood events and the pandemic (Figure 6A7A). These mainly reinforce deeply rooted vulnerabilities, like the reluctance of the population to collaborate with first responders and/or authorities (Fekete et al. 2023), or the low-performance of the Romanian medical system that is largely reported in the literature (OECD 2021, Lupu and Tiganasu 2022, Popescu et al. 2022). The top 3 most impact-augmented vulnerabilities also includes the deficiency in aligning flood management with pandemic conditions (Table 2), which ~~was~~ can be associated with local increases in the COVID-19 new cases (Albulescu 2023) and is expected to cause further issues in similar future multi-hazard scenarios unless amended. Other top impact-augmented vulnerabilities are related to medical or emergency management failures (i.e., insufficient medical personnel, lack of equipment for first responders). All of the above said vulnerabilities were addressed by various adaptation options, but most of them produced short-term effects and were not part of larger vulnerability reduction schemes. Several examples are the on-the-spot clever solutions brought up by first responders to engage with the uncooperative population, the hiring of additional medical staff and volunteers during the pandemic, and the support received by Romania from other countries in terms of medical resources.

The second line along which the augmentation vulnerability propagates is established between the adaptation options that misfire and end up increasing vulnerabilities (Figure ~~6B~~7B). The most augmented vulnerabilities in this regard concern the preparedness phase of DRM: the shallow implementation of preventive measures against the COVID-19 pandemic and the absence of preparedness at individual level when confronted with floods (Table 2). In Romania, the~~The~~ low level of preparedness was associated with an external locus of control (Armaș 2008, Armaș et al. 2015, Albulescu et al. 2021), and it was also reported by first responders who performed interventions during the floods of 2020-2021 (Fekete et al. 2023). Th~~is~~e analysis unravels the possibility that these coping capacity-related vulnerabilities can evolve into (vulnerability) drivers. Against this background, a major gap emerges between the efforts undertaken by first responders in the response phase, and the lack of interest on the part of citizens, who take no or little action to prepare to withstand floods or to prevent the spread of the SARS-CoV-2 virus during the preparedness phase.

Another thing to consider is that the top 3 impact-augmented vulnerabilities are the same as the ones that rank vulnerabilities based on the combined augmentation effects of impacts and adaptation options. However, the vulnerabilities that were augmented by both impacts and adaptation options (to different extents) are the uncooperative population, the lack of adaptation of flood management to pandemic conditions, and the shallow implementation of preventive measures against the pandemic (Table 2). In future multi-risk management plans, special emphasis should be placed on addressing these vulnerabilities, particularly given that the first two are related to both hazards.

The third conceptual path of increasing vulnerability is through inaction (Figure ~~6C~~7C), standing out since the number of vulnerabilities (26) is two times larger than the ones of adaptation options (13), and only about a third of the vulnerabilities were targeted by adaptation options. When looking at the entire enhanced Impact Chain, a striking imbalance is highlighted: most flood-related mitigation efforts focused on impacts rather than vulnerabilities, while pandemic-related adaptation options primarily addressed vulnerabilities rather than pandemic impacts. The only flood-related vulnerability addressed by adaptation options is the improper mapping and visualisation of affected areas. This means that human communities might be equally or more vulnerable to floods in the future. What is more, even the adaptation options that mitigated the flood impacts mostly provide short-term solutions (e.g., the heightening of river banks with sand banks to prevent or limit the flooding of houses or households) or have negative unforeseen effects (e.g., the RO-Alert SMS messages or the hydrological warnings that can reduce the motivation of the people who are not located in an area affected by a particular flood event to prepare for future floods or to undertake COVID-19 prevention measures, as described in Appendix B).

On the contrary, many of the key pandemic vulnerabilities were tackled by adaptation options (e.g., low-performance medical system, insufficient medical personnel, insufficient ICU capacity), and the same can be stated for multi-hazard vulnerabilities (e.g., flood management not adapted to the COVID-19 context, ineffective institutional communication, lack of equipment for first responders, uncooperative population) (Appendix A). Nevertheless, the brighter perspective described here is overshadowed by the fact that the very same vulnerabilities (except the ineffective institutional communication) were augmented by hazard impacts and/or adaptation options.

This approach leaves deeply engrained vulnerabilities to floods unaltered (e.g., the location of households and/or assets at short distance from the river, the improper governance structure for effective flood management, the shallow implementation of the absence of individual flood preparedness), but ready to resurface during future hazardous events. In other words, the implemented adaptation options belong to the response and/or recovery phase of the DRM, and no initiatives have been undertaken in the preparedness phase. What is worse, as argued above, certain adaptation options augment the two prominent vulnerabilities specific to the preparedness phase (e.g., the shallow implementation of COVID-19 preventive measures, and the absence of individual flood preparedness measures).

The reactive approach is typical to developing societies, or to the early, one-dimensional flood management approach (Scott et al. 2013), being complemented by an external locus of control of the population (Armaș 2008, Armaș et al. 2015). Sound risk mitigation requires factoring in preparedness for future hazards into the recovery process (Johnson and Jensen 2023), all with a high degree of flexibility (White and Haughton 2017), but such efforts were absent in the presented case study. Therefore, the unbalanced DRM-phase distribution of the adaptation options holds prominent implications for the dynamics of vulnerability~~ies~~ in the sense that it allows it~~them~~ to perpetuate and further contribute to future hazard impacts.

Another aspect to ponder is that the depleted capacity due to seasonal patterns of hazards, although not augmented, was not addressed by any adaptation options. Both floods and pandemic waves follow seasonal patterns, allowing human communities to prepare for their impacts (to some extent) by following a predictive but tight timeline. Considering the unaddressed vulnerabilities together with the short~~-~~sighted nature of the adaptation options, human communities affected by the COVID-19 pandemic did not fully recover until the occurrence of floods, or until the next pandemic wave, or perhaps not even from one flood event to the next. In this context, it can be expected that the overall vulnerability level will increase, since the recovery process is not only slow (de Ruiter and van Loon) but also fragmented.

The short time intervals between pandemic waves, which unfold during the cold months of the year (Figure 2), and the clusters of flood events at the end of spring and beginning of summer require expedited mitigation efforts and updated multi-risk management plans that account for the particularities of the co-occurrent hazards. This holds particular importance since the most prominent adaptation option is the great capacity of first responders to develop creative solutions in crisis and cope with new challenges. This is the only adaptation option that mitigates multiple top-level~~,~~ augmented vulnerabilities that pertain to both hazards: the uncooperative population, flood management not adapted to the COVID-19 context, lack of equipment for first responders including protective gear, and ineffective institutional communication. The umbrella adaptation option covers a large spectrum of mitigation actions thought about and implemented by first responders on the spot, to cover for the lack of resources or specific protocols. This means that there are no adaptation options that account for the challenges imposed by the two independent but co-occurrent hazards, highlighting a lack of vision of the current risk management plans applied in Romania.

5.2. Contribution and novelty

Although vulnerability dynamics has gained traction over the last decades, ~~I~~interest in vulnerability dynamics within multi-hazard contexts has surfaced since 2020, and discussions have remained at a theoretical level (de Ruiter and Van Loon 2022), with no case study up to date. Moreover, few studies investigated the interactions between flood hazards and the COVID-19 pandemic (Simonovic et al. ~~2020~~2021, Patwary and Rodriguez-Morales 2021, Pramanik et al. 2021, Turay 2022). This paper addresses a double research gap, aiming to advance our understanding of both vulnerability variations against a multi-hazard background and of compound~~ed~~ impacts of the two hazards of interest.

The methodological framework proposed to reach this goal carries multiple elements of novelty, as it enhances the Impact Chain to account for the fluctuations in vulnerability by establishing new elements and connection types and taking an in-depth look at the double status of certain augmented vulnerabilities (i.e., those that also act as derived impacts). The enhanced Impact Chain is a readily available operational tool suitable for replication across various multi-hazard, timeframes, scales, and geographic settings. This ~~improved~~ upgraded version of the chain can extend the list of methods for vulnerability dynamics modelling put together by de Ruiter and Van Loon (2022), also emerging as a solution to the issue raised by Tilloy et al. (2019): "We believe there is a need to not only study case studies inclusive of multi-hazard interrelationships but to generalise to more inclusive frameworks that are applicable to a broad range of hazards and locations." The dual functionality highlights the capability of the methodological framework to account for both changes in vulnerability and the ~~intricacies~~ interconnectivity of multi-hazard impacts.

It should be noted that the present analysis on the augmentation of vulnerability against a multi-hazard background is an initial research work. Prospective avenues for research include the development of a model of systemic vulnerability in a multi-hazard context, which will be tested on multiple Impact Chains, including the enhanced one discussed in this study, to further validate its effectiveness and applicability.

5.3. Limitations and constraints

Pursuing scientific rigour and transparency, the limitations of the study have to be acknowledged too. The case study aimed for a comprehensive analysis of the multi-hazard of interest, drawing on various data and information sources. However, this is only as comprehensive as possible, given the fact that there are no official sources that detail the impact of flood events. Also, the exact quantification of the impacts is constrained by the lack of official data. Along the same lines, the absence of information on the COVID-19 preventive measures implemented during flood evacuation procedures and inside emergency shelters raises uncertainties that are integrated into the Impact Chain. Another shortcoming concerns the limited time range, that does not cover the entire pandemic period but only its first two years. It should be mentioned that 2022 was a dry year in Romania (Iuga 2022, Toreti et al. 2022a, b), implying that flood occurrences were scarce. In addition, Albulescu (2023) reports no flood events that required the evacuation of the population in the first 8 months of 2022 (including the flood season in Romania). A fourth limitation regards the tangled configuration of the Impact Chains, which does not allow for a figure-based visualisation in the paper. Nevertheless, the visualisation available via the Kumu link holds the advantage of interactive manipulation of connections and elements, as well as access to the descriptions, source types, references, maps, and images embedded in the Impact Chains. A~~Nevertheless, a~~ comprehensive understanding of the paper is facilitated by engaging with the online platform.

The implication of stakeholders in the construction of the multi-hazard Impact Chain is limited to the feedback provided by first responders who performed on-site emergency interventions during the floods of 2021 (Fekete et al. 2023). Future research directions focus on a broader involvement of different stakeholders in order to maximise the benefits of co-produced knowledge and refine the details specific to the multi-hazard context from a transdisciplinary perspective. A notable methodological limitation refers to the lack of testing against other case studies and external validation; which we plan to address in the future by applying the methodological framework to other Impact Chains focusing on different multi-hazard situations~~case studies~~. Finally, the paper provides a limited view on the dynamics of vulnerability, relying only on two temporal pictures captured by the initial Impact Chain and the enhanced version of it. In the future, the development of Impact Chains within the same multi-hazard context but for multiple years, and the tracking of the augmentation of vulnerability across multiple temporal snapshots will yield more nuanced results that can also be validated with narratives from grey literature. Some of these methodological limitations are inherent to Impact Chain-based analyses, as highlighted in the literature review performed by Menk et al. (2022).

6 Conclusions

Since the start of the decade, the co-occurrence of natural hazards amid the COVID-19 pandemic put us in front of unparalleled challenges that demanded a new way of approaching multi-risk~~hazard~~ management and adaptability to both public health crisis and the impacts of various natural hazards. This increase in multi-hazard frequency ta~~ho~~ught us valuable lessons that we still have to study in order to reduce our vulnerability in the face of future similar multi-hazard events.

~~Here, w~~We posit that particular ~~emphasis should be placed~~attention should be dedicated to ~~on~~ understanding the dynamics of vulnerability within a multi-hazard context, and that we still have to develop the tools for analysis focusing on the fluctuations of vulnerability across hazards, time, and space. In pursuit of this goal, we enhanced the Impact Chain regarding the multi-hazard of the floods and COVID-19 pandemic that affected Romania in 2020-2021, transforming it from a documentation tool to ~~a~~ one that can capture the dynamics of vulnerability. The main enhancements are: the introduction of ~~of new types of elements (i.e., augmented vulnerabilities, derived impacts),~~ new types of connections between the impacts/adaptation options and vulnerabilities, of new types of elements (i.e., augmented vulnerabilities, derived impacts), and the ranking of vulnerabilities based on their augmentation. The key findings of the paper can be summarised as follows:

- In a multi-hazard context, vulnerability can be augmented by both impacts and adaptation options in ways that can be captured by an Impact Chain, but it can also perpetuate over time due to inaction to address it.
- Certain augmented vulnerabilities can also ~~be considered~~function as impacts (here called “derived impacts”) that sharpen the impact that initiated the augmentation of that vulnerability in the first place.
- In the case study of the floods and the COVID-19 pandemic in Romania (2020-2021), vulnerability is augmented mostly by hazard impacts and, to a lesser extent, by adaptation options. This is explained mainly by the surface-level approach to multi-hazard management, which lacks sufficient integration of adaptation options capable ~~to generate~~of generating positive or negative effects on vulnerabilities.
- The most augmented vulnerabilities (by both impacts and adaptation options) in the proposed Impact Chain are: uncooperative population, low-performance medical system, and flood management not adapted to the COVID-19 context.
- The most augmented vulnerabilities by adaptation options alone (i.e., shallow implementation of preventive measures and absence of preparedness at individual level) show that ~~adaptation options~~the implemented mitigation strategies can undermine preparedness ~~to~~for both floods and ~~the~~ pandemics.

These results reinforce the idea that old ways will not solve new or reinforced problems and that a proper understanding of all components of multi-risk – and especially of those that can be mitigated (i.e., impacts and vulnerabilities), is the key to improving multi-risk management. The Impact Chain brings to light the shallow approach of multi-hazard management in Romania, which fails to cover all three DRM phases (i.e., preparedness, response, recovery) or to account for the co-occurrence of multiple hazards and to raise to the challenges faced in~~of~~ the last few years. Such situations motivate the need for improved “multi-hazard approach and inclusive risk-informed decision-making” mentioned in the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR 2015). Although such goals were set before the COVID-19 pandemic, their achievement is still an ongoing process, the progress of which hinges on our understanding of the dynamics of multi-hazard vulnerability.

Data availability. The data can be provided by the authors upon reasonable request.

Author contributions. ACA and IA contributed equally to this study during all stages: conceptualisation, Impact Chain construction, ranking, calibration, visualisation, writing the first draft, editing, and validation.

Competing interests. The authors declare no conflict of interest.

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References

1. Albulescu, A. C.: Exploring the connections between flood events and COVID-19 infection cases in Romania in the new multi-hazard-prone era, Natural Hazards, 117(2), 1611–1631, https://doi.org/10.5194/nh-117-1611-2023, 2023.

2. Albulescu, A. C., Larion, D., & Grozavu, A. Seismic risk perception and seismic adjustments in Vaslui City, Romania. Natural Hazards Review, 22(2), 05021005. https://doi.org/10.1061/(ASCE)NH.1527-6996.000045, 2021

3. Albulescu, A. C., Grozavu, A., Larion, D.: Transformations of the multi-hazard concept and its management under the COVID-19 pandemic (In Romanian). In: Turbulențe, discontinuități și adaptări teritoriale în Antropocen, "Alexandru Ioan Cuza" University of Iasi Publishing House, 43–62, 2022

~~4. Ali Maher, O.: Disaster management cycle and COVID-19 breaking the silos, Archives of Community Medicine and Public Health, 203–204, https://dx.doi.org/10.17352/acmph, 2021.~~

~~5.~~4. Alfieri, L., Burek, P., Feyen, L., & Forzieri, G.: Global warming increases the frequency of river floods in Europe, Hydrology and Earth System Sciences, 19(5), 2247–2260, https://doi.org/10.5194/hess-19-2247-2015, 2015.

~~6.~~5. Andrews, R. G.: What happens if a 'big one' strikes during the pandemic?, Atlantic Media Company, Available online: https://www.theatlantic.com/science/archive/2020/05/hurricane-earthquake-wildfire-tornado-disaster-pandemic/611455/, Accessed at 04.08.2023.

~~7.~~6. Armaş, I.: Natural risk perception: earthquakes, floods, landslides [In Romanian]. University of Bucharest Publishing House, Bucharest, Romania, 2008.

~~8.~~7. Armas, I., Ionescu, R., & Posner, C. N.: Flood risk perception along the Lower Danube River, Romania. Natural Hazards, 79, 1913-1931. https://doi.org/10.1007/s11069-015-1939-8, 2015

~~9. Asare, P., & Barfi, R.: The impact of the Covid-19 pandemic on the Global economy: emphasis on poverty alleviation and economic growth. Economics, 8(1), 32-43, https://orcid.org/0000-0001-8324-6521, 2021.~~

~~10.~~8. Ashraf, A.: Lessons learned from COVID-19 response for disaster risk management. Natural Hazards, 107(2), 2027-2032, https://doi.org/10.1007/s11069-021-04658-0, 2021.

~~11.~~9. Barbos, V., Feciche, B., Bratosin, F., Bogdan, I., Negrean, R. A., Latcu, S., ... & Cumpanas, A. A.: A Retrospective Analysis of the Challenges of Urothelial Cancer Management during the COVID-19 Pandemic at a Single Academic Center in Romania. Healthcare.. 11(6), 812. DOI: 10.3390/healthcare11060812, 2023.

~~12.~~10. Becker, D., K. Renner, & Schneiderbauer, S: Assessing and mapping climate change vulnerability with the help of GIS: Example of Burundi. GI_Forum 2014, Salzburg, Austria, Geospatial Innovation for Society, 101–104, 2014, Available at: http://austriaca.at/ 0xc1aa5576_0x0030d408.pdf., Accessed 19.02.2024

~~13. Begun, J. W., & Jiang, H. J.: Health care management during Covid-19: Insights from complexity science. NEJM Catalyst Innovations in Care Delivery, 1(5), DOI: 10.1056/CAT.20.0541, 2020.~~

~~14. Buheji, M., da Costa Cunha, K., Beka, G., Mavric, B., De Souza, Y. L., da Costa Silva, S. S., ... & Yein, T. C.: The extent of the COVID-19 pandemic socio-economic impact on global poverty: a global integrative multidisciplinary review. American Journal of Economics, 10(4), 213-224, doi:10.5923/j.economics.20201004.02, 2020.~~

~~15.~~11. CCR (Romanian Constitutional Court): Press release from the 15th of February 2022. Available online: https://www.ccr.ro/comunicat-de-presa-15-februarie-2022/, Accessed at 15.06.2023.

~~16.~~12. CDC: Long COVID or Post-COVID Conditions. Available online: https://www.cdc.gov/coronavirus/2019-ncov/long-term-effects/index.html.

~~17.~~13. Chendes, V., Balteanu, D., Micu, D., Sima, M., Ion, B., Grigorescu, I., Persu, M., Dragota, C. (2015): A database design of major past flood events in Romania from national and international inventories. Aerul si Apa. Componente ale Mediului. Available online: https://www.researchgate.net/profile/Viorel-Chendes/publication/275639288_A_database_design_of_major_past_flood_events_in_Romania_from_national_and_international_inventories/links/5540dec60cf2718618dba6ad/A-database-design-of-major-past-flood-events-in-Romania-from-national-and-international-inventories.pdf, Accessed at 03.09.2023.

~~18. Chua, A. Q., Tan, M. M. J., Verma, M., Han, E. K. L., Hsu, L. Y., Cook, A. R., ... & Legido-Quigley, H.: Health system resilience in managing the COVID-19 pandemic: lessons from Singapore. BMJ Global Health, 5(9), e003317, DOI: 10.1136/bmjgh-2020-003317, 2020.~~

~~19.~~14. Ciurean, R., Gill, J., Reeves, H. J., O'Grady, S., & Aldridge, T.: Review of multi-hazards research and risk assessments, 2018. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://nora.nerc.ac.uk/id/eprint/524399/1/OR18057.pdf

~~20.~~15. Constantin-Horia, B., Simona, S., Gabriela, P., Adrian, P.: Human factors in the floods of Romania. In: Jones, J.A.A. (ed) Threats to global water security: population growth, terrorism, climate change, or commercialisation? Springer, Dordrecht, 187–192, https://doi.org/10.1007/978-90-481-2344-5_20, 2009.

~~21.~~16. Constantinescu, Ş., Achim, D., Rus, I., & Giosan, L.: Embanking the Lower Danube: from natural to engineered floodplains and back. Geomorphic approaches to integrated floodplain management of lowland fluvial systems in North America and Europe, 265-288, DOI: 10.1007/978-1-4939-2380-9_11, 2015.

~~22.~~17. Cucu, A. M., Dima, C., Georgescu, D., & Bratu, E. C.: Access to tertiary mental health care services during the Covid-19 pandemic in Romania. Acta Medica Transilvanica, 26(2), 14-16. https://doi.org/10.2478/amtsb-2021-0024, 2021

~~23.~~18. Dankers, R., & Feyen, L.: Climate change impact on flood hazard in Europe: An assessment based on high-resolution climate simulations. Journal of Geophysical Research: Atmospheres, 113(D19), https://doi.org/10.1029/2007JD009719, 2008.

~~24.~~19. De Angeli, S., Malamud, B. D., Rossi, L., Taylor, F. E., Trasforini, E., & Rudari, R.: A multi-hazard framework for spatial-temporal impact analysis. International Journal of Disaster Risk Reduction, 73, 102829, 2022.

~~25.~~20. de Ruiter, M. C., Couasnon, A., van den Homberg, M. J., Daniell, J. E., Gill, J. C., & Ward, P. J.: Why we can no longer ignore consecutive disasters. Earth's future, 8(3), e2019EF001425, https://doi.org/10.1029/2019EF001425, 2020.

~~26.~~21. de Ruiter, M. C., Couasnon, A., & Ward, P. J.: Breaking the Silos: an online serious game for multi-risk disaster risk reduction (DRR) management, Geosci. Commun., 4, 383–397, https://doi.org/10.1004/s11069-015-2074-2, 2021a.

~~27.~~22. de Ruiter, M. C., de Bruijn, J. A., Englhardt, J., Daniell, J. E., de Moel, H., & Ward, P. J.: The asynergies of structural disaster risk reduction measures: Comparing floods and earthquakes. Earth's Future, 9(1), e2020EF001531, https://doi.org/10.1029/2020EF001531, 2021b.

~~28.~~23. de Ruiter, M. C., & Van Loon, A. F.: The challenges of dynamic vulnerability and how to assess it. IScience, 104720, https://doi.org/10.1016/j.isci.2022.104720, 2022.

~~29.~~24. Decree no. 195/2020, Decree no. 195/16.03.2020 concerning the establishment of Emergency State in Romania, Available online: https://legislatie.just.ro/Public/DetaliiDocumentAfis/223831, Accessed at 15.06.2023.

~~30.~~25. Digi24. Digi23 National News Portal, Available online: https://www.digi24.ro/, Accessed at 10.08.2023, 2023

~~31.~~26. Dionisie, V., Ciobanu, A. M., Moisa, E., Manea, M. C., & Puiu, M. G.:The Impact of the COVID-19 Pandemic on Inpatient Admissions for Psychotic and Affective Disorders: The Experience of a Large Psychiatric Teaching Hospital in Romania. Healthcare, 10(8),1570. DOI: 10.3390/healthcare10081570, 2022

~~32.~~27. Džakula, A., Banadinović, M., Lovrenčić, I. L., Vajagić, M., Dimova, A., Rohova, M., ... & Rechel, B.: A comparison of health system responses to COVID-19 in Bulgaria, Croatia and Romania in 2020. Health Policy, 126(5), 456-464. https://doi.org/10.1016/j.healthpol.2022.02.003, 2022.

~~33.~~28. EM-DAT. Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters (CRED), Query on natural hazard in the world 2020-July 2022. Available online: https://www.emdat.be/, Accessed at 17.07.2022, 2022

~~34.~~29. EM-DAT. Emergency Events Database (EM-DAT), Centre for Research on the Epidemiology of Disasters (CRED). Query on natural hazards in Romania 1900-2023. Available online: https://public.emdat.be/data. Accessed at 03.09.2023, 2023

~~35.~~30. Eurostat. Life expectancy decreased in 2020 across the EU, 2021. Available online: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20210407-1, Accessed at 10.06.2023, 2021

~~36.~~31. Fekete, A., Rufat, S., Armas, I., & Aslam, A.: Survey results on preparedness, coordination, and lived experience of first responders in Germany and Romania 2021. DIE ERDE–Journal of the Geographical Society of Berlin. https://doi.org/10.12854/erde-2023-654, 2023.

~~37.~~32. Frausto-Martínez, O., Aguilar-Becerra, C. D., Colín-Olivares, O., Sánchez-Rivera, G., Hafsi, A., Contreras-Tax, A. F., & Uhu-Yam, W. D.: COVID-19, storms, and floods: impacts of Tropical Storm Cristobal in the western sector of the Yucatan Peninsula, Mexico. Sustainability, 12(23), 9925, https://doi.org/10.3390/su12239925, 2020.

~~38.~~33. Gill, J. C., & Malamud, B. D.: Reviewing and visualizing the interactions of natural hazards. Reviews of Geophysics, 52(4), 680-722, https://doi.org/10.1002/2013RG000445, 2014.

~~39.~~34. Gill, J.C., Duncan, M., Ciurean, R., Smale, L., Stuparu, D., Schlumberger, J, de Ruiter M., Tiggeloven, T., Torresan, S., Gottardo, S., Mysiak, J., Harris, R., Petrescu, E. C., Girard, T., Khazai, B., Claassen, J., Dai, R., Champion, A., Daloz, A. S., … Ward, P.: MYRIAD-EU D1.2 Handbook of Multi-hazard, Multi-Risk Definitions and Concepts. H2020 MYRIAD-EU Project, Grant Agreement number 101003276, 2022.

~~40. Haldane, V., De Foo, C., Abdalla, S. M., Jung, A. S., Tan, M., Wu, S., ... & Legido-Quigley, H.: Health systems resilience in managing the COVID-19 pandemic: lessons from 28 countries. Nature Medicine, 27(6), 964-980, https://doi.org/10.1038/s41591-021-01381-y, 2021.~~

~~41. Haldane, V., & Morgan, G. T.: From resilient to transilient health systems: the deep transformation of health systems in response to the COVID-19 pandemic. Health Policy and Planning, 36(1), 134-135, DOI: 10.1093/heapol/czaa169, 2021.~~

~~42.~~35. Han, J., & He, S.: Urban flooding events pose risks of virus spread during the novel coronavirus (COVID-19) pandemic. Science of the Total Environment, 755, 142491. https://doi.org/10.1016/j.scitotenv.2020.142491, 2021.

~~43.~~36. HANZE v2.1. River flood in Romania, 2020. Available online: https://naturalhazards.eu/details,16960, Accessed 01.12.2023, 2023

~~44. Hariri-Ardebili, M. A.: Living in a multi-risk chaotic condition: pandemic, natural hazards, and complex emergencies. International Journal of Environmental Research and Public Health, 17(16), 5635, DOI: 10.3390/ijerph17165635, 2020.~~

~~45.~~37. Hariri-Ardebili, M. A., Sattar, S., Johnson, K., Clavin, C., Fung, J., & Ceferino, L.: A perspective towards multi-Hazard resilient systems: natural hazards and pandemics. Sustainability, 14(8), 4508, https://doi.org/10.3390/su14084508, 2022.

~~46.~~38. Hettiarachchi, S., Wasko, C., & Sharma, A.: Increase in flood risk resulting from climate change in a developed urban watershed–the role of storm temporal patterns. Hydrology and Earth System Sciences, 22(3), 2041-2056. https://doi.org/10.5194/hess-22-2041-2018, 2018.

~~47.~~39. Hewitt, K., & Burton, I.: The hazardousness of a place: a regional ecology of damaging events. University of Toronto Press, Toronto, 1971.

~~48.~~40. HSRM (COVID-19 Health System Response Monitor). Romania: Physical infrastructure. Available online: https://eurohealthobservatory.who.int/monitors/hsrm/all-updates/hsrm/romania/physical-infrastructure, Accessed at 10.06.2023, 2021a

41. HSRM (COVID-19 Health System Response Monitor). Romania: Workforce. Available online: https://eurohealthobservatory.who.int/monitors/hsrm/all-updates/hsrm/romania/workforce, Accessed at 10.06.2023, 2021b

~~49.~~42. IPCC: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014a.

~~50.~~43. IPCC: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. V. R. Barros et al., Eds., Cambridge University Press, 2014b, Available online: https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartB_FINAL.pdf, Accessed 19.02.2024.

~~51.~~44. Ishiwatari, M., Koike, T., Hiroki, K., Toda, T., & Katsube, T.: Managing disasters amid the COVID-19 pandemic: Approaches of response to flood disasters. Progress in Disaster Science, 6, 100096, https://doi.org/10.1016/j.pdisas.2020.100096, 2020.

~~52.~~45. Iuga, F.: Official data: 2022, the driest year in Romania, warn the meteorologists. Press Article. AgroTV. Available online: https://agro-tv.ro/2022-cel-mai-secetos-an-avertizeaza-meteorologii/, Accessed 10.10.2023, 2022

~~53.~~46. Izumi, T., & Shaw, R.: A multi-country comparative analysis of the impact of COVID-19 and natural hazards in India, Japan, the Philippines, and USA. International Journal of Disaster Risk Reduction, 73, 102899, https://doi.org/10.1016/j.ijdrr.2022.102899, 2022.

~~54.~~47. Johnson, T., & Jensen, J.: "Have a kit, make a plan, and be informed": Does the recovery literature support our pervasive understanding of preparedness?. International Journal of Disaster Risk Reduction, 103897, https://doi.org/10.1016/j.ijdrr.2023.103897, 2023.

~~55.~~48. Kassegn, A., & Endris, E.: Review on socio-economic impacts of 'Triple Threats' of COVID-19, desert locusts, and floods in East Africa: Evidence from Ethiopia. Cogent Social Sciences, 7(1), 1885122, https://doi.org/10.1080/23311886.2021.1885122, 2021.

~~56. Kaye, A. D., Okeagu, C. N., Pham, A. D., Silva, R. A., Hurley, J. J., Arron, B. L., ... & Cornett, E. M.: Economic impact of COVID-19 pandemic on healthcare facilities and systems: International perspectives. Best Practice & Research Clinical Anaesthesiology, 35(3), 293-306, DOI: 10.1016/j.bpa.2020.11.009, 2021~~

~~57. Kruczkiewicz, A., Klopp, J., Fisher, J., Mason, S., McClain, S., Sheekh, N. M., ... & Braneon, C.: Compound risks and complex emergencies require new approaches to preparedness. Proceedings of the National Academy of Sciences, 118(19), e2106795118, https://doi.org/10.1073/pnas.210679511, 2021.~~

~~58.~~49. Kumu. General presentation, Available online: https://kumu.io/, Accessed at 10.08.2023, 2023

~~59.~~50. Lupu, D., & Tiganasu, R. COVID-19 and the efficiency of health systems in Europe. Health Economics Review, 12(1), 1-15. https://doi.org/10.1186/s13561-022-00358-y, 2022

~~60.~~51. Majumdar, B., & DasGupta, S.: Let Bengal be heard: dealing with Covid and cyclone Amphan together. South Asian History and Culture, 11(3), 317-322, https://doi.org/10.1080/19472498.2020.1780063, 2020.

~~61.~~52. Mangubhai, S., Nand, Y., Reddy, C., & Jagadish, A.: Politics of vulnerability: Impacts of COVID-19 and Cyclone Harold on Indo-Fijians engaged in small-scale fisheries. Environmental Science & Policy, 120, 195-203, https://doi.org/10.1016/j.envsci.2021.03.003, 2021.

~~62. Matenge, S., Sturgiss, E., Desborough, J., Hall Dykgraaf, S., Dut, G., & Kidd, M.: Ensuring the continuation of routine primary care during the COVID-19 pandemic: a review of the international literature. Family Practice, 39(4), 747-761, DOI: 10.1093/fampra/cmab115, 2022.~~

~~63.~~53. Mavroulis, S., Mavrouli, M., Carydis, P., Agorastos, K., & Lekkas, E.: The March 2021 Thessaly earthquakes and their impact through the prism of a multi-hazard approach in disaster management. Bulletin of the Geological Society of Greece, 58, 1-36, https://doi.org/10.12681/bgsg.26852, 2021a.

~~64.~~54. Mavroulis, S., Mavrouli, M., & Lekkas, E.: Geological and hydrometeorological hazards and related disasters amid COVID-19 pandemic in Greece: Post-disaster trends and factors affecting the COVID-19 evolution in affected areas. Safety Science, 138, 105236, https://doi.org/10.1016/j.ssci.2021.105236, 2021b.

~~65.~~55. Mavroulis, S., Mavrouli, M., Kourou, A., Thoma, T., & Lekkas, E.: Multi-hazard emergency response for geological hazards amid the evolving COVID-19 pandemic: good practices and lessons learned from earthquake disaster management in Greece. Sustainability, 14(14), 8486, https://doi.org/10.3390/su14148486, 2022.

~~66.~~56. Mecenas, P., Bastos, R. T. D. R. M., Vallinoto, A. C. R., & Normando, D.: Effects of temperature and humidity on the spread of COVID-19: A systematic review. PLoS one, 15(9), e0238339. https://doi.org/10.1371/journal.pone.0238339, 2020.

57. Menk, L., Terzi, S., Zebisch, M., Rome, E., Lückerath, D., Milde, K., & Kienberger, S.: Climate change impact chains: a review of applications, challenges, and opportunities for climate risk and vulnerability assessments. Weather, Climate, and Society, 14(2), 619-636, 2022, https://doi.org/10.1175/WCAS-D-21-0014.1

~~67.~~58. Meteo Romania: Annual Report of the National Meteorological Asministration of Romania 2020, 2020, Available at: https://www.meteoromania.ro/despre-noi/raport-anual/raport-anual-2020/, Accessed at 18.02.2024

~~68.~~59. Meteo Romania: Annual Report of the National Meteorological Asministration of Romania 2021, 2021 Available at: https://www.meteoromania.ro/despre-noi/raport-anual/raport-anual-2021/, Accessed at 18.02.2024

~~69.~~60. Mishra, A., Bruno, E., & Zilberman, D.: Compound natural and human disasters: Managing drought and COVID-19 to sustain global agriculture and food sectors. Science of the Total Environment, 754, 142210, https://doi.org/10.1016/j.scitotenv.2020.142210, 2021.

~~70.~~61. Mohammadi, S., De Angeli, S., Boni, G., Pirlone, F., & Cattari, S.: Current approaches and critical issues in multi-risk recovery planning of urban areas exposed to natural hazards. EGUsphere [preprint], 2023, 1-39, https://doi.org/10.5194/egusphere-2023-504, 2023.

~~71.~~62. Mureșan, A. V., Russu, E., Arbănași, E. M., Kaller, R., Hosu, I., Arbănași, E. M., & Voidăzan, S. T. Negative impact of the COVID-19 pandemic on kidney disease management—A single-center experience in Romania. Journal of Clinical Medicine, 11(9), 2452. DOI: 10.3390/jcm11092452, 2022

~~72.~~63. National Synthesis of the Flood Risk Management Plan. Second version. Available online: https://inundatii.ro/wpcontent/uploads/2023/02/Sinteza-PMRI-Ciclul-II-v3.pdf. Accessed at 03.09.2023, 2023

~~73.~~64. OECD/European Observatory on Health Systems and Policies. Romania: Country Health Profile 2021, State of Health in the EU, OECD Publishing, Paris, https://doi.org/10.1787/74ad9999-en, 2021.

~~74.~~65. Otto, F.E.L., Raju, E. Harbingers of decades of unnatural disasters. Commun Earth Environ, 4, 280. https://doi.org/10.1038/s43247-023-00943-x, 2023.

~~75.~~66. Paprotny D., Mengel M.: Population, land use and economic exposure estimates for Europe at 100 m resolution from 1870 to 2020. Scientific Data, 10, 372, https://dx.doi.org/10.1038/s41597-023-02282-0, 2023.

~~76.~~67. Paprotny D., Terefenko P., Śledziowski J.: An improved database of flood impacts in Europe, 1870–2020: HANZE v2.1. Earth System Science Data Discussions, https://doi.org/10.5194/essd-2023-321, 2023.

~~77.~~68. PARATUS Deliverable 1.1. Report on participatory workshops in the four application case study sites, including impact chains diagrams for each analysed event. 2023, Available online: https://www.paratus-project.eu/portfolio-items/d1-1/?portfolioCats=4, Accessed at 04.08.2023, 2023

~~78.~~69. Patwary, M. M., & Rodriguez-Morales, A. J.: Deadly flood and landslides amid COVID-19 crisis: a public health concern for the world's largest refugee camp in Bangladesh. Prehospital and disaster medicine, 37(2), 292-293. doi: 10.1017/S1049023X22000164, 2022.

~~79.~~70. Peptenatu, D., Grecu, A., Simion, A.G., Gruia, K.A., Andronache, I., Draghici, C.C., Diaconu, D.C.: Deforestation and frequency of floods in Romania. In: Negm AM, Romanescu G, Zeleňáková M (eds) Water resources management in Romania. Springer International Publishing, Cham, 279–306. https://doi.org/10.1007/978-3-030-22320-5_9, 2020.

~~80.~~71. Phillips, C. A., Caldas, A., Cleetus, R., Dahl, K. A., Declet-Barreto, J., Licker, R., ... & Carlson, C. J.: Compound climate risks in the COVID-19 pandemic. Nature Climate Change, 10(7), 586-588. https://doi.org/10.1038/s41558-020-0804-2, 2020.

~~81.~~72. Pittore, M., Zebisch, M., Cocuccioni, S., Renner, K., Fruchter, S., & Schneiderbauer, S.: Impact Chains – Guideline and specifications v1.0, Eurac Research, Bolzano, 2023.

~~82.~~73. Popescu, M., Ştefan, O. M., Ştefan, M., Văleanu, L., & Tomescu, D. ICU-associated costs during the fourth wave of the COVID-19 pandemic in a tertiary hospital in a low-vaccinated Eastern European Country. International Journal of Environmental Research and Public Health, 19(3), 1781. https://doi.org/10.3390/ijerph19031781, 2022

~~83.~~74. Potutan, G., & Arakida, M.: Evolving disaster response practices during COVID-19 pandemic. International journal of environmental research and public health, 18(6), 3137. doi: 10.3390/ijerph18063137, 2021.

~~84.~~75. Pramanik, M., Szabo, S., Pal, I., Udmale, P., Pongsiri, M., & Chilton, S.: Population health risks in multi-hazard environments: action needed in the Cyclone Amphan and COVID-19–hit Sundarbans region, India. Climate and Development, 14(2), 99-104. https://doi.org/10.1080/17565529.2021.1889948, 2022.

~~85.~~76. Quigley, M. C., Attanayake, J., King, A., & Prideaux, F. A multi-hazards earth science perspective on the COVID-19 pandemic: the potential for concurrent and cascading crises. Environment Systems and Decisions, 40, 199-215. https://doi.org/10.1007/s10669-020-09772-1, 2020.

~~86. Rawaf, S., Allen, L. N., Stigler, F. L., Kringos, D., Quezada Yamamoto, H., van Weel, C., & Global Forum on Universal Health Coverage and Primary Health Care.: Lessons on the COVID-19 pandemic, for and by primary care professionals worldwide. European Journal of General Practice, 26(1), 129-133. doi: 10.1080/13814788.2020.1820479, 2020.~~

~~87.~~77. Reichstein, M., Riede, F., & Frank, D.: More floods, fires and cyclones—plan for domino effects on sustainability goals. Nature, 592(7854), 347-349. Available online: https://www.nature.com/articles/d41586-021-00927-x, 2021.

~~88.~~78. Romanescu, G., Cimpianu, C. I., Mihu-Pintilie, A., & Stoleriu, C. C.: Historic flood events in NE Romania (post-1990). Journal of maps, 13(2), 787-798. https://doi.org/10.1080/17445647.2017.1383944, 2017.

~~89.~~79. Schipper, E. L. F.: Maladaptation: when adaptation to climate change goes very wrong. One Earth, 3(4), 409-414. https://doi.org/10.1016/j.oneear.2020.09.014, 2020.

~~90.~~80. Schneiderbauer, S., Baunach, D., Pedoth, L., Renner, K., Fritzsche, K., Bollin, C., ... & Ruzima, S.: Spatial-explicit climate change vulnerability assessments based on impact chains. Findings from a case study in Burundi. Sustainability, 12(16), 6354, 2020, https://doi.org/10.3390/su12166354

~~91.~~81. Scott, M., White, I., Kuhlicke, C., Steinführer, A., Sultana, P., Thompson, P., ... & Russell, E.: Living with flood risk/The more we know, the more we know we don't know: Reflections on a decade of planning, flood risk management and false precision/Searching for resilience or building social capacities for flood risks?/Participatory floodplain management: Lessons from Bangladesh/Planning and retrofitting for floods: Insights from Australia/Neighbourhood design considerations in flood risk management/Flood risk management–Challenges to the effective implementation of a paradigm shift. Planning Theory & Practice, 14(1), 103-140. https://doi.org/10.1080/14649357.2012.761904, 2013.

92. Sikder, M., Zhang, W., & Ahmod, U.: The consequential impact of the Covid-19 pandemic on global emerging economy. American Journal of Economics, 10(6), 325-331. doi:10.5923/j.economics.20201006.02, 2020.

82. Simonovic, S. P., Kundzewicz, Z. W., & Wright, N.: Floods and the COVID-19 pandemic—A new double hazard problem. Wiley Interdisciplinary Reviews: Water, 8(2), e1509. DOI: 10.1002/wat2.1509, 2021.

93. Sparkes, E., Hagenlocher, M., Cotti, D., Banerjee, S., Masys, A. J., Rana, S., ..., Werners, S. E.: Understanding and characterizing complex risks with Impact Webs: A guidance document, 2023. Available at: https://collections.unu.edu/view/UNU:9266, Accessed at 31.03.2024

94.83. Swain, D. L., Wing, O. E., Bates, P. D., Done, J. M., Johnson, K. A., & Cameron, D. R.: Increased flood exposure due to climate change and population growth in the United States. Earth's Future, 8(11), e2020EF001778. https://doi.org/10.1029/2020EF001778, 2020.

95.84. Tanoue, M., Hirabayashi, Y., & Ikeuchi, H.: Global-scale river flood vulnerability in the last 50 years. Scientific reports, 6(1), 36021. https://doi.org/10.1038/srep36021, 2016.

96.85. Terzi, S., De Angeli, S., Miozzo, D., Massucchielli, L. S., Szarzynski, J., Carturan, F., & Boni, G.: Learning from the COVID-19 pandemic in Italy to advance multi-hazard disaster risk management. Progress in disaster science, 16, 100268. https://doi.org/10.1016/j.pdisas.2022.100268, 2022.

97.86. Tilloy, A., Malamud, B. D., & Joly-Laugel, A.: A methodology for the spatiotemporal identification of compound hazards: wind and precipitation extremes in Great Britain (1979–2019). Earth System Dynamics, 13(2), 993-1020. https://doi.org/10.5194/esd-13-993-2022, 2022.

98.87. Tilloy, A., Malamud, B. D., Winter, H., & Joly-Laugel, A.: A review of quantification methodologies for multi-hazard interrelationships. Earth-Science Reviews, 196, 102881. https://doi.org/10.1016/j.earscirev.2019.102881, 2019.

99.88. Toreti, A., Masante, D., Acosta Navarro, J., Bavera, D., Cammalleri, C., De Jager, A., Di Ciollo, C., Hrast Essenfelder, A., Maetens, W., Magni, D., Mazzeschi, M., Spinoni, J. and De Felice, M.: Drought in Europe July 2022, EUR 31147 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-54953-6, doi:10.2760/014884, JRC130253, 2022a.

100.89. Toreti, A., Bavera, D., Acosta Navarro, J., Cammalleri, C., De Jager, A., Di Ciollo, C., Hrast Essenfelder, A., Maetens, W., Magni, D., Masante, D., Mazzeschi, M., Niemeyer, S. and Spinoni, J.: Drought in Europe August 2022, EUR 31192 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-55855-2, doi:10.2760/264241, JRC130493, 2022b.

101. Traverson, L., Mathevet, I., Correia, A., Paz, K., Andrade, A., Ost, K., ... & Ridde, V.: Lessons learned from the resilience of public health systems, hospitals and their personnel to the COVID-19 pandemic: a scoping review protocol. Preprint from medRxiv. https://doi.org/10.1101/2021.04.22.21255908, 2020.

~~102.~~90. Trifanescu, O. G., Gales, L., Bacinschi, X., Serbanescu, L., Georgescu, M., Sandu, A., ... & Anghel, R.: Impact of the COVID-19 pandemic on treatment and oncologic outcomes for cancer patients in Romania. In vivo, 36(2), 934-941. DOI: 10.21873/invivo.12783, 2022

~~103.~~91. Tudora, A., Lungeanu, D., Pop-Moldovan, A., Puschita, M., & Lala, R. I.: Successive Waves of the COVID-19 Pandemic Had an Increasing Impact on Chronic Cardiovascular Patients in a Western Region of Romania. Healthcare, 11(8), 1183. DOI: 10.3390/healthcare11081183, 2023

~~104.~~92. Turay, B.: Flood hazard management in a multiple hazard context: a systematic review of flood hazard management during the COVID-19 pandemic in Africa. Discover Water, 2(1), 6. https://doi.org/10.1007/s43832-022-00014-w, 2022.

~~105.~~93. UN: Paris Agreement, 2015. Available at: http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf, Accessed at 19.02.2024

~~106.~~94. UNISDR: Sendai Framework for Disaster Risk Reduction 2015-2030, United Nations Office for Disaster Risk Reduction (UNISDR), 2015. Available at: https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030, Accessed at 19.02.2024

95. ~~UNU-EHS: Interconnected Disaster Risks. [Authors: O'Connor, Jack; Eberle, Caitlyn; Cotti, Davide; Hagenlocher, Michael; Hassel, Jonathan; Janzen, Sally; Narvaez, Liliana; Newsom, Amy; Ortiz Vargas, Andrea; Schütze, Simon; Sebesvari, Zita; Sett Dominic; and Yvonne Walz]. United Nations University – Institute for Environment and Human Security (UNU-EHS): Bonn, Germany, 2021~~

~~107.~~96. UNDRR: Report of the open-ended intergovernmental expert working group on indicators and terminology relating to disaster risk reduction, 2017. Available online: https://www.undrr.org/drr-glossary/terminology, Accessed at 31.03.2024.

~~108.~~97. UNDRR: UNDRR Asia-Pacific COVID-19 Brief: Combating the dual challenges of climate-related disasters and COVID-19, Available online: https://www.undrr.org/publication/undrr-asia-pacific-covid-19-brief-combating-dual-challenges-climate-related-disasters. Accessed at 04.08.2023, 2020

~~109.~~98. UNDRR: Technical Guidance on Comprehensive Risk Assessment and Planning in the Context of Climate Change. United Nations Office for Disaster Risk Reduction. Available online: https://www.undrr.org/publication/technical-guidance-comprehensive-risk-assessment-and-planning-context-climate-change, Accessed at 04.08.2023, 2022

~~110.~~99. Vinke-de Kruijf, J., Kuks, S. M., & Augustijn, D. C.: Governance in support of integrated flood risk management? The case of Romania. Environmental development, 16, 104-118. https://doi.org/10.1016/j.envdev.2015.04.003, 2015.

~~111.~~100. Ward, P. J., de Ruiter, M. C., Mård, J., Schröter, K., Van Loon, A., Veldkamp, T., ... & Wens, M.: The need to integrate flood and drought disaster risk reduction strategies. Water Security, 11, 100070. https://doi.org/10.1016/j.wasec.2020.100070, 2020.

~~112.~~101. White, I., & Haughton, G.: Risky times: Hazard management and the tyranny of the present. International journal of disaster risk reduction, 22, 412-419. https://doi.org/10.1016/j.ijdrr.2017.01.018, 2017.

~~113.~~102. WHO. Floods. Available online: https://www.who.int/health-topics/floods?fbclid=IwAR1xDiSs8WlRLVyrZzK68m-3lyEQkmD_RIz7a0vva4sqOaVBFFWvR4vZ0#tab=tab_1. Accessed 03.08.2022, 2020a

~~114.~~103. WHO. Public health criteria to adjust public health and social measures in the context of COVID-19: annex to considerations in adjusting public health and social measures in the context of COVID-19, 12 May 2020. World Health Organization. https://apps.who.int/iris/handle/10665/332073, 2020b

~~115.~~104. WHO Dashboard. COVID-19 data for Romania. Available online: https://covid19.who.int/region/euro/country/ro, 2023

~~116. Younas, A., & Kassim, A. A. M.: Empirical review of business challenges and opportunities from the covid-19 pandemic. Journal of Business Management and Accounting, 12(2), 63-79. https://doi.org/10.32890/jbma2022.12.2.4, 2022.~~

~~117.~~105. Zaharia, L., & Ioana-Toroimac, G.: Overview of river-induced hazards in Romania: impacts and management. Water management and the environment: case studies, 197-211, 2018.

~~118.~~106. Zebisch, M., Schneiderbauer, S., Fritzsche, K., Bubeck, P., Kienberger, S., Kahlenborn, W., ... & Below, T.: The vulnerability sourcebook and climate impact chains–a standardised framework for a climate vulnerability and risk assessment. International Journal of Climate Change Strategies and Management, 13(1), 35-59, 2021, doi: 10.1108/IJCCSM-07-2019-0042

~~119.~~107. Zebisch, M., S. Schneiderbauer, K. Renner, T. Below, M. Brossmann, W. Ederer, & Schwan, S.: Risk supplement to the Vulnerability Sourcebook: Guidance on how to apply the Vulnerability Sourcebook's approach with the new IPCC AR5 concept of climate risk. Deutsche Gesellschaft fur¨ Internationale Zusammenarbeit Rep., 2017, Available at: https://www. adaptationcommunity.net/wp-content/uploads/2017/10/GIZ2017_Risk-Supplement-to-the-Vulnerability-Sourcebook.pdf, Accessed 19.02.2024

~~120.~~108. Zschau, J.: Where are we with multihazards, multirisks assessment capacities? In: Poljanšek, K., Marín Ferrer, M., De Groeve, T., Clark, I. (Eds.). Science for disaster risk management 2017: knowing better and losing less. EUR 28034 EN, Publications Office of the European Union, Luxembourg, Chapter 2.5, doi: 10.2788/688605, 2017.

~~121.~~109. Zscheischler, J., Westra, S., Van Den Hurk, B. J., Seneviratne, S. I., Ward, P. J., Pitman, A., ... & Zhang, X.: Future climate risk from compound events. Nature Climate Change, 8(6), 469-477. https://doi.org/10.1038/s41558-018-0156-3, 2018.

Appendix A

Table A1. Vulnerabilities grouped by hazard, type, and scale

Hazard	Vulnerability	Type of vulnerability	Scale	Mitigated	Augmented
COVID-19 pandemic	Insufficient COVID-19 testing capacity	Vulnerability related to medical management	National	No	Yes
COVID-19 pandemic	Insufficient ICU capacity (e.g., no. of beds, ventilators, O2 supply)	Vulnerability related to medical management	Local	Yes	Yes
COVID-19 pandemic	Insufficient medical personnel	Vulnerability related to medical management	Local	Yes	Yes
COVID-19 pandemic	Low-performance medical system	Vulnerability related to medical management	National	Yes	Yes
COVID-19 pandemic	Shallow implementation of preventive measures	Vulnerability related to medical management	Local	No	Yes
Floods	Absence of preparedness at individual level	Vulnerability related to coping capacity	Individual	No	Yes
Floods	Assets at short distance from river	Vulnerability related to territorial planning	Local	No	No
Floods	Defective coordination of first responders from multiple counties	Vulnerability related to emergency management	Regional	No	Yes
Floods	Deforestation	Vulnerability related to territorial planning	Local	No	Yes
Floods	Development of infrastructure in flood prone areas	Vulnerability related to territorial planning	Local	No	No
Floods	Development of inhabited areas in flood prone areas	Vulnerability related to territorial planning	Local	No	No
Floods	Households at short distance from the river	Vulnerability related to territorial planning	Local	No	Yes
Floods	Improper governance structure for effective flood management	Vulnerability related to emergency management	National	No	No
Floods	Improper mapping and visualisation of affected areas	Vulnerability related to emergency management	Local	Yes	Yes
Floods	Ineffective sewage system	Vulnerability related to infrastructure	Local	No	No
Floods	Insufficient/Ineffective hard engineering infrastructure/measures	Vulnerability related to infrastructure	National	No	Yes
Floods	Long shifts of first responders	Vulnerability related to emergency management	Local	No	Yes

Floods	Low quality construction materials	Vulnerability related to infrastructure	Local	No	No
Floods	Significant psychological tension of first responders	Vulnerability related to emergency management	Local	No	Yes
Floods	Work overload on first responders	Vulnerability related to emergency management	Local	No	Yes
Floods, COVID-19 pandemic	Depleted capacity due to seasonal patterns of hazards	Vulnerability related to coping capacity	National	No	No
Floods, COVID-19 pandemic	Flood management not adapted to the COVID-19 context	Vulnerability related to emergency management	National	Yes	Yes
Floods, COVID-19 pandemic	Ineffective institutional communication	Vulnerability related to emergency management	Local	Yes	No
Floods, COVID-19 pandemic	Lack of equipment for first responders (including protective gear)	Vulnerability related to emergency management	Local	Yes	Yes
Floods, COVID-19 pandemic	Poverty, especially in uneducated/roma/migrant population	Vulnerability related to coping capacity	Local	No	Yes
Floods, COVID-19 pandemic	Uncooperative population	Vulnerability related to coping capacity	Local	Yes	Yes

Appendix B

Table B1.Details on the new connection types and derived impacts included in the Enhanced Impact Chain. The * marks the cases where the impact in the first column or the vulnerability in the second column relate both to floods and the COVID-19 pandemic. In such cases, the type of augmentation can be both deepening and shifting vulnerability, but the choice was based on the explanation given in the fourth column.

Impact/ Adaptation option	Augmented vulnerability	Type of augmentation (New connection)	Explanation of augmentation	Augmented vulnerability turned into derived impact
Water contamination	Households at short distance from the river	Deepens vulnerability	Floods can contaminate the water of rivers, which fosters water-borne diseases. Human communities located close to rivers are especially exposed to such contamination, which makes them more vulnerable (to floods and diseases).	Households at a short distance from the river, under specific environmental and river valley morphology conditions, will increase water contamination issues downstream.
Railway transportation impairment	Shallow implementation of preventive measures	Shifts vulnerability	Flood-determined railway transportation impairment can increase the vulnerability of travellers to COVID-19 by causing unnecessary crowding of trains or prolonged exposure due to delays. This is particularly relevant since few preventive measures were implemented to limit the spread of the SARS-CoV2 virus during train travel.	
Lockdown	Deforestation	Shifts vulnerability	The lockdown imposed in March-May 2020 favoured the illegal cutting of the forest, especially in mountainous, isolated areas. As a protective measure, forest authorities decided to guard the forests.	

Disrupted ambulance service	Insufficient COVID-19 testing capacity	Shifts vulnerability	In the early pandemic months, the COVID-19 testing of the population was done by calling the ambulance and requesting to be tested. During or after floods, ambulances could not reach the potential COVID-19 patients, which deepened the limitation of the testing capacity.	The vulnerability of insufficient COVID-19 testing capacity also acts as a derived impact, since this limitation in testing caused disruption in the functioning of the ambulance service. During the pandemic, ambulances worked at full capacity, especially for testing or other COVID-19-related emergencies, to the expense of the non-COVID patients that also requested health care.
Interventions to remove flood water	Flood management not adapted to the COVID-19 context	Rebounds vulnerability	The emergency management personnel in charge of removing the flood water and cleaning after a flood event are exposed to COVID-19 during these operations that minimise social distancing. This prolonged contact with each other, the population, and contaminated water increases the vulnerability that stems from the absence of adaptation of flood management protocols to the pandemic conditions.	
Potential increase in the COVID-19 new cases	Insufficient ICU capacity (e.g., no. of beds, ventilators, O2 supply)	Deepens vulnerability	The potential increase in the COVID-19 positive cases augments the pressure on the ICUs that already function at full capacity.	
Effects on other diseases	Low-performance medical system	Deepens vulnerability	The COVID-19 diseases delayed the provision of health care to non-COVID patients (with the effect of aggravating their pre-existing disease), therefore reducing the performance of the medical system and also increasing the vulnerability of non-COVID patients.	Under additional pandemic pressure, the low-performance medical system will have a derived impact with multiple adverse effects on other diseases patients suffer from.
Human casualties	Insufficient medical personnel	Deepens vulnerability*	The death toll of COVID-19 among medical personnel reduced the number of health care professionals available to carry on the fight against the pandemic.	The shortage of medical personnel represents a derived impact that increases the number of human casualties, since many COVID-19 and non-COVID-19 patients in need of health care could have been saved if they would have benefited from medical attention.
RO-Alert SMS messages	Shallow implementation of preventive measures	Rebounds vulnerability	The RO-Alert SMS messages issued as part of the emergency-related communication to the population in the context of floods may have caused panic, increasing the chances of abandoning the protective behaviour against the COVID-19 infection.	
Flooded public institution buildings (including 1 hospital)	Low-performance medical system	Shifts vulnerability	The flooding of buildings that host hospitals appears as a supplementary problem that contributes to the low performance of the medical system, diverting financial resources from other pressing issues.	
Cut off supply of electricity/gas/water	Insufficient ICU capacity (e.g., no. of beds, ventilators, O2 supply)	Shifts vulnerability	The frequent blackouts of electricity/gas/water that occur during or immediately after flood events can greatly impact the functionality of ICUs, limiting their capacity to provide health care.	
Effects on other diseases	Insufficient medical personnel	Deepens vulnerability	The medical personnel have to face increased workloads because the COVID-19 infection aggravates the pre-existing diseases of patients. These complex situations reduce the personnel available to tend to COVID-19 patients in certain medical units.	Insufficient medical personnel is not only a vulnerability but also a derived impact. The shortage of doctors and nurses can also contribute to the progression of certain diseases that were already aggravated by the infection with SARS-CoV2.
Flooded/Damaged households or houses	Flood management not adapted to the COVID-19 context	Shifts vulnerability*	The flooding of houses or households determines the evacuation of the population, a procedure that is not adapted to the new pandemic conditions. During evacuation operations, people get in close contact with each other, favouring the spread of the COVID-19 infection. Also, the evacuees that are accommodated in temporary shelters are exposed to the spread of the virus.	

Economic loss	Low-performance medical system	Shifts vulnerability*	The economic loss resulting from the flood events or the pandemic perpetuates the low performance of the medical system because of the implicit, "chronical" lack of financial support.	At the same time, the low performance of the medical system determines economic loss, in direct relation to treatment delays, a shortage of medical and human resources, etc.
Displaced/(Self-) Evacuated people	Flood management not adapted to the COVID-19 context	Shifts vulnerability*	The evacuation procedures performed before, during, or after floods increase the vulnerability of the evacuees and/or the emergency management staff, who get in close contact with each other and are exposed to the spread of the SARS-CoV-2 virus both during transportation and inside temporary emergency shelters.	
Road transportation impairment	Insufficient COVID-19 testing capacity	Shifts vulnerability	The flood-induced damages to the road infrastructure, together with the subsequent road transportation impairment, limited the capacity of COVID-19 testing, since people were unable to reach testing centres and ambulances were unable to reach the people requesting to be tested at home.	The insufficient COVID-19 testing capacity also caused road transportation impairment, as many people were unable to get tested or vaccinated in the settlement of residence and chose to undertake road journeys on different distances (considerable, in some cases) to available testing/vaccination centres located in other settlements. This COVID-19-related transportation boost caused traffic jams in numerous places and on occasions.
Increased stress/anxiety	Insufficient medical personnel	Deepens vulnerability*	The increased stress/anxiety during the pandemic waves severely affected the mental health and wellbeing of the medical personnel. In certain cases, the doctors or nurses became unable to perform their medical duties, even for short periods of time, which deepened the shortage of medical personnel at different times.	The insufficient medical personnel also represents a derived impact, since it is an additional cause of stress/anxiety for both the existing medical staff and the patients, or the general population.
Vaccination campaign against the SAR-CoV-2 virus	Shallow implementation of preventive measures	Creates negative externalities	The vaccination campaign had the unwanted effect of diluting the interest in implementing early COVID-19 prevention measures (e.g., the wearing of masks, social distancing). In certain instances, even unvaccinated people can lower their guard in self-protection, assuming that being surrounded by vaccinated individuals prevents them from contracting infections.	
Cut off supply of electricity/gas/water	Shallow implementation of preventive measures	Shifts vulnerability	The cut off of energy/gas/water may cause people to gather in neighbours' or relatives' houses, which reduces social distancing and increases the chances of COVID-19 infection.	
Economic loss	Insufficient/ineffective hard engineering infrastructure/measures	Shifts vulnerability*	The economic loss sets the premises for underfunding the insufficient/ineffective hard engineering infrastructure/measures.	Insufficient/ineffective hard engineering measures are a derived impact, since they provoke an increase in economic losses in the case of exposed and vulnerable communities.
Economic challenges	Low-performance medical system	Deepens vulnerability	The economic challenges resulting from the COVID-19 pandemic may divert attention and financial resources from improving the medical system, accentuating its low performance.	A low-performance medical system will be a derived impact raising new economic challenges due to its ineffectiveness in coping.
Heighten river banks with sand bags	Absence of preparedness at individual level	Rebounds vulnerability	The implementation of last-minute, on-the-spot solutions like the heightening of river banks with sand bags offers a false impression of security, reducing the interest of people in preparedness at household level.	
Flooded hospital basement	Flood management not adapted to the COVID-19 context	Shifts vulnerability	The flooding of hospital buildings increases the vulnerability of emergency management staff who have to remove the water, perhaps entering contaminated areas and getting in contact with medical personnel or patients who are infected with COVID-19. The patients infected with the SARS-CoV-2 virus can be moved into other wards/rooms/buildings, which become overcrowded in the aftermath of a flood event that affects the hospital buildings. Both the gathering and the transportation of the patients increase	

			their exposure to COVID infection and disrupt their health care routines, all leading to increased vulnerability.	
Hydrological warnings	Absence of preparedness at individual level	Creates negative externalities	The people located in areas that were not mentioned in the hydrological warnings for one flood event gained a false feeling of security, which can reduce their interest in implementing flood preparedness measures at individual level.	
Vaccination campaign against the SARS-CoV-2 virus	Uncooperative population	Creates negative externalities	The vaccination campaign against the SARS-CoV-2 virus was accompanied by abundant misinformation that fueled conspiracy theories. This exacerbated the reluctance of people to cooperate with authorities.	
Increased stress/anxiety	Uncooperative population	Deepens vulnerability*	The stress/anxiety induced by floods can make people uncooperative in relation to first responders, making rescue or evacuation operations harder to implement.	The uncooperative population also represents a derived impact, as the lack of support and availability of collaboration with authorities increase stress/anxiety in both parts.
Deas/Missing domestic animals	Uncooperative population	Deepens vulnerability	The death or disappearance of domestic animals during a flood can make people reluctant to evacuate and wanting to search for their animals. Also, people can put themselves in danger in their endeavour to find and save their missing animals.	
Mental health issues (e.g., depression)	Uncooperative population	Shifts vulnerability	One of the notable consequences of mental health issues is a diminished inclination towards collaboration. This escalation of uncooperative behaviour can hinder communication with first responders or medical personnel.	
Lockdown	Uncooperative population	Deepens vulnerability	The restrictions imposed by authorities during the lockdown (March-May 2020) meant to tilt the SARS-CoV-2 infection curve negatively affected the freedom of citizens, with the effect of reducing their availability to cooperate and also their trust in authorities.	
Diminished trust in authorities	Uncooperative population	Deepens vulnerability*	The eroded trust in authorities determined by the faulty management of the COVID-19 pandemic and fuelled by the resulting economic problems contributed to a diminished spirit of cooperation between the population and first responders.	Conversely, the heightened reluctance to collaborate with first responders and authorities further eroded trust in authorities, creating a positive feedback loop.
Road transportation impairment	Work overload on first responderts	Deepens vulnerability	The restricted access to certain areas affected by floods because of flood-determined road transportation impairment can increase the work load on first responders, as the possibility of getting more people on the ground where and when needed is limited. This means that the first responders who managed to arrive in the affected areas have to cover more ground without supplementary personnel.	
Road transportation impairment	Long shifts of first responders	Deepens vulnerability	Impaired road transportation hinders the arrival of the next shift of first responders in the intervention area, potentially leading to extended shifts for the already deployed responders.	
Potential increase in the COVID-19 new cases	Work overload on first responders	Deepens vulnerability*	High local viral loads can increase the risk of SARS-CoV-2 infection for first responders, which means that the work load of the uninfected ones can increase.	Excessive workloads for first responders can contribute to a rise in new COVID-19 cases within their units as their exposure to infection increases
Cut off supply of electricity/gas/power	Lack of equipment for first responders (including protecting gear)	Deepens vulnerability	The outages of electricity/gas/power determined by floods can alter the functionality of the equipment used by first responders during flood management interventions.	
Road transportation impairment	Lack of equipment for first responders (including protecting gear)	Deepens vulnerability	The obstruction of road transportation caused by floods can prevent first responders from transporting certain equipment in flood-affected areas.	

Economic loss	Lack of equipment for first responders (including protecting gear)	Shifts vulnerability*	The economic loss resulting from the flood events or the pandemic can reduce interest in investing in equipment needed for flood-related interventions.	The absence of proper equipment in flood-related interventions can amplify the economic loss caused by floods, as it reduces the capacity to safeguard assets on the ground.
Cut off supply of electricity/gas/power	Improper mapping and visualisation of affected areas	Deepens vulnerability	Power outages can affect the functionality of computers and other devices used for the mapping and visualisation of affected areas, hindering flood management, especially on short term.	
Economic loss	Improper mapping and visualisation of affected areas	Shifts vulnerability*	The financial setbacks resulting from flood events or the pandemic can divert attention and funds from investing in the technological and human resources involved in mapping and producing visualisations of flood-affected areas.	Inadequate mapping and visualisation of flood-affected areas can increase the economic loss by hindering the acquisition and utilisation of accurate data and information on the ground.
Flooded hospital basement	Significant psychological tension of first responders	Deepens vulnerability	The challenges linked to flood mitigation efforts inside buildings housing vulnerable people (e.g., hospitals) can increase the psychological tensions experienced by first responders.	
Road transportation impairment	Defective coordination of first responders from multiple counties	Deepens vulnerability	Impaired road transportation obstructs coordination among units of first responders in neighbouring counties, potentially diminishing the effectiveness of flood mitigation actions.	
Increased unemployment	Poverty, especially in uneducated/roma/migrant population	Deepens vulnerability	The temporary layoffs prompted by the COVID-19 pandemic exacerbated the poverty of the vulnerable population, most of whom are people with low levels of education, roma, or migrant minorities.	