

multi-Risk sciEnce for resilienT commUnities undeR a changiNgcLimate

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ABSTRACT

This Deliverable presents a methodological framework for applying risk storylines as a scenario-building technique to engage diverse stakeholders in Disaster Risk Management (DRM), promote shared knowledge production, and enhance risk awareness. Storylines are used to frame complex, multi-hazard situations in a narrative form that makes scientific information accessible and actionable for decision-makers, practitioners, and citizens. Building on the recent state of the art, the document outlines the conceptual and operational foundations of the approach, detailing the steps of territorial characterization, stakeholder engagement, impact-chain exploration, and identification of strategic actions.

The second part illustrates the application of the Risk Storyline model developed by the RETURN research team in two Urban Territorial Environments (UTES). In the Genoa UTE, the storyline focuses on concurrent heatwaves and downburst events, hazards that in recent years have increasingly stressed both the urban microclimate and critical infrastructures. The process involved a targeted selection of local actors, who contributed to co-developing impact chains that highlight cascading effects on health, mobility, and emergency response systems, ultimately leading to a set of strategic actions for risk mitigation and preparedness. In the Friuli Venezia Giulia (FVG) UTE, the storyline addresses storm surge and tsunami scenarios, exploring how coastal morphology, exposure hotspots, and governance structures interact in shaping regional vulnerability. Here, stakeholder participation contributed to refining multi-hazard scenarios and identifying priority measures for coastal resilience, emergency planning, and long-term adaptation.

The final section of the Deliverable is devoted to risk culture, citizen science, and capacity-building initiatives in FVG, emphasizing their role in strengthening local awareness and adaptive capacities. Activities include climate-change outreach sessions in high schools, a regional conference on climate and coastal risks, training programmes with the University of the Third Age, and broader dissemination and knowledge-transfer actions. These experiences underscore the value of participatory, place-based approaches for fostering informed communities and integrating scientific insights into DRM strategies.

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4. Risk Storyline a methodological proposal

In this paragraph, we illustrate the theoretical basis that inspires the use of risk storylines in Disaster Risk Management (DRM), as well as the main steps of our methodological proposal. In particular, Section 4.1 explores the research question and the needs from which the idea of retrieving and adapting a scenario-based technique originally developed within climate science for DRM emerged. Section 4.2 reconstructs the relevant literature, identifies the existing knowledge gaps, and examines their relationship with the methodological proposal described in this dissertation. Section 4.3 illustrates the steps of the storyline construction process. Part of the content presented in this section has been published in an international peer-reviewed scientific journal (Marciano et al., 2024).

4.1 Introduction

Teams composed of members with relevant cognitive diversity are more likely to achieve innovative results (Vedres and Stark, 2010). This diversity includes a variety of previous work experiences, training and ways of thinking and behaving, expanding the repertoire of actions available to the team and predisposing it to go beyond the 'taken for granted' (Ganz, 2000). However, cognitive diversity alone is not enough. It must be organised through structures that facilitate the exchange and generation of new knowledge between expertise otherwise isolated or barely able to communicate (de Vaan, Stark and Vedres, 2014).

In Disaster Risk Management (DRM), one of the areas where innovation is most needed concerns the anticipation of new phenomena caused by climate change. For instance, in reducing uncertainty about the direct, indirect and combined impacts of more than one hazard on a given area (Pregolato et al. 2024). This and other tasks require multi-risk governance (Gallina et al. 2016), a new approach to risk management that aims to identify causal and temporal relationships between multiple hazards and to integrate the physical dimension of vulnerability with the socio-economic and environmental dimension.

Achieving these goals requires the involvement of social actors responsible for DRM in a cooperative knowledge production process. However, the specialization of scientific production, while advancing knowledge and its applications (Pirni, 2022), makes it increasingly difficult to synthesize and apply interdisciplinary findings in problem-solving contexts. Moreover, integrating interdisciplinary scientific production with the diverse forms of knowledge developed in DRM by actors with greater transformative agency than universities and research centers, starting with public authorities, is still far from being achieved.

In design thinking and foresight, scenario techniques are crucial for attempting to reach this goal (Hines and Bishop, 2007). Related to this are storylines, which aim to realistically reconstruct impact chains of multi-hazard events and potential stakeholder responses to plausible traumatic events (Shepherd et al., 2018). Despite the growing use of this tool in DRM, there is no common definition of a storyline's basic design or consideration of the stakeholders' role in its development.

This article proposes a participatory methodology to organize and bridge cognitive distances between stakeholders by developing multi-risk storylines that illustrate the potential impacts of a strong heat wave followed by intense rainfall in two different Italian territorial contexts (a peri-urban and a metropolitan area). The methodology is still under construction and the applications are too limited to be considered a new technique. However, the complexity of the experience could provide valuable insights into the ongoing debate about using storytelling and, in doing so, to engage 'society' (or at least a little part of it) in DRM.

This methodology was developed as part of the Extended Partnership (EP) RETURN initiative, focused on "multi-risk science for resilient communities under a changing climate". The project, which is funded by the Italian PNRR (Piano Nazionale di Ripresa e Resilienza), addresses environmental, natural, and anthropogenic risks and their interaction with climate change. The objective of RETURN is to reinforce national research networks and enhance participatory approaches to DRM through optimised knowledge transfer and technological application. One of the RETURN project's core objectives is to assess multi-risk and develop resilient communities, with a specific focus on urban and metropolitan contexts.

Section 4.2 provides an overview of the literature on risk storyline experimentation and the involvement of diverse actors in their creation. Section 4.3 outlines the proposed methodological design for the multi-risk storylines and the stakeholder involvement process. Section 4.4 presents the results of the application in the RETURN project. Section V discusses these results, focusing on strengths and tensions that emerged in stakeholder interactions. Finally, the conclusion offers suggestions for future research directions.

4.2 Storyline: a brief state of art

The increasing demand for storylines in disaster risk management (DRM) arises from both scientific and policy spheres. In the scientific community, there is growing recognition of the limitations of probabilistic techniques in capturing the nuances of multi-risk events and reducing uncertainty (Shepherd et al., 2018). Global climate models (GCMs) are inadequate for providing insights into the regional manifestations of climate change and its local impacts (Kennel et al., 2016). Similarly, risk maps often fail to account for indirect effects beyond the immediate area of occurrence and do not consider sequential interactions with critical infrastructures (De Bruijn et al., 2016).

Effective DRM policy, however, relies not only on professional expertise but also on community preparedness. One key factor influencing readiness and response capacity is not merely awareness of the risk or recommendations on actions to take (Bracco et al., 2015), but rather the direct experience of past events (Tulving, 2002; Kahneman, 2011). This cognitive structure applies to both individuals and socio-technical systems (Levitt and March, 1988). According to Shepherd et al. (2018), significant financial investments in risk reduction typically occur only after disasters, whereas mere awareness of exposure and vulnerability leads to minimal actions, such as drafting emergency plans. Consequently, storylines have become essential tools for training response institutions and engaging communities, generating "constructed" episodic memory for rare but plausible high-impact events, for which there is often no prior experience (Munz et al., 2023).

The development of storylines does not follow a specific design; various approaches are employed. The most common steps, though rarely present in a single application, include: i) identifying the event context and characteristics; ii) reconstructing impact chains at both physical-environmental and socio-economic levels; iii) outlining possible responses. These steps integrate quantitative and qualitative data collection techniques, such as data and trend analysis, interviews, and workshops (Munz et al., 2023).

A consistent feature in these experiments is the active involvement of stakeholders with responsibilities or interests in risk management. Storylines are collaboratively created by researchers from various fields and institutional actors, including civil protection agencies, ministries, regional or local administrations, and socio-economic actors such as trade associations, insurance companies, and critical infrastructure operators. The engagement method varies. Often, stakeholders provide information that researchers then use to independently create storylines (De Bruijn et al., 2015; Van der Hurk et al., 2023; Munz et al., 2023). In some cases, researchers facilitate the process while stakeholders construct the storylines, detailing impact chains and appropriate responses (Shepherd et al., 2018).

While the literature describes stakeholder involvement in storyline development, it rarely critically examines it. Extending the analysis to similar practices, such as constructing causal risk maps (Pregolato et al., 2024) or econometric models of the indirect effects of catastrophic events (Hochrainer-Stigler and Reiter, 2021), reveals several fundamental themes that will also be explored in this study. Firstly, the criteria for identifying and evaluating stakeholders are crucial. There is a need to go beyond traditional variables of “power and influence” (Freeman, 1984) and incorporate factors more relevant to DRM, such as prior experience with events and expertise in applicable knowledge production (Bryson, 2004). Secondly, the interaction between disciplines, particularly between hard and social sciences, and the roles assigned to each, is an important consideration (Wendling, 2014). Finally, a significant theme concerns post-engagement activities: how to institutionalize stakeholder consultation, making it a permanent practice, and how to integrate and highlight the outcomes of these consultations in public policy?

4.3 Methodology and Framework

In this paragraph we illustrate the design of the multi-risk storyline, developed in RETURN project. The process can be summarized in four steps (Tab.1): context identification, selection and engagement of stakeholders, reconstruction of impact chains, identification of strategic actions in response, regeneration and learning.

Scoping	Definition of main purpose and goals of storylines as well as the indication of any further assumptions and boundary conditions necessary to better contextualise it.
Setting	Assessment of level of exposure of territorial contexts to the hazardous events of interest. Definition of the main features of the selected territorial context that play a crucial role in managing risk and description of the multi-hazard scenario.
Mapping and Engagement of Stakeholders	Identification of multidisciplinary expertise from different social fields (academia, politics, economics, civil society etc.) in the development of storylines
Exploratory Phase	Identification of possible direct effects on the population, services, natural environment and critical infrastructure during and immediately after each event.
Prescriptive Phase	Identification of strategic actions in the event response, medium-long term restoration and preparedness phase

Table 1: The “multi-risk storylines” Path.

Defining the urban context of interest is crucial for developing multi-risk storylines, as it helps identifying specific vulnerabilities and exposures. The presence and amount of certain assets (e.g., people, housing, infrastructure, species or ecosystems), along with various vulnerability factors, significantly

influence the level of impact and the effectiveness of response and recovery efforts against natural hazards. For instance, high population density in cities increases the risk of casualties and damage during events like earthquakes, floods, and hurricanes (Kelman, 2017).

Ideally, an in-depth knowledge of all the features of the specific urban context being analyzed is required for setting the context in the development of risk storylines. However, providing too much information on the urban context can result in a risk storyline that is overly specific, limiting its applicability to other areas. Generalizing the storyline allows it to be adapted to various urban contexts with similar features, enhancing its relevance for broader risk assessments. Additionally, data on urban settlement features is often limited and typically available only at the administrative level.

4.3.1 The Characterization of the territorial context and of the multi-hazards

In our methodological proposal, the characterisation of a territorial context and of multi-hazards is carried out in four steps (fig 1).

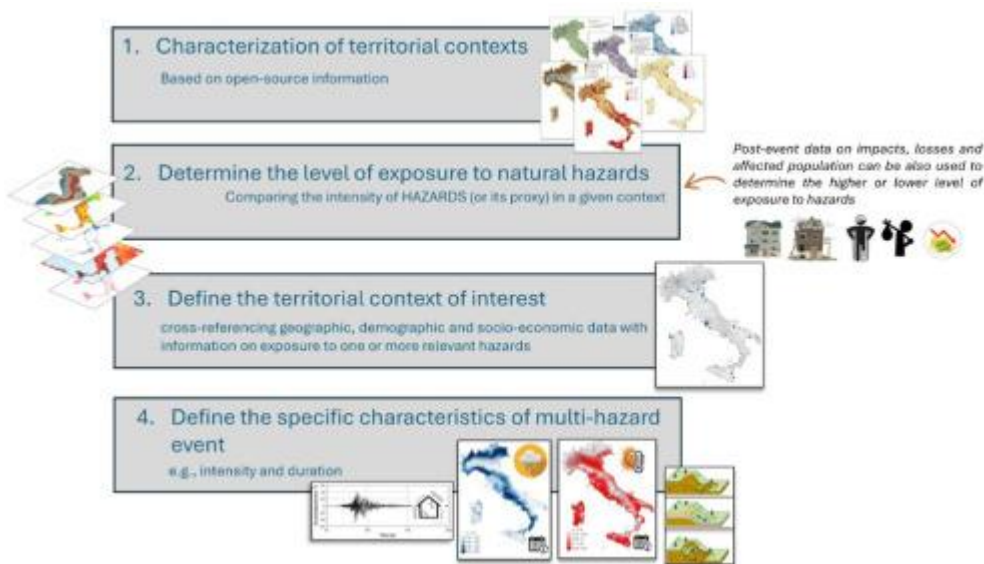


Figure 1: Steps for the characterization of Context and Multi-Hazard

In this procedure, the municipality is used as the boundary for urban settlements, and data from ISTAT (the National Institute of Statistics in Italy) are used to classify Italian municipalities for urban context identification. Specifically, information adopted is related to (i) the degree of urbanization, that accounts for geographical contiguity and population density; (ii) urban centeredness degree, that quantifies the level of centrality of an area within an urban context; (iii) the number of inhabitants, derived from the last census (ISTAT 2011); (iv) the altimetric zone, that refers to the classification of the geographic area based on its elevation above sea level. Additional demographic and socio-economic information (e.g., age, income level, employment status, education level) can also be obtained from ISTAT as well. This data can be used to classify municipalities based on their social vulnerability (Frigerio et al., 2018; Tocchi et al., 2023).

For the identification of urban context, it is also essential to determine its level of exposure to natural hazards, which indicates the presence of people, property, infrastructure, economic activities and other assets that could be adversely affected by hazards like earthquakes, floods and tsunamis (IPCC, 2014; UNDRR, 2016). This involves assessing the presence and value of assets in hazard-prone areas as well as the frequency and severity of hazards. A GIS-based procedure is proposed herein to evaluate the exposure level of urban

settlements to several hazardous events. For the hazards of interest, intensity measures values at municipal level are derived from the related hazard maps. When hazard maps are unavailable, a significant proxy for the intensity measure is adopted. This approach enables the ranking of various hazards for each urban setting and the identification of municipalities with high exposure to one or multiple hazards. Historical damage data, if available, can also be integrated to identify consistently vulnerable urban settlements and regions.

The urban context for the development of risk storylines is defined by specifying the characteristics of the selected context based on the investigated information (e.g., a municipality that is an attraction hub, with over 50,000 inhabitants, located in a hilly area) and cross-referencing this data with information on exposure to one or more relevant hazards (e.g., extreme rainfall and landslides). The aim is to define an ideal-typical context that is abstract yet concrete, resembling one or more real urban contexts without explicitly referring to any specific one.

In addition, the setting for risk storylines also requires defining the specific characteristics of the hazard or multi-hazard event. As a matter of fact, the characteristics of a hazard, such as its intensity, duration, and frequency, significantly influence the extent of impacts and losses. For instance, rapid landslides, such as debris flows and rock avalanches, occur suddenly and move at high speeds, causing immediate and severe damage to structures and infrastructure, and posing significant risks to human life. Slow landslides, like soil creep and earthflows, progress gradually over time, leading to long-term ground deformation and damage to buildings and roads, often without immediate catastrophic impacts but with persistent and costly effects (IUGS/WGL, 1995; Glastonbury & Fell, 2008).

4.3.2 Phase II: Stakeholders Engagement

The term 'stakeholder' refers to any group or individual who can influence or be influenced by the achievement of the company/organization's objectives (Freeman 1984) and who can influence (or be influenced by) the organization's resources and outcomes (Bryson 2004). In the context of the RETURN project, this concept of corporatist derivation (Bobbio and Pomatto, 2007) can be reconsidered, since it is not the company's profit that is at stake, but the production of knowledge aimed at innovating the DRM. In the elaboration of multi-risk storylines, stakeholder engagement has a specific objective: to reduce the complexity and uncertainty inherent in the impacts of natural hazards in different urban contexts, and to track the strategic actions to be practised through the organisation of the cognitive diversity of stakeholders. Therefore, the mapping and classification of stakeholders is done in accordance with their competences and capabilities, their ability to influence or be influenced by the research results.

This purpose makes the 'stakeholder' a carrier of knowledge and experience. These considerations have led us to identify stakeholders based on two main criteria: i) heterogeneity; ii) territoriality.

- The heterogeneity criterion implies the involvement of actors with different characteristics. In the case of scientific actors, they may have different disciplinary backgrounds or even different theses on the same subjects. In the case of institutional actors, such as public administrations with expertise in DRM, who have experienced different risks in different areas in terms of geography and resources.
- The territoriality criterion favors actors who have expertise or specific knowledge of a territorial typology, such as large urban centers or inland rural areas. The storylines are set in ideal-typical territories whose characteristics, as described in the previous paragraph, cumulate various indicators of exposure and vulnerability typical of real territories. Whether mayors, law enforcement officials, entrepreneurs or representatives of voluntary associations, the value of stakeholder knowledge depends on how well it can be located.

The structure of the storylines has an explorative phase, aimed at reconstructing the impact of a multi-hazard event, and has a normative phase, aimed at identifying the good DRM practices to mitigate it. Here we use the adjective 'normative' in the sociological sense of a norm that guides behaviour based on what a subject has 'good reason' to believe is right (Boudon, 1981). This framework suggests also a division of labor in the involvement of stakeholders, i.e. in the things we "do together" with them.

Maintaining the criteria of heterogeneity and territoriality, we propose to privilege actors with explicit knowledge in the elaboration of the explorative phase (knowledge-holders) and those with practical knowledge and direct experience in the normative phase (experience-holders).

- Knowledge-holders are organisations whose main purpose is to produce and validate specialised knowledge on DRM, mainly universities, research centers, specialised civil protection structures.
- Experience-holders, on the other hand, are more diversified and refer to a heterogeneous set of organisations with different roles in the management of DRM: multi-level public authorities, prefectures and police forces, professional associations of operators and entrepreneurs, trade unions, voluntary civil associations, grassroots.

4.3.3 Exploration of the impact chains

This phase consists of identifying the impact chains of the multi-hazards on the territorial context chosen as the "setting" of the storylines.

Impact Chains (ICs) are an explorative tool that helps to better understand, systemise and prioritise the factors that drive risks in a specific system of concern and serve as a backbone for an operational risk assessment. Impact chains provide conceptual models that describe risk-related impacts as cause-effect relationships within a socio-ecological system, focusing on identifying and describing important linkages between the different components of risks.

The concept was first co-developed by Eurac Research for studies on climate vulnerability in the Alps, and then proposed in collaboration with the German Institute for International Cooperation (GIZ) as part of a methodological framework to assess vulnerability to climate change (Zebish et al.2022; 2023). This approach, in the last years, gained significant attention in the international community of (mostly climate) risk scholars and practitioners due to a combination of useful and appealing features, including:

- The clear and intuitive conceptual and visual representation of the main drivers of risk (hazard, exposure, vulnerability) and their relationships, including aspects related to cascading of risks,
- the explicit reference to impacts as key observable components of risk, and their (possibly causal) interrelation,
- the clear focus on vulnerability as a paramount risk driver which is often underrated due to its inherent complexity,
- the potential for the explicit consideration of risk mitigation and climate change adaptation measures
- the potential for integration of quantitative, semi-quantitative, qualitative and narrative approaches

We have developed a design thinking tool to assist in identifying impacts as well as different domains in which they can be observed (fig.2).

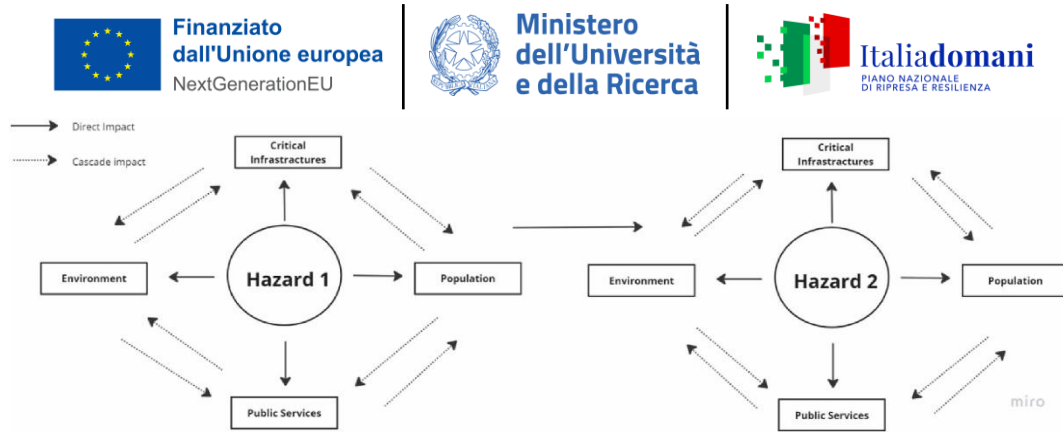


Figure 2: The Explorative Phase - Design Tool

This scheme considers the combined impact of two different hazards that have a relationship (causal or temporal) between them. The impact of each hazard is reconstructed across four dimensions:

- Physical and natural environment, observing the impact chains on flora and fauna
- Population, particularly the most vulnerable groups
- Public services, including schools, health, and commerce
- Critical infrastructure, especially electricity, water, and transport networks

Once the direct impacts of a hazard on a given dimension are identified, the next step is to consider potential “cascade” impacts. This involves examining how an impact on one dimension (e.g., natural environment, or critical infrastructures) could also affect others (e.g., population, public services etc.). The final step is to observe the integration of impacts between the two events, identifying impacts that only arise when both events occur. This helps to understand the multi-hazard nature of the event.

4.3.4 Identification of Strategic Action

The narrative and impact chains are managed by the panel of stakeholders engaged in the implementation phase of the storylines. As anticipated in section 3.2, the panel of experts in this case is made up of subjects who, in real life, could be confronted with the event and who have a different level of responsibility and/or representation in the implementation of a response: from civil protection to local administrations, from utilities to the insurance sector, from environmental associations to the grassroots. In this final part, the aim is to reconstruct the actions that an efficient risk management unit would implement if it were faced with the multi-hazard event described in the previous steps.

Like the reconstruction of the impacts, the targets of the strategic actions are the population, essential services, critical infrastructure and buildings, and the natural environment (fig.3)

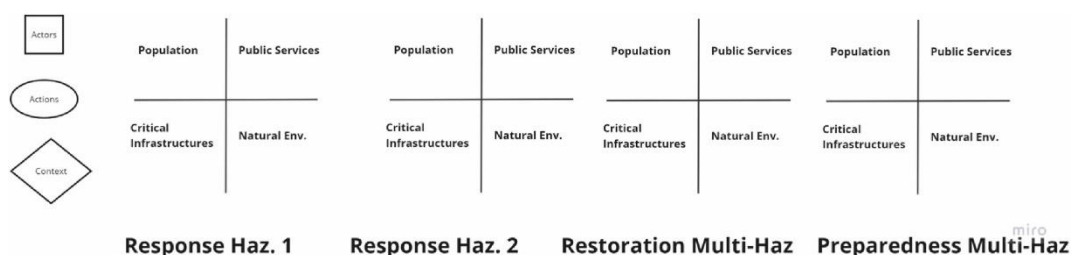


Figure 3: The Normative Phase - Design Tool

For each of these dimensions, the experts involved in the panel identify: i) the actors most responsible for making decisions or needing/possible to intervene; ii) the best actions they can take either individually or in a network; iii) the contextual variables that may enable or inhibit effective action.

The storylines follow a timeline divided into four sections: (i) immediate response to the first hazard, i.e. a set of activities carried out from the moment the event is expected and/or occurs; ii) immediate response to the second hazard; (iii) restoration actions during and immediately after the event; (iv) preparedness actions aimed at improving preparedness after the event. If the event consists of two or more hazards, as is the case with the storylines described below and tested in the RETURN project, the immediate response is reconstructed in relation to each event and based on what has already been done in terms of strategic actions.

The panelists work in sub-groups, simulating a real emergency control room. At the end of each phase (response, restoration and preparedness) they compare their work with that of other sub-groups, presenting their theses in plenary, with the aim of composing a single storyline.

1. The Risk Storyline in Action

In this paragraph, we present two applications of the model described in the previous section. The two contexts in which the storylines were developed are those of two UTEs, Genoa and FVG, where impacts and mitigation actions are envisaged with reference to two multi-hazard clusters: heat waves and intense rainfall in Genoa; storm surges and tsunamis in FVG. In addition to having fully contributed to the construction of both storylines, the research unit of the UTE of Naples also tested two different storylines in its own context, which served as a laboratory for the two applications presented below.

5.1 Heat Wave and Down Storm: the RS in the Genoa UTE

Risk Storylines (RS) are scenario techniques that consist of anticipating the physical, social and environmental impacts of potentially catastrophic events and, based on these potential impacts, inferring effective and as yet unimplemented prevention/mitigation actions.

One of the objectives that inspired the research line on storylines within the WP research group is to find a field of collaboration and intersection of expertise between the various local DRM stakeholders. A large and diverse group of organizations was involved in a task that was both predictive and strategic, consisting of identifying the possible impacts of the two events on the city and the most effective mitigation and prevention actions.

This chapter describes the main results obtained through the implementation of the risk storyline model in the Genoa context, which is highly exposed to several multi-hazard scenarios, particularly those in which heat waves and intense rainfall are combined. The following section focuses on the characterisation of events (Section 5.1.1), as the context has already been described in detail in DV 5.6.1, Paragraph 4.3.2. Section 5.1.2 then concerns the engagement of participants, followed by the analysis of impacts in Section 5.1.3. Finally, the strategic actions for mitigation and prevention are presented in the last sections.

5.1.1 Heatwave and downburst in the city of Genoa

The following table describes the RS heatwave in Genoa.

Day	Max Temp (°C)	Humidity (%)	Heat Index °	Physiological Discomfort
July 25	30	65	38.5	Very hot
July 26	32	65	41.5	Extremely hot

July 27	35.3	60	44.9	Extreme hot
July 28	35.5	55	44.1	Extreme hot
July 29	33.5	60	40.8	Extreme hot
July 30	32.6	60	38.5	Very hot
July 31	26.8	80	29.3	Hot
August 1	27.2	80	30.1	Hot

Table 2: Data on the simulated heatwave in Genoa

The heatwave observed between 25 July and 1 August shows a progressive dynamic characterised by a rapid increase in maximum temperatures and the combined action of relative humidity, responsible for raising the perceived heat index and therefore physiological discomfort. On the opening day, 25 July, the maximum temperature reached 30°C with 65% humidity, producing a heat index of 38.5°C and causing severe thermal discomfort classified as 'very hot'. The following day, 26 July, there was a further increase in temperature to 32°C, with humidity stable at 65%; the heat index exceeded the 40°C threshold, reaching 41.5°C, and the level of discomfort rose to 'extreme hot', implying increasing difficulty in thermoregulation for the population. 27 July represented one of the peaks in the sequence, with maximum temperatures of 35.3°C and humidity slightly reduced to 60%, but still sufficient to generate a very high heat index (44.9°C), which remained in the 'extreme hot' range and was associated with a potentially critical physiological load, especially for frail individuals. On 28 July, the situation did not improve: despite a slight decrease in humidity to 55%, the maximum temperature rose again to 35.5°C, and the heat index remained extremely high (44.1°C), confirming a situation of prolonged exposure to extreme heat for the fourth consecutive day.

From 29 July, the heat slowly began to decrease, but without resolving the perceived discomfort. Maximum temperatures fell to 33.5°C and humidity returned to 60%, keeping the heat index above 40°C (40.8°C), still in the 'extreme hot' range. Only on 30 July was there a further drop to 32.6°C, although humidity remained stable at 60%; the heat index fell to 38.5°C, equivalent to the 'very hot' level, still very challenging for the body. 31st July marked an apparent break: the maximum temperature dropped significantly to 26.8°C, but humidity rose to 80%, generating a heat index that was still high (29.3°C), classified as 'hot'. Conditions remain similar on 1 August, with a slightly higher maximum (27.2°C) and humidity still at 80%, bringing the heat index to 30.1°C and keeping the thermal perception in the 'hot' range.

Overall, the heatwave consists of four consecutive days of extreme heat stress (26–29 July) surrounded by days of intense heat before and after the peak, resulting in significant cumulative physiological exposure. The combination of high daytime temperatures and persistent humidity, especially in the middle of the event, indicates a continuous heat load that reduces the body's ability to recover even at night and creates weather

and climate conditions conducive to urban heat accumulation and saturation of human thermoregulation mechanisms.

The second table (tab.12) describes in detail the storm/downburst that breaks the heatwave but exposes the city to other hazards and affects other vulnerabilities (some of which were created by the heatwave itself).

Event	Start Event	Estimated Duration (h)	Rainfall (mm/h)	Total Estimated Rainfall	Humidity (%)	Temperature Drop ΔT (°C)	Max Wind Gust (km/h)
July 30	17:20	2.5 hours	100 mm/h	250	98%	9°C	138 km/h
July 31	16:45	2.3 hours	95 mm/h	220	96%	7°C	127 km/h

Table 3: Data on the simulated downburst in Genoa

The downburst that hit the city between 30 and 31 July manifested itself as a double sequence of phenomena less than twenty-four hours apart, with very similar characteristics but with cumulative impacts on the territory already weakened by the previous heatwave.

The first event begins at 5:20 p.m. on 30 July and lasts for about two and a half hours. From the early stages, rapid convective condensation is observed, followed by the collapse of the storm cell, which gives rise to an intense downdraft. The jet of cold air falling to the ground, typical of wet downbursts, expands horizontally with a turbulent and chaotic front, reaching gust values comparable to those of a vortex system. The rainfall is extremely concentrated, with an estimated rate of 100 mm/h and a total accumulation of 250 mm over the duration of the event, making the water supply unsustainable for the soil and drainage systems. Atmospheric humidity reaches levels close to saturation (98%) and a sharp drop in temperature of 9°C confirms the extent of the vertical transport of cold air. The gusts at their peak reach 138 km/h, imparting sufficient kinetic energy to cause structural damage, the felling of mature trees and the dangerous projection of debris.

The following day, 31 July, shortly after 4:45 p.m., a second downburst hit the same urban area, triggered by a new storm cell in an atmosphere that was still unstable and thermally contrasting. Again, the event developed rapidly and lasted for about 2.3 hours. Although slightly lower than the values of the first event, the rain remained very intense, reaching 95 mm/h for an estimated total of 220 mm, combined with 96% humidity, which highlights the high water content of the precipitation. The atmospheric cooling remains significant, with a temperature decrease of 7°C in a very short time, while maximum gusts reach 127 km/h, still compatible with destructive effects in anthropised contexts.

The most significant aspect of the sequence lies not only in the intensity of the individual phenomena, but also in the cumulative effect generated by the second event in an urban context already destabilised by the first.

The drainage networks, already saturated by the intense rainfall on 30 July, quickly reached critical conditions during the second episode, leading to sudden and localised flooding. The vegetation, already weakened by the previous mechanical stress, showed higher levels of failure, with a greater likelihood of trees and branches falling. Exposed structures, such as roofs, advertising hoardings, port warehouses and construction sites, further reduced their residual strength, amplifying the likelihood of detachment and projection of materials. In this configuration, the urban system has to simultaneously manage conditions of reduced visibility, destructive wind, mechanical impacts from debris, torrential rain and sudden temperature changes — a combination that multiplies the operational difficulties of emergency and rescue operations and reduces the safety margin for the population and essential service personnel.

In summary, the double episode of wet downbursts on 30 and 31 July was a highly complex and dangerous event, in which the close succession of the two events was decisive: the second struck when the city had not yet recovered the functionality of its physical and organisational networks, helping to transform an extreme weather event into a rapidly spreading multi-factor crisis.

5.1.2 Selection of participants

The Genoa risk storyline was developed with the contribution of two working groups. The attached table shows the organisations, the type of ecosystem to which they belong (with respect to the proposal formulated in paragraph III), and the phase of the storylines to which they adhered (the exploratory phase refers to impacts, the regulatory phase to prevention measures).

Given the task of the exploratory phase, preference was given to a panel of interdisciplinary DRM experts, mainly from research institutions or public agencies, for a total of 17 participants, representing 8 different organisations, including 4 from the University of Genoa. The second working group worked on mitigation and prevention actions, i.e. the regulatory phase: there were more participants in this part of the storylines, with 35 people involved, representing 20 organisations.

Organisation	Type of stakeholders	Engagement phase
University of Genoa - Department of Political Science	Knowledge	Exploratory / Regulatory
University of Genoa - Department of Civil Engineering	Knowledge	Exploratory / Normative
University of Genoa - Department of Economics	Knowledge	Exploratory
University of Genoa - Department of Education	Knowledge	Exploratory
Cima Foundation	Knowledge	Exploratory / Regulatory
Liguria Environmental Protection Agency (ARPAL) -	Decision-maker / Knowledge	Exploratory / Regulatory

Meteorology and Hydrology Sector		
Liguria Health Authority (ALISA) - Heatwave Prevention Centre	Decision-maker / Knowledge	Exploratory / Regulatory
Western Ligurian Sea Port Authority - Port of Genoa	Decision-maker	Regulatory
AMIAT	Decision-maker	Regulations
Prefecture of Genoa	Decision-maker	Regulations
Italian Red Cross	Learning	Regulations
Municipality of Genoa - Civil Protection	Decision-maker	Regulations
Doctors for the Environment - ISDE	Learning	Regulations
Eco institute RE.GE	Learning	Regulations
Friends of Ponte Carrega Association	Learning	Regulations
Agorà Cooperative	Learning	Regulations
Genoa Food Bank	Learning	Regulations
Coldiretti Liguria	Decision-maker / Learning	Regulations
Order of Architects	Knowledge	Regulations
Order of Engineers	Knowledge	Regulations
Port Authority	Decision-maker	Regulations
Confindustria Genoa	Decision-maker	Regulations

Marsh	Learning	Regulations
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Table 4: Participants in the RS in Genoa

With regard to decision-makers and knowledge producers, the selection was made on the basis of competence and availability on the days scheduled for the operational workshops. In relation to the civil society ecosystem, the choice fell on voluntary organisations involved in activities directly or indirectly related to DRM (from the Red Cross to the Food Bank) and environmental associations, or associations of reference for civic committees mobilised during flood events (Ponte Carrega Association, ISDE, etc.).

5.1.3 Impact Chains

The following table summarises the main impacts identified by the working group involved in the exploratory phase during a 4.5-hour workshop held in May 2025 at the University of Genoa. The first column highlights the target of the impact: as can be seen in the attached article, the RS proposes to observe the impacts of events on four domains: population, critical infrastructure, local public services and the natural environment. The second column provides a brief description of the impact, which is then repeated in the text of the paragraph. Finally, the last column divides the impacts in relation to the reference event and indicates 'combined' if the effect is the result of the interaction of the impacts between the two events.

Impact target	Brief description of the impact	Reference event
Population	Increase in mortality and hospitalisations due to cardiorespiratory diseases and dehydration	Heatwave
Population	Deterioration in psychological well-being, irritability, loss of sleep and concentration	Heatwave
Population	Trauma and injuries caused by flying objects, falling trees and partial collapses	Downburst
Population	Sudden exposure in outdoor environments (beaches, parks) without the possibility of shelter	Downburst
Population	Drastic decline in individual and collective response capabilities due to previous heat stress	Combined effect
Critical infrastructure	Overloading of the electricity grid and risk of blackouts	Heatwave
Critical infrastructure	Damage to roofs, power lines, port facilities and roads	Downbursts
Critical infrastructure	Slowdown in recovery times due to already compromised operating conditions	Combined effect

Public services	Hospital overload and reduced care capacity	Heatwave
Public services	Rapid increase in demand for emergency and civil protection services	Downburst
Public services	Temporary organisational collapse due to dual pressure on health and social care services	Combined effect
Public services	Stress on the water network and urban sanitation services	Heatwave
Natural environment	Deterioration in air quality and increased ozone levels	Heatwave
Natural environment	Localised flooding, spills into the sea and microbiological risk	Downbursts
Natural environment	Deterioration of coastal waters and temporary loss of bathing suitability	Combined effect
Economy (cross-cutting)	Reduced consumption, increased energy costs, material damage and logistical delays	Combined effect

Table 5: Standalone and Combined Impacts

The most significant health impact concerns the over-80s, with an expected increase in mortality from kidney failure, heart failure and severe dehydration; emergency room admissions increase exponentially within 48 hours of the onset of the heatwave, putting pressure on the hospital system. However, the health effects are not limited to vulnerable groups: weakness, irritability, loss of concentration and reduced sleep quality spread among the general population, with repercussions on road safety, accidents at work, school/university performance and psychological well-being.

The heatwave also triggers cultural and socio-economic dynamics that intensify vulnerability: perceived underestimation of risk, resistance to the use of air conditioning for economic or cultural reasons, difficulties in managing daily habits among the elderly, and income inequalities in terms of access to air-conditioned spaces, private care or holidays. There are also social implications: isolated individuals are at greater risk than those who live in social networks, while groups such as tourists and the homeless are exposed to a lack of shaded areas or personalised warning systems.

In terms of services and infrastructure, the sudden and prolonged increase in demand for air conditioning could lead to network overload, micro-blackouts and the need for rationalisation, especially in urban areas with high residential density and in hilly neighbourhoods served by more vulnerable electrical infrastructure.

The water network is exposed to increased consumption and possible stress on reserves, with effects on pressure reduction, while the increase in organic waste and the faster degradation of materials on the streets requires a strengthening of urban sanitation operations at a time when the operational capacity of staff may be reduced by the heat itself. Public and private transport are affected by overheating: road vehicles suffer more

breakdowns and waiting times, railways can suffer thermal expansion, and transport operators work in less safe conditions.

As the exercise showed, at the economic level, heat waves change consumer behaviour: primary goods are favoured and unnecessary purchases are reduced, with a particular impact on retail trade and non-seaside tourist services. The increase in energy costs for air conditioning in commercial establishments erodes profit margins precisely in the months when spending is highest. Impacts are also expected on the insurance market, which is seeing an increase in claims for coverage for damage caused by prolonged heat and equipment breakdowns.

In terms of the urban environment, rising temperatures increase ozone levels and the stagnation of pollutants, worsening air quality and aggravating pre-existing respiratory conditions. The overheating of sea water promotes mucilage and algal blooms, which limit bathing, recreational activities and the tourist economy of beaches. The absence of breezes accentuates the perception of heat in densely urbanised areas and transforms unshaded public spaces into areas that pose a health risk.

Under these conditions, the city found itself in a situation of systemic vulnerability when, between 29 and 30 July, there was a double episode of wet downbursts, characterised by gusts of up to 138 km/h, very intense precipitation (20.3 mm in 15 minutes) and hail. The transition from extreme heat to violent storms did not allow the population, infrastructure and services to recover. Downbursts are highly unpredictable, with extremely short reaction times and highly variable spatial impacts. Wind gusts cause trees to fall, damage power lines, overturn containers and signs, and cause the loss of roofing and facade elements, while wind-blown debris obstructs road and rail traffic.

Port areas, due to the presence of containers, cranes and heavy vehicles, are among the most exposed to damage and economic disruption, with potential risks for operational personnel. Highly concentrated rainfall causes localised flooding, especially in underpasses and low-lying areas with inadequate drainage, exacerbated by hailstones blocking drains. The sewerage system can become pressurised and cause spills into the sea, leading to a sudden deterioration in coastal water quality and microbiological risks.

Downbursts also affect people's movements: those who, due to the heat, have sought refreshment on the beach, in parks or on karst walks suddenly find themselves outdoors and potentially in an unsafe environment, with no time to seek shelter; the two most exposed groups of the population are those who travel on foot or by motorbike and those who practise outdoor sports. The healthcare system, already overburdened by the heatwave, has to cope with a sudden spike in trauma and injuries, with staff working in conditions where their physical and mental health is worsened by the persistent heat.

Added to this is the increased need for civil protection interventions, not only to assist the population but also to quickly restore traffic flow, secure port areas, manage dangerous trees and provide support for power outages. A further level of impact concerns the economic dimension: there is significant material damage to buildings, vehicles and public infrastructure, an increase in insurance claims and potential delays in business operations.

For some sectors, the downburst generates greater losses than the heatwave, especially in the construction, logistics and agricultural sectors, while the indirect effects — suspension of activities, delays in freight transport, reduced accessibility to services — can continue over time. Since the two events occur in close succession, the overall vulnerability is not the sum of the impacts, but the product of their chain reaction: the downburst finds a city already physiologically stressed, public services at their limit, a population with reduced adaptive capacity and institutional resources already partially allocated to cope with the heat.

The storyline confirms that the sequential concurrence of extreme climate events not only amplifies critical issues within the sector, but also generates new interdependencies between health, economic, social and infrastructural areas, requiring a risk planning approach geared towards multiple shocks and cumulative effects over time, with particular attention to inequalities in vulnerability and access to protection.

5.1.4 The Strategic Actions

The following table lists the main prevention and mitigation actions planned by the actors involved in the regulatory phase (tab.15).

Action	Description	Risk
Institutional coordination and volunteering	Extension of agreements between institutions and the Region for the activation of volunteering, reduction of fragmentation in the management of interventions, establishment of a single coordination centre (CCS or similar).	Heat + Downburst
Shared civil protection exercises	Real and integrated simulations with the participation of all institutions and the involvement of citizens.	Heat + Downburst
Training for journalists and official sources	Mandatory courses for journalists in collaboration with the Order, strengthening official sources and trust in institutions.	Heat + Downburst
Safety in port workplaces	Uniform application of the measures provided for by safety legislation (Legislative Decree 81/2008), development of best practices for port operators.	Heat
AI for utilities and services management	Use of artificial intelligence systems to adapt utility activities (e.g. organic waste collection during cooler hours).	Heat
Energy redundancy (cogeneration, PV)	Development of cogeneration systems and renewable sources (e.g. photovoltaics) to ensure continuity of critical services in the event of a blackout.	Heat + Downburst
Network of on-call GPs	Creation of an on-call service similar to 118 to contact GPs available outside of normal hours.	Heat
Green infrastructure and safe routes	Enhancement of green areas, shaded areas, misting systems and water fountains. Creation of safe and cool routes	Heat

Simplified building file	Objective vulnerability assessment of buildings (roofs, openings, materials) compiled by university students.	Downburst
Management and reduction of water network leaks	Reduction of network leaks, creation of collection basins and rural water management systems.	Heat
Electrification of quays and fleet renewal	Measures to reduce port emissions (cold ironing, less polluting fleets).	Heat
Adjustment of working hours and services	Rescheduling of working hours, smart working, adaptation of business hours and public transport.	Heat
Climate-friendly urban planning	Increase in green areas and cooling zones, selection of suitable plant species, inter-institutional coordination.	Heat
Green solutions for downbursts	Increased soil permeability and green infrastructure to absorb rainwater.	Downbursts
Resilient beach facilities + insurance	Improvement of beach facilities and promotion of insurance against tornadoes and downbursts.	Downbursts

Table 6: List and description of prevention and mitigation actions

The first line of action concerns the strengthening of institutional coordination and volunteering: the aim is to create a stable command and control mechanism, with structured agreements between the Region, Municipalities, Fire Brigade, Civil Protection and associations, capable of acting quickly without fragmentation of responsibilities. The objective is to make the decision-making and operational process faster, more orderly and more transparent, ensuring a timely response to the population and limiting the risk of overlap between teams and services.

To consolidate this response capacity, joint civil protection exercises based on realistic, high-impact scenarios are also organised on a regular basis. These exercises involve the integrated participation of public bodies, health services, public utility companies, port facilities, schools and citizens, with the aim of testing the effectiveness of protocols in the field and increasing the capacity for collective action in situations of climate stress. Part of this effort also focuses on public communication of the emergency: training courses for journalists, developed in conjunction with the professional association, aim to consolidate the role of institutional and scientific sources and to combat misinformation during extreme events. More accurate and verified communication is a determining factor for collective safety because it improves understanding of risks and helps to increase trust in the responsible authorities.

A particularly sensitive area is the workplace, especially in port operations, where exposure to heat and wind is a growing risk factor. The action dedicated to safety in port workplaces proposes the uniform and reinforced application of the provisions of Legislative Decree 81/2008, the definition of climate thresholds for the temporary suspension of activities, the introduction of cooling zones and the management of shifts according

to weather conditions. The expected benefit is a reduction in accidents and health risks for workers, with positive repercussions also for the efficiency and continuity of port activities.

Other measures focus on essential services in a more technological way. The introduction of artificial intelligence for the management of utilities (a management system that is envisaged to be integrated, especially in terms of the data held by the various concessionaires/operators) makes it possible to predictively reschedule activities such as waste collection, water network management and energy distribution based on forecast weather conditions, reducing worker exposure and ensuring continuity of services during temperature peaks.

Health measures emerge as a fundamental pillar. The proposal for a network of on-call GPs based on the 118 model responds to the need to quickly identify situations of health vulnerability during heat peaks, especially among the elderly, people living alone and the chronically ill. Early intervention across the territory reduces inappropriate visits to A&E and better protects those most at risk. This approach is accompanied by investment in energy redundancy through cogeneration systems and photovoltaic installations in critical sites — hospitals, nursing homes, water facilities, operational centres — to ensure continued operation even in the event of a blackout. Together, these solutions aim to limit the impact of heatwaves on essential services and daily life.

At the same time, action is being taken in public spaces to limit their hostility during extreme events. The enhancement of green infrastructure, the introduction of shaded areas, misters, water fountains and the creation of cool and safe routes allow for sustainable travel even during the hottest hours of the day and reduce the isolation of vulnerable groups. In line with this approach, climate-responsive urban planning aims to integrate green structures, ecological corridors and landscaping solutions designed to mitigate the urban heat island effect and promote widespread cooling, with a particular focus on the most densely built-up and socially fragile areas.

Another strategic front concerns water: the management and reduction of water network leaks — combined with the creation of collection basins and rural water regulation systems — is a form of prevention against both water scarcity during heatwaves and damage from abnormal runoff caused by sudden and violent rainfall. The measure aims to protect households, agricultural activities and public services by making the entire water cycle more resilient.

The actions also focus on the climate resilience of port and coastal areas, which are highly exposed. The electrification of quays and the renewal of naval fleets will reduce air pollution from emissions when ships are stationary, a factor that exacerbates the effects of heatwaves on the resident population. Added to this is the issue of the economic and structural protection of seaside businesses: the construction of establishments that are more resistant to linear winds and hail, together with the spread of insurance dedicated to extreme events, protects an economic sector that is vulnerable to downbursts and makes recovery after impacts more sustainable.

The risk of downbursts is also addressed in urban construction with the introduction of a simplified building dossier that identifies structural vulnerabilities quickly and economically. The involvement of university students, under technical supervision, speeds up data collection and spreads a culture of prevention based on knowledge of the built heritage. Alongside this, the application of absorbent urban green solutions — rain gardens, draining surfaces, widespread basins — helps to reduce the impact of extreme rainfall typical of downbursts, reducing flooding and damage from hydraulic pressure on underground networks.

Finally, many economic and social organisations have emphasised the importance of adapting working hours and services during periods of extreme heat. Rescheduling shifts, smart working, revising business hours and adjustments to public transport reduce the thermal exposure of workers and citizens, while improving quality of life and production continuity.

Taken together, these actions outline a model of climate resilience built around institutional cooperation, technological innovation, public health protection, urban quality and the protection of economic activities. The region aims not only to respond better to emergencies, but also to become structurally less vulnerable, more coordinated and capable of adapting intelligently and collectively to current and future climatic conditions.

5.2 Storm Surge and Tsunami: the RS in the FVG UTE

5.2.1 Introduction

One of the main activities carried out by the FVG UTE team of research, is the contribution to the development of the **multi-risk storylines** methodology, namely qualitative scenarios for multi-hazard events, aimed at

anticipating potential impacts and outlining actions and contextual conditions that can improve territorial resilience to risks. The general methodological approach and its development within the project is described in detail in the section IV of this DV and in the paper “*A participatory foresight approach in disaster risk management: the multi-risk storylines*” by Marciano et al. (2024), available at: <https://doi.org/10.1016/j.ijdr.2024.104972>.

A physical description of a broad set of relevant individual and multiple hazards (ranging from geo-hazards, to anthropogenic and climate related ones), as well as a collection of sample risk storylines with a focus on impact chains, is provided in the deliverable **DV 5.3.1 “Report and scenarios for multi-risk, cascading and compounding effects and emerging risks”**.

Within the UTE-FVG, the development and testing of the multi-risk storyline methodology further continued, exploring the possibility of adopting a scenario based approach, which relies on the physical modelling of plausible hazardous events, to develop realistic site specific multi-risk storylines for urban contexts of different typologies. Physical modelling of earthquakes and cascading hazards (e.g. earthquake induced tsunamis or landslides, described in previous sections), as well as sequential hazards (e.g. a storm surge followed by a tsunami), in fact, may provide the basis for defining plausible (yet unobserved) multi-hazard and risk scenarios. For the definition of possible impacts, high-resolution exposure models are also needed at the local scale, especially for hazards which exhibit high spatial variability. In the specific UTE-FVG testing cases the methodology by Badreldin et al., (2025), described in previous sections, is considered, which allows us to develop high-resolution exposure models for population and residential buildings. Ultimately, the **methodology for plausible scenario based multi-risk storylines development** (namely the definition of plausible scenarios for **existing urban context**, described below) intends to supply the basis to explore the complex interactions and consequences emerging from different hazards, highlighting how one event can amplify the effects of another within a shared environment.

The experimental testing of the multi-risk storyline methodology in the UTE-FVG involved the participation of quite heterogeneous groups of both institutional and non-institutional stakeholder groups. The first phase of this experimentation, conducted for the coastal area of the UTE-FVG (one of the three territorial units identified for this purpose, together with Genoa and Naples), took place in Trieste on 6 March 2025 and allowed for the identification of potential impacts of the proposed scenarios on the different components of the urban ecosystem. The second phase was carried out in Lignano Sabbiadoro (one of the investigated municipalities within the UTE) on 21 October 2025. The aim of the second stage was to identify possible interventions and strategies that can prevent and address multi-hazard events in a holistic and effective manner, highlighting relevant complexities and interactions to enhance the resilience of the territory in the face of the possible occurrence of such scenarios. Through a participatory process, the multi-risk storylines engaged institutional actors, technical experts, and local communities, transforming data, experiences, and perceptions into dynamic and shared risk scenarios. The resulting narratives do not intend to merely describe past events, but rather to anticipate plausible future scenarios and viable response, recovery and mitigation actions, contributing towards integrated multi-risk management strategies. The study highlighted the importance of accurately describing assets (including possible mitigation interventions and alert systems), exposure, and socio-economic and physical vulnerabilities of urban systems, since these factors may influence impacts and the effectiveness of response and mitigation strategies. The developed scenarios supply a systematic methodology for exploring how the complex interplay between hazards and urban systems may impact a society, and can be applied to support and rationalize decision making and inform preparedness for multi-risks management and mitigation. The methodology, developed and tested considering selected coastal areas along the Northern Adriatic, as described hereinafter, turned out very effective to facilitate discussion of impacts and mitigation strategies for the proposed scenarios, for both frequent (storm surge) and rare (tsunami) events. The

proposed approach can be easily applied to other urban areas with similar features, e.g. those located along the coasts of Western Adriatic.

5.2.2 Definition of the territorial context and the multi-hazard scenario

Defining the urban context of interest is essential for the development of risk storylines, as it enables the identification of local vulnerabilities, exposures, and relevant hazards affecting the urban system. Exposure, i.e., the presence and quantity of specific assets such as people, housing, infrastructure, species, or ecosystems, together with vulnerability factors, significantly determines both the level of impact and the effectiveness of response and recovery strategies against natural hazards. Urban vulnerability depends on multiple dimensions—physical, social, economic, environmental, and institutional—that shape the susceptibility of systems to hazard impacts. Socio-economic characteristics, such as the proportion of elderly residents, employment rates, and education levels, can influence vulnerability due to reduced capacity to respond to and manage hazard effects. Historical evidence indicates that older populations are often more vulnerable due to limited mobility, health constraints, and communication barriers, while education level affects risk awareness, preparedness, and adaptive capacity.

a. Ideal-typical context (abstract yet concrete)

Advantages:

- **Generalizability:** Facilitates the identification of common risk patterns applicable across multiple real-world contexts, supporting broader applicability of findings.
- **Multi-stakeholder engagement:** Promotes dialogue among actors from diverse territories while minimizing conflicts or resistance linked to specific contexts.
- **Flexibility:** Allows modeling of risk scenarios independently of data limitations or constraints of an existing context.
- **Mitigation of bias and political sensitivity:** Reduces controversies or pressures associated with particular geographic areas, institutions, or policy decisions.

Disadvantages:

- **Reduced territorial accuracy:** Absence of direct contextual references may result in less detailed descriptions of impacts and actions.
- **Challenges in empirical validation:** Lack of concrete data may hinder the comparison of scenario outcomes with observed impacts.
- **Lower operational effectiveness:** May be less directly useful for local administrations requiring strategies tailored to their specific territory.

b. Existing Contexts

Advantages:

- **Higher analytical precision:** Incorporation of real-world data enables more accurate modeling of risk processes and potential impacts.
- **Validation potential:** Scenarios can be compared against historical events, enhancing the reliability of simulations.
- **Practical relevance:** Outputs are directly applicable to risk management policies and context-specific adaptation strategies.
- **Enhanced local engagement:** Familiarity with the context increases stakeholder motivation and participation; risk storylines also improve awareness and provide alternative perspectives on the urban system.

Disadvantages:

- **Need for detailed context-specific information:** Developing storylines for a specific urban context necessitates additional data on regulations, early warning systems, and mitigation measures.

- Limited transferability: While methodologies may be adapted to other urban contexts with similar characteristics, direct applicability remains a key limitation.

Overall, the use of existing contexts allows complex interactions, vulnerabilities, and specific impacts to emerge that cannot be identified in an ideal-typical context.

The proposed methodology has been tested considering selected coastal areas within the UTE-FVG, identifying two contexts with basically different physical and social typologies, namely the “Historic center in urban hub” (corresponding to Trieste historical centre), and a “Seaside tourist urban area” (relate to Grado and Lignano Sabbiadoro).

Two independent and concurrent hazards have been considered to develop the storylines: the first event to occur is a severe storm surge, which combines with a second event, namely an earthquake-induced tsunami, which starts a few hours later. For the storm surge we considered a modeled event (e.g. Manzan et al., 2022) with a relatively long return period of about 30 years. Though such an event is nominally quite infrequent, a meteo-alert can be generally delivered for possible storm surges about 24 hours in advance; moreover severe storm surges have been experienced in the considered contexts during the past decade, and therefore the population is well aware about the related hazard.

For the earthquake-induced tsunami, we considered an event modeled as described in section 5.2.3 of DV 5.6.1. The tsunami is generated by a strong offshore earthquake (magnitude about 6.5-7.0) located at about 200 km distance from the considered sites (given the distance, no major effects are due to the earthquake shaking). An advisory message is issued by the national early warning system (SiAM - Sistema Allertamento Maremoti) for a moderate tsunami (tsunami waves up to 50 cm offshore, run-up less than 1 m). After a while (about a couple of hours) the tsunami waves reach the site of interest and combine with the storm surge, further increasing the water height and consequently the extent of the inundated area. Differently from storm surges, tsunamis in the Northern Adriatic are moderate and extremely infrequent events; therefore the population is not aware about this hazard. However, due to climate change SLR and rapidly increasing exposure in coastal areas, the related risk might significantly increase in the next decades.

Independent and compounding Hazards
Event 1: Storm surge (literature)
Event 2: Earthquake-induced tsunami (modeled)
Combined: Storm surge + tsunami (modeled)

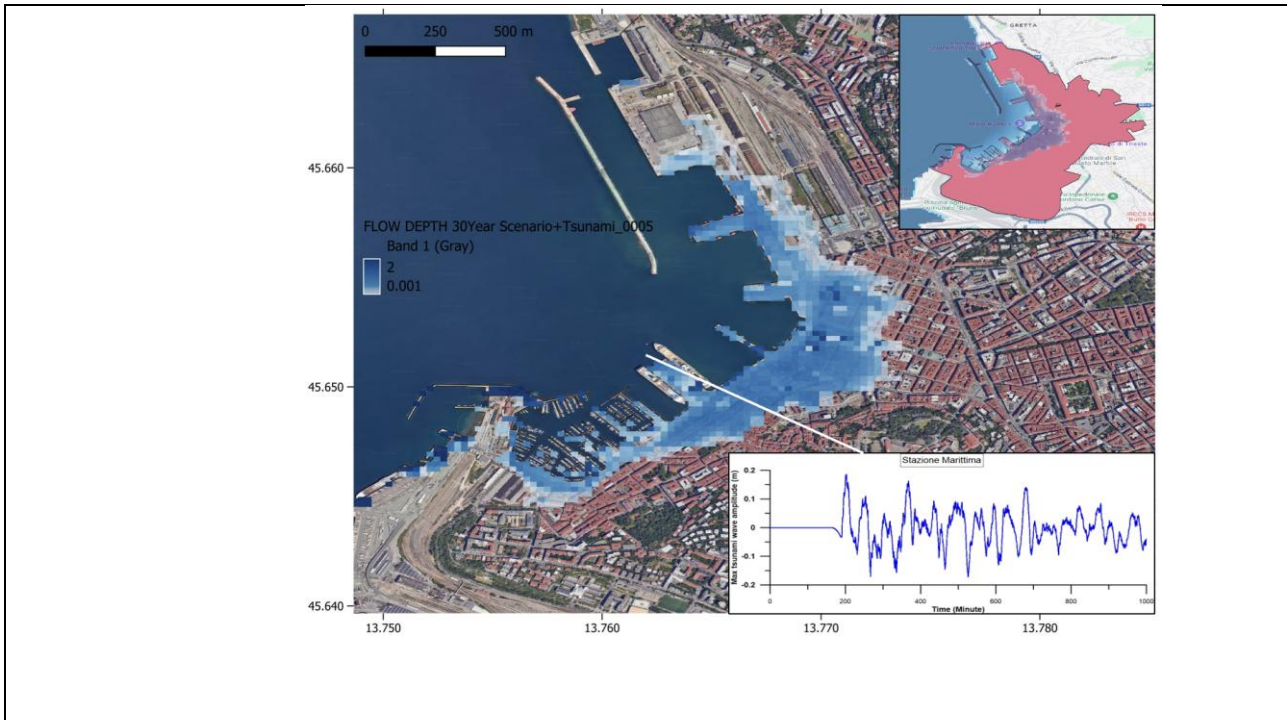


Figure 4: Example of compound scenario for tsunami and storm surge concurrent events, modeled based on the methodology described in Section 5.2.3 (DV 5.6.1). Map of inundated area (water depth); map of the territorial context (pink area, top-right panel); modeled mareogram for tsunami event (bottom-right panel).

The objects of study examined within the storylines are succinctly described in the following table.

Coastal area – Historic center in Urban Hub	Coastal area – Seaside tourist Urban area
<p>The context is situated within a metropolitan city (urban hub) of approximately 200,000 inhabitants, located in a coastal area. Due to its geographic position, geological characteristics, and variable topography, the area is exposed to landslide phenomena and has a history of previous storm surges. The port city, which also serves as the regional capital, offers a wide range of essential services (higher education, healthcare, railway transportation) and functions as a major center of attraction, generating significant catchment areas that include both domestic and international tourism.</p> <p>The context under consideration corresponds to the city's historic core, covering an area of approximately 5 square kilometers, and is characterized by a very high population density (over</p>	<p>The context is an intermediate area with a population of approximately 6,900 inhabitants in a coastal zone, which has grown by about 15% over the past 20 years. The municipality extends over a peninsula 8 km long and 1.4 km wide, located between the lagoons of Grado and Marano and the Adriatic Sea, at an elevation of 2 meters above sea level. The territory, which forms part of the Tagliamento delta system, features a low and sandy coastline and extensive reclaimed land dating back to historical reclamation works.</p> <p>The population density is twice the national average (444 inhabitants per km² compared to a national average of less than 200 inhabitants per km²). The municipality represents an important tourist hub during the summer period. Visitor numbers are</p>

<p>6,000 inhabitants per km², compared to a national average of less than 200 inhabitants per km²). The population is relatively old, with more than 30% of residents aged over 65 and only about 10% of school-age. At the municipal level, 12% of the resident population is foreign-born (compared to 9% nationally), although the area affected by the event exhibits an even higher concentration of migrants.</p> <p>Social vulnerability is relatively low, given the high employment rate (around 70%), per capita income, and educational attainment, all of which exceed the national average. The area is predominantly composed of residential and historical masonry buildings of moderate height. In terms of services, the area hosts several schools (around 30), the main railway station, and a hospital—the second largest in the metropolitan area in terms of size and service provision.</p>	<p>highly dependent on tourism, as 90% of total presences occur between May and September, with an average of 143,000 people in August compared to 19,500 in February. The municipality accounts for approximately 36% of all tourist presences in Friuli Venezia Giulia, confirming its status as one of the region's leading destinations.</p> <p>Tourism has fostered significant urban development: the coastal strip is almost entirely urbanized, while the inland area retains flat, historically reclaimed land.</p> <p>In the area under consideration, the average age is 48 years; the elderly population accounts for 26% of residents, while foreign nationals represent 12% (compared to 9% nationally and 11.5% in northeastern Italy).</p> <p>The employment rate stands at 62%, and the average annual income is approximately €20,000. The area is served by primary and secondary schools and basic healthcare services, but lacks hospitals and direct railway connections (the nearest station being Latisana–Lignano–Bibione).</p>
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Table 7 The contextual characteristics of the areas considered

5.2.3 Stakeholders

The following table illustrates the composition of the stakeholder group engaged in the Exploratory and Regulatory phases.

Organisation and role	Type of stakeholders	Engagement Phases
Municipality of Trieste - Department of Territory, Environment, Public Works and Assets Environmental, Green Spaces and Urban Hygiene Service Head of the Green Projects Operating Unit	Decision-maker	Exploratory
Municipality of Trieste - Head of the Civil Protection Unit	Decision-maker	Exploratory

Autonomous Region of Friuli Venezia Giulia - Prevention and Protection Service Organizational Position for the Management and Development of the Decentralized Functional Center	Decision-maker	Exploratory / Regulatory
Autonomous Region of Friuli Venezia Giulia - Regional Civil Protection Decentralized Functional Center	Decision-maker	Exploratory
Municipality of Trieste - Head of the Green Areas and Tree Management Unit	Decision-maker	Exploratory
Autonomous Region of Friuli Venezia Giulia - Administrative Officer	Decision-maker - Knowledge production	Exploratory
Municipality of Lignano Sabbiadoro - Head of the IT and Demographic Services Department	Decision-maker - Knowledge production	Exploratory / Regulatory
Municipality of Lignano Sabbiadoro - Councillor with responsibilities for Health, IT Services, and Social and Youth Policies	Decision-maker	Exploratory / Regulatory
Engineer	Knowledge production	Exploratory
Regional Red Cross - Regional Delegate for Operations, Emergencies and Rescue Regional Committee of Friuli Venezia Giulia	Decision-maker- Knowledge transfer learning	Exploratory / Regulatory
AcegasApsAmga - Engineer	Decision-maker - Knowledge production	Exploratory
University of Trieste - Associate Professor, Environmental Sociology	Knowledge production	Exploratory
University of Trieste - Associate Professor of Geography	Knowledge production	Exploratory
OGS - Senior Researcher	Knowledge production	Exploratory / Regulatory
University of Trieste - Full Professor Stratigraphic Geology and Sedimentology	Knowledge production	Exploratory

University of Trieste - Research Fellow, Department of Mathematics, Computer Science and Geosciences	Knowledge production	Exploratory / Regulatory
ARPA FVG - Technical Scientific Director Head of the SOC: SOC Osmer and Natural Risk Management	Decision maker - Knowledge production	Exploratory
University of the Third Age "Danilo Dobrina" of Trieste - Professor & Course Director	Knowledge transfer learning	Exploratory
Ansa - Journalist	Knowledge transfer learning	Exploratory
"Galileo Galilei" State Scientific High School of Trieste - Teacher	Knowledge transfer learning	Exploratory / Regulatory
"Galvani" Nautical Institute - School Principal	Knowledge transfer learning	Exploratory
OGS - Communications Office	Knowledge transfer learning	Exploratory / Regulatory
OGS - Communications Office	Knowledge transfer learning	Exploratory / Regulatory
Autonomous Region of Friuli Venezia Giulia - Administrative Officer	Decision-maker - Knowledge production	Exploratory
Journalist	Knowledge transfer learning	Exploratory
Lignano Pineta Spa- Beach Facilities Management - President and Owner	Decision-maker - Knowledge transfer learning	Regulatory
Municipality of Lignano Sabbiadoro - Deputy Commander of the Local Police	Decision-maker	Regulatory
Architect	Knowledge production	Regulatory
Architect	Knowledge production	Regulatory
Municipality of Lignano Sabbiadoro - Senior Technical Instructor - Urban Planning	Decision-maker - Knowledge production	Regulatory
Citizen	Knowledge transfer learning	Regulatory
OGS - Technical Collaborator	Knowledge production	Regulatory

Municipality of Lignano Sabbiadoro - Head of the Building and Land Management Department	Decision-maker - Knowledge production	Regulatory
Architect	Knowledge production	Regulatory
ARPA FVG - Climate, Data and Monitoring Unit	Knowledge production	Regulatory
Autonomous Region of Friuli Venezia Giulia - Administrative Officer	Decision-maker - Knowledge production	Regulatory
Municipality of Lignano Sabbiadoro - Senior Technical Instructor - Public Works	Decision-maker - Knowledge production	Regulatory
Lisagest - Presidente	Decision-maker	Regulatory
Energy Agency of Friuli Venezia Giulia - President	Decision-maker - Knowledge production	Regulatory
Citizen	Knowledge transfer learning	Regulatory

Table 8: Stakeholders involved in the Exploratory and Regulatory phases.

5.2.4 Main Results

The potential identified impacts, distinguished by context and analytical dimension, is provided in table 9.

Main/Relevant impacts - Storm Surge	
Coastal area – Historic center in Urban Hub	Coastal area – Seaside tourist Urban area
<p>Population: Students (especially children), Teachers, Elderly, Workers (particularly port workers, public transport drivers, and local shopkeepers), People with disabilities, Homeless individuals and Tourists.</p> <p>Environment: Public green spaces (especially trees), Animals (small-sized species), Water (deterioration of quality) and coastal areas</p> <p>Services: Transport, Emergency services, Shops,</p>	<p>Population: Evacuees and individuals to be evacuated, People with disabilities, elderly, and vulnerable individuals, Students in schools, Residents living on lower floors, Public officials, Parents waiting for their children at schools, Individuals putting themselves at risk to save personal belongings.</p> <p>Environment: Coast, Beaches, Flora and Fauna, Lagoon.</p> <p>Services: Road (buses and taxis) and maritime</p>

<p>Hospitals, Nursing homes, Schools of various levels, Offices, Information points (Infopoints), Accommodation facilities.</p> <p>Infrastructure: Infrastructure networks such as (electricity, water, gas) internal roads, port, and rail systems.</p> <p>Built Environment: Underground parking lots, Basements and cellars, Ground floors, Underpasses, Historic buildings, Poorly maintained houses, Monuments located near the coast.</p>	<p>transport, Water supply network, Schools, Hospitals.</p> <p>Infrastructure: Infrastructure networks: telephone, internet and electricity), Roads, Electricity substations, Sewer system, Port infrastructure.</p> <p>Built Environment: Old areas of the city, Residences, particularly single-family houses, Monuments, Churches and Museums.</p>
Main/Relevant impacts - Storm Surge + Tsunami	
<p>Coastal area – Historic center in Urban Hub</p>	<p>Coastal area – Seaside tourist Urban area</p>
<p>Population: All resident and temporary populations, including transients, even extending beyond the area previously impacted by the storm surge.</p> <p>Environment: Coastal and cliff areas, Flora and fauna, extending beyond the areas previously impacted by the storm surge.</p> <p>Services: Traffic lights, Prefecture, Increased pressure on hospitals, Disruption of trains, healthcare, and social services.</p> <p>Infrastructure: Public lighting, Bridges, Canals, Ports, Underground infrastructure.</p> <p>Built Environment: Dilapidated or uninhabited houses (particularly cornices and roofs) located inland, Urban furnishings, Artistic, architectural, and archaeological heritage.</p>	<p>Population: Vulnerable individuals and people with disabilities, Tourism.</p> <p>Environment: Coast, Pine forests and Animals.</p> <p>Services: Shops, Road transport (taxis), Maritime transport, Communication systems and Hospitals.</p> <p>Infrastructure: Protective barriers, Marinas and small boat yards, Sewer system, Houses and churches.</p> <p>Built Environment: Buildings, particularly basements, under-stair areas, and underground rooms, Aged structures, Houses and churches, Structures previously affected by the storm surge.</p>

Table 9: Potential identified impacts in the two contexts analyzed.

The findings concerning the mitigation and prevention measures identified by the participants working on the *Coastal area - Historic center in Urban Hub* have been reformulated and concisely synthesized in table 10.

<p>Mitigation and prevention measures</p>
--

Coastal area – Historic center in Urban Hub

The storm surge alert occurred:

The population has been informed of the warning, and local and regional authorities have activated monitoring and operational measures. Citizens are advised to secure belongings and prepare for possible school closures. Improved guidance and an effective, reliable information system are needed to prevent misinformation. Communication should also reach those not using social media through tourism operators and multilingual channels.

The storm surge takes place:

Following the event, affected areas are mapped and data are collected, including an assessment of the effectiveness of prior measures. The Municipal Operational Centre is activated, vulnerable populations are assisted, and temporary shelters are identified, including provisions for tourists. Coordination among institutions leads to the issuance of municipal ordinances.

In the transport sector, the relocation of vulnerable individuals presents critical challenges, necessitating appropriate internal procedures; Trieste benefits from multi-story buildings and operational plans for cruise ship traffic.

Citizens are expected to act proactively, while urban planning should be revised to increase green spaces and sustainable drainage systems. Building maintenance adheres to existing regulations, whereas the management of historical heritage is overseen by the relevant supervisory authorities.

Shelters for exposed groups, such as migrants, are already included in emergency plans. Communication must be continuous, multilingual, and reliable, with alternative methods in the absence of internet access, such as amateur radio operators and satellite-based systems.

Operational Management Following the Storm Surge:

The principal operational measures encompass systematic data collection and damage mapping, establishment of temporary shelters for vulnerable populations and tourists, rapid interventions in basements and underpasses, traffic regulation through municipal ordinances, activation of internal logistical plans, and ensuring the availability of municipal response teams. These measures are considered of high priority.

- *Key actors* include municipal authorities, local police, law enforcement agencies, civil protection, the Red Cross, and fire services, with support from tourism operators.
- *Principal challenges* involve limited training exercises, complex inter-agency coordination, unforeseen contingencies, and constrained resources.

Tsunami alert and Risk Mitigation measures:

Avoid placing vulnerable infrastructure in high-risk areas. Increase safety elevations and designate sacrificial zones (e.g., plazas, sloped areas). Establish dedicated evacuation routes and strengthen early warning and communication systems. Expand and adapt communication networks, and install non-return valves in sewer systems.

Adopt a resilience-oriented urban planning approach, integrating artificial barriers and nature-based

solutions (NBS). Implement selective protections in highly sensitive areas (e.g., ports) based on cost–benefit analyses, analogous to the MOSE project. Enact special legislation for coastal cities and promote gradual relocation of exposed areas. Attention should also be given to reclaimed lands and long-term scenarios, including projected sea-level rise by 2100.

Table 10 Mitigation and prevention measures.

5.2.5 Further Insights

The results indicate that both storylines, conducted within two distinct workshops (the first one in Trieste in March 2025; the second one in Lignano in October 2025, both described later in section 5.2.4), enabled participants to critically examine the territory, focusing not only on events that might occur in the future but also emphasizing measures for their mitigation and prevention. Moreover, stakeholders expressed satisfaction with both activities and provided feedback ranging from the potential implementation of this methodology in contexts similar to their own (as in the case of a high school teacher and university professors and researchers) to highlighting the challenges that may arise when modeling in well-defined contexts, where the hypothesis of an event may conflict with the socio-economic realities of the examined context. Finally, it was observed that storylines also serve as a tool for fostering relational and professional networks, where diverse stakeholders meet, exchange knowledge, and develop collaborations.

2. Risk Culture in FVG UTE

As part of the RETURN project, multiple awareness-raising, outreach, and citizen science activities have been carried out in the selected municipalities. These initiatives involved various segments of the population, raising awareness of natural and anthropogenic risks and their potential impacts in urban contexts, from both physical and social exposure perspectives. The main citizen-science, capacity building and dissemination activities are outlined below.

6.1 Citizen Science & Capacity Building

6.1.1 Capacity building activities: the Conference on “Climate Change and Coastal Risks: A Multi-risk Approach in Urban areas”

One of the main capacity building activities organised in the UTE-FVG consisted in the Conference on “*Climate Change and Coastal Risks: A Multi-risk Approach in Urban areas*” (Giornate di Studio: “Cambiamenti climatici e rischi costieri: un approccio multi-rischio in ambiente urbano”), Lignano Sabbiadoro, 20–21 October 2025. This two-days conference intended to provide an interdisciplinary dialogue platform to highlight and discuss the complex interactions and the role of the human factor - social, political, and economic - in defining and managing risks associated with natural hazards in urban contexts. By sharing innovative tools and approaches, the initiative aimed at promoting, within the UTE-FVG, the development of multi-hazard strategies capable of enhancing the resilience of coastal communities to climate change

The scope of these study days was multiple:

- to provide a state-of-the-art overview of the elements contributing to the definition of coastal risks in urban contexts, presenting recent research and methodologies developed within the RETURN project;
- to emphasize the importance of integrated multi-hazard planning for the prevention and mitigation of impacts;
- to examine the role of the “human factor” (social, political, and economic) in determining risks associated with natural events and in their management.

The ultimate goal was to identify interventions and strategies that allow for the integrated and effective prevention and management of these risks, often amplified by climate change, highlighting critical complexities and interactions to enhance the resilience of urban centers in coastal areas.

The first day (Monday, October 20) was dedicated to a series of lectures on “Climate Change and Coastal Risks in Urban Contexts”. The morning sessions addressed the characterization of coastal hazards and their interactions, as well as exposure and vulnerability of urban contexts, including social and cultural heritage vulnerability. The afternoon sessions focused on multi-risk urban planning, from emergency response to prevention, as well as on the political and social dimensions of risk mitigation.

The day ended up with two events open to the general public. The first event, the “**Dialogues of Memories**”, commemorated the 1976 Friuli earthquake as a bridge between the cities of Gemona, which was destroyed by the earthquake, Lignano, which hosted the displaced refugees from Gemona during the winter season. The dialogue, moderated by a journalist (Alberto Terasso) who experienced the earthquake, involved two citizens from Lignano and Gemona respectively, who shared their touching memories and views during those dramatic times. The dialogue also involved Anna Maria Zaccaria, who discussed these memories, relating their experience to that of other Italian events (i.e. the 1980 Irpinia and the 2009 L’Aquila earthquakes).

A **round table** with local stakeholders, political and national civil protection representatives, scientists, environmental associations, technical experts and economic actors, discussed emphatically about multi-risk urban mitigation in tourist coastal cities. The round table, moderated by Andrea Pirni, highlighted a number of very interesting issues, different perspectives and possible solutions - involving citizens as major actors towards risk mitigation.

The second day (Tuesday, October 21) was dedicated to the interactive **Second Workshop on Multi-Risk Storylines**. As a follow up of the first Workshop carried out in Trieste on 6 March 2025, this event was aimed to develop the second phase of the Storylines for the UTE-FVG, described in Section 5.2.4. Through facilitated discussion tables involving institutional and social stakeholders operating locally, working groups discussed integrated actions and strategies to strengthen the resilience of coastal territories.

The overall event involved more than 80 participants, including several key political and technical representatives of the UTE-FVG municipalities, professionals (both engineers, architects and urban planners), representatives from civil protection and civil society, thus providing an opportunity for effective knowledge transfer and capacity building.

6.1.2 Citizen-science targeting high-school students

Young generations are increasingly committed to understanding disasters, and are a key player in current and future disaster risk reduction activities. The availability of online tools opened new perspectives in the organization of risk-related educational activities, in particular in earthquake-prone areas. This is the case of CEDAS (building CEnsus for seismic Damage ASsessment), a pilot training activity aimed at collecting risk-related information while educating high-school students about seismic risk (Peresan et al., 2023, <http://dx.doi.org/10.3389/esss.2023.10088>). During this experimental activity, students collected and elaborated crowdsourced data on the main building typologies in the proximity of their homes. In this way, students created a dataset of valuable risk-related information, while getting familiar with the area where they live (Scaini et al., 2022, <https://doi.org/10.1016/j.ijdr.2021.102755>). Data collection was performed both on-site, using smartphones, and online, based on remote sensing images provided by multiple sources (e.g. Google maps and street view). This allowed all students, including those with limited mobility, to perform the activity. The CEDAS experience pointed out the potential of online tools and remote sensing images, combined with practical activities and basic training in exploratory data analysis, to engage students in an inclusive way. The proposed approach can be naturally expanded in a multi-risk perspective, and can be adjusted, eventually increasing the technical content of collected information, to the specific training and expertise of the involved students, from high-school to university level.

a. Activity Description

This activity builds on past experience from the citizen science pilot project CEDAS (*Censimento dell'Edificato per la stima del Danno Sismico*), which involved more than 300 students from high schools in Udine (Italy) and allowed collecting more than 8000 building questionnaires (Peresan et al., 2023; Scaini et al., 2021) in different municipalities of the Friuli Venezia Giulia Region, including Udine and surrounding areas.

The activity, conducted by Matteo Sema, Antonella Peresan, Carla Barnaba and Chiara Scaini, was carried out between January and May 2025. It involved 3 classes of students (n=60) from the “Copernico” High School in Udine, Italy, and included:

- General lectures on seismological topics, seismic hazard, exposure and risk, as well as interactive quizzes to evaluate participants risk awareness;

- Training lectures on data acquisition, carried out through dedicated online platforms (e.g. <https://smile.mi.imati.cnr.it>), as well as on exploratory analysis of the collected data and their interpretation;
- Data collection in the study area, both within the city of Udine and in the surrounding municipalities;
- Group work activity carried out by students regarding multivariate and comparative statistical analyses, between the newly collected and the existing datasets, including results interpretation;
- Reporting the results obtained to an audience composed of representatives of local institutions, regional Civil Protection personnel, engineers, OGS researchers, and students from previous editions;
- Design and administration of the Awareness Questionnaire regarding the activities and covered topics.

b. The Quantitative Research Tool: The Awareness Questionnaire

Compared to earlier experiences from the CEDAS project, this activity emphasized the social dimension of this citizen science activity, enriching education content of the proposed experience, and quantitatively investigating the perceived improvement of the participants regarding the covered topics. To this purpose, a specific questionnaire was created by adapting existing scales from the literature, predominantly based on 5/7 point Likert scales (such as the dimensions of difficulties and engagement), and designing new ad hoc instruments to address the content of the specific activities implemented, using multiple-choice items, likert and scoring scales. The questionnaire is composed of 38 items defined across twelve dimensions, with the purpose of creating a measurement tool that can quantify similar activities in a longitudinal perspective.

In addition, 10 items were included, developed and used in previous studies, with the aim of investigating students' perception of the usability of the online platform used for data collection.

The questionnaire was administered to 60 students during the final day of the activity. A general and concise overview of the variables analyzed is provided below.

The first section includes some sociodemographic variables, such as *Gender* (Male, Female, Non-binary, Prefer not to answer) and other contextual variables are included like Prior use of software for exploratory data analysis - *Previous software use* - expressed in dichotomous form (yes/no).

Regarding the theoretical-practical content of the activity, two measurement scales analysed the dimension of Perceived learning. This was assessed through a prospective pretest concerning the improvement of students knowledge about the Building Characteristics, Survey Area and Seismic Risks (e.g. “*Compared to before the Activity, I believe my knowledge has improved regarding the characteristics...*”) and on the perceived improvement assessed through prospective pretest and posttest regarding the Exploration of Statistical Data (e.g. *For each skills listed below, give yourself a score (1-10), distinguishing between before and after the activity... “Plot two variables”*)

The subsequent sections address the psychosocial aspects of the participants, specifically focusing on the dimensions of Engagement and its subscale (Social Loafing, negative polarity, and *Positive Group Interaction*, positive polarity), *Difficulties* encountered during the activity (negative polarity), *Dissemination of the activity* and its contents to other social spheres; overall Feedback on the experience, assessed through two methods: *Evaluation of activity*, a 4-level rating scale (poor, sufficient, very good, excellent) previously used by researchers in similar extracurricular activities, and overall *Satisfaction*, a linear satisfaction scale (1–10). Finally, *Word of Mouth* was investigated.

C) Main Results

The participants understood various theoretical and practical aspects of the course. They received training on exploratory statistics, the main software tools used for database analysis, building characteristics, and the online platform employed for data collection. Students were also engaged in interactive activities focused on the perception of natural and anthropogenic risks affecting the territory. Specifically, they took part in online quizzes with multiple-choice and closed-ended questions aimed at raising their awareness of both natural and anthropogenic events and exposure, as well as of the personal actions that can contribute to their mitigation and prevention, with particular attention to seismic phenomena. An example of an interactive activity was the development of word clouds. The results of which are presented in the following figures (The questions were as follows: *Which natural hazards come to mind? Which elements are exposed to earthquakes?*).



Figure 5: Results of the word cloud for the question “Which natural hazards come to mind?”.



Figure 6: Results of the word cloud for the question “Which elements are exposed to earthquakes?”.

The preliminary outcomes of such activities already highlighted some interesting aspects. For instance, the most frequent hazard appearing in the word-clouds is the “tsunami” (never experienced in the region where students live), surpassing the “earthquake” hazard (despite the large earthquake that occurred in 1976). This might reveal a high influence of the media (e.g. news, movies...), as well as a short memory about past events, on students’ risk awareness.

The responses collected from the questionnaires were systematically coded into an Excel matrix and subsequently analyzed using the statistical software RStudio.

The statistical tests employed were Pearson’s chi-squared test, the paired t-test, and other statistical tests. To determine whether the perceived improvement by participants differed across course topics (Building Characteristics, Territory, and Seismic Phenomena), a Pearson's Chi-squared test was conducted.

The test results ($\chi^2 = 25.50$, $df = 12$, $p = 0.013$) indicate a statistically significant difference in perceived improvement across the three analyzed variables (Building, Territory, and Seismic Risks and Phenomena). Specifically, greater perceived improvements were observed in the dimensions of Seismic Risks and Phenomena. The response frequencies, measured on a 7-point Likert scale, are shown in Figure 7.

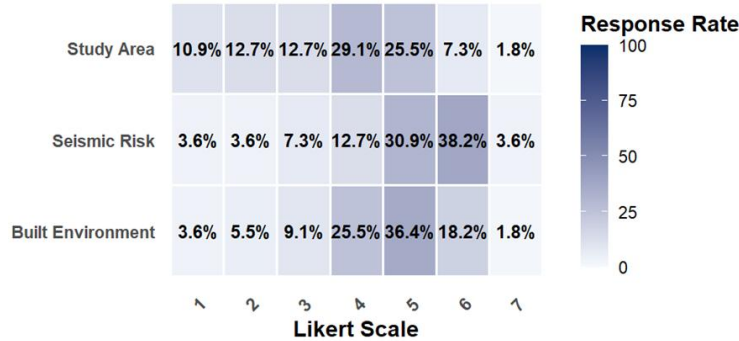


Figure 7: Response frequencies measured on a 7-point Likert scale.

To investigate the potential perceived improvement in statistical data exploration (a variable composed of 10 items measured on a 1–10 scale), a paired t-test was conducted. For this purpose, Cronbach's alpha coefficients were calculated for the 10 items in both the prospective pretest and the posttest. Subsequently, two composite indices (Pre and Post) were created by averaging the scores of each participant across all items. Finally, the paired t-test was carried out to assess the statistical significance of the observed differences. The paired t-test revealed a statistically significant mean difference of 1.10 points ($p\text{-value} = 4.999 \times 10^{-15}$). The results are illustrated in Figure 8.

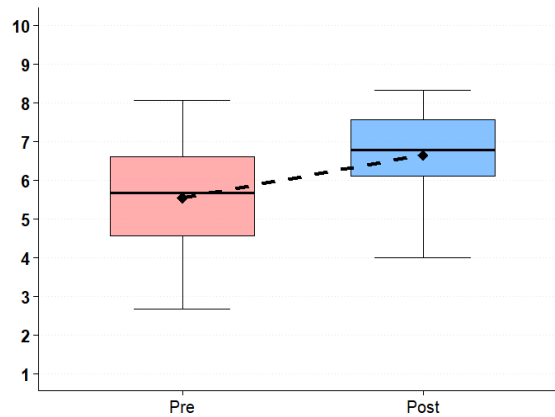


Figure 8: Paired t-test results in the exploration of statistical data analysis.

An additional objective of the study was to understand whether, and to what intensity, participants discussed the activity within their social circles. The results indicate that the dissemination of information primarily reaches what are referred to as "close circles," particularly parents and those who directly participated in the activity.

The response frequencies regarding the dissemination of the activity are shown in Figure 9.

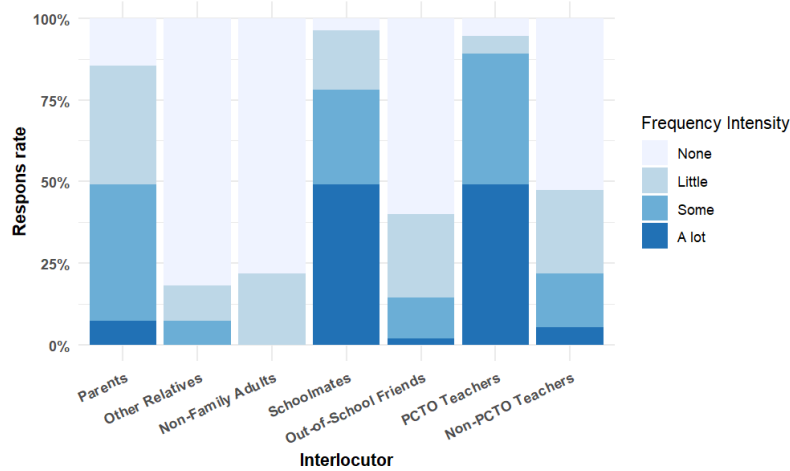


Figure 9: Response frequencies concerning the dissemination of the activity.

The abstract derived from the mentioned study have been presented at the SSPCR Conference (EURAC, Bolzano, 9 -12 December 2025).

6.1.3 Dissemination and Awareness Programme at the University of the Third Age of Trieste

In recent years, several awareness-raising and capacity-building lectures have been conducted at the Università della Terza Età “Danilo Dobrina” (TS). The aim of the course is to raise awareness among the elderly population by analysing their perceptions and understanding of natural and anthropogenic risks, with the aim of highlighting the generational features of risk culture within the study area.

In the 2024/2025 academic year, senior researchers and technologists staff of the Seismological Research Centre – CRS – (Antonella Peresan, Matteo Sema, Carla Barnaba, Piero Brondi and Chiara Scaini) delivered lectures of outreach and training modules. These modules, held on April 4 and 11, 2025, covered the following topics:

- Organization, Mission, Principles, and Activities of the OGS and CRS;
- Interactive activity aimed at understanding perceptions and awareness regarding natural and anthropogenic events, as well as personal measures to be adopted for their mitigation and prevention;
- Main characteristics of several natural and anthropogenic risks, such as earthquakes, landslides, storm surges, and tsunamis (also from a multi-risk perspective, whether concurrent or cascading);
- Urban evolution of Trieste and an in-depth analysis of the main risks to which the city is vulnerable;
- Training activity preparatory to a subsequent Citizen Science initiative concerning data collection on the built environment within the Municipality of Trieste. The training focused on building characteristics and their components.

The course held during the 2024/2025 academic year described above laid the foundation for a subsequent program jointly organized in collaboration with the same institution in the 2025/2026 academic year, characterized by a laboratory-based approach (Antonella Peresan, Matteo Sema, Carla Barnaba, Piero Brondi, Chiara Scaini and Denis Sandron). The modules officially began on October 30 and will conclude in December 2025. In addition to the theoretical modules already presented in the previous academic year, the following activities have been scheduled.

- Interactive activities carried out using qualitative methodologies (Photo Elicitation and Storyline) with the aim of actively engaging participants, recalling the historical memory of the study area, highlighting the changes that have characterized its urban, economic, and social context, and promoting active awareness by involving participants in identifying potential impacts resulting from multiple hypothetical events modeled on the historic center of Trieste;
- Short training session and subsequent fieldwork aimed at collecting information on buildings in the city of Trieste;
- Overview of an activity conducted in collaboration between OGS and the Regional Civil Protection Department, concerning the macroseismic data collection on the earthquakes felt in Trieste.

6.1.4 Awareness raising and knowledge transfer activities

Several initiatives were carried out to raise awareness of natural and anthropogenic hazards, including: participation in the *Festival Lignano 180°* event (13 June 2025), during which Antonella Peresan delivered a presentation that, based on future scenarios outlined by modelling, aimed at stimulating discussion on the need for holistic urban planning to face climate change and natural hazards effects in integrated manner; involvement of OGS scientific staff at the *Trieste Next* science festival (26–28 September 2025), which provided an opportunity to raise awareness among both local and international audiences about seismic phenomena; the *third Italy-Slovenia Citizen Science* event in Nova Gorica (12 November 2025), where the citizen science activities carried out in recent years were presented; hosting the Serre d’Estate summer camp at the Seismological Research Center in Udine, during which young pupils were introduced to the characteristics of seismic phenomena, and familiarized with the tools of the seismic monitoring room, complemented by educational games designed to strengthen earthquake related knowledge in an interactive manner.

Knowledge transfer and **science for policy activities**, aimed at research implementation towards natural hazards understanding and risks mitigation, were carried out not only at the local, but also at the international level, in Europe and worldwide. Since the end of 2023, Antonella Peresan has been appointed as the Policy Officer of the “Natural Hazards” Division of the European Geosciences Union (EGU), to help promote evidence-based policy-making and support researchers to ensure that evidence-based decisions are made in the policy-making processes related to Natural hazards (<https://blogs.egu.eu/divisions/nh/2024/02/26/how-can-you-contribute-to-science-based-policy-making-ask-the-new-policy-officer-in-the-natural-hazards-division/>). In this framework, several dedicated sessions focused on multi-hazard assessment, as well as on the interplay between science and society have been organised at the annual EGU General Assembly and a number of presentations of project research were delivered in the period 2023-2025 (the full list of sessions and presentations is provided separately). Amongst the specific sessions organised at EGU2025 General Assembly 2025 (Vienna, Austria, 27 April – 2 May 2025), we recall the following.

- Advancing the integration of citizen and stakeholders’ knowledge in disaster risk assessment, reduction and governance (Conveners: Santos, P.A., Peresan, A., De Angeli, S., Komendatova, N., Van Maanen, N.)
- Mastering Risk Communication: Tools and Strategies for Effective Engagement (Conveners: Gargiulo, M.V., Cumiskey, L., Jäpölä, J.P., Peresan, A., and Russo, R.)
- Multi-parametric Short-Term Seismic Hazard monitoring and Physical and Statistical Models for Earthquake Risk assessment (Conveners: Tramutoli, V., Biagi, P.F., Peresan, A., Filizzola, C., Genzano, N., Hattori, K., Rupakheti, R.)
- Advancing Disaster Resilience through Transdisciplinary Approaches: Insights and Innovations (Conveners: Pecoraro, G., Mantini, M., Peresan, A., Comiskey, L., Jäpölä, J.P., Gargiulo, M.V.)

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