

Civil Protection, Disaster Management, and Resilience

TEXTBOOK

Thomas Glade
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Natural Hazards and Risks within Disaster Management

Concepts, Applications, and Future Trends

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Civil Protection, Disaster Management, and Resilience

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Thomas Glade · Philipp Marr ·
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Foreword by the Commissioner to the EUMA Book Series Volumes

Crises today are more complex and interconnected than ever before.

The world is warming at an unprecedented pace, especially in Europe, with global temperatures now approaching 1.5 °C above pre-industrial levels. In this context of growing geopolitical uncertainty, the need for strong preparedness and response systems has never been clearer.

Recent record-breaking wildfires, floods, and other extreme weather events—all linked to climate change—illustrate the mounting impact of a heating planet and the urgency of building resilience not only to natural disasters but also to human-made crises such as conflict.

One of the European Commission's top priorities is to strengthen crisis management and civil preparedness across Europe—to move from reacting to crises to being ready for them. This means fostering a genuine culture of preparedness and resilience, one that is woven into every part of our societies—from schools and communities to governments and businesses.

But we cannot do this alone. Collaboration is key—and the academic community has a crucial role to play. By educating students and practitioners in Disaster Risk Management, universities help us raise awareness, build a shared understanding of the risks we face, and inspire the innovation and mindset needed to turn preparedness into a way of life.

This book series marks an important milestone for the EUMA project—Creating a European Higher Education Network for Master's Programmes in Disaster Risk Management—and for the postgraduate Master's degree in International Disaster Management and Civil Protection it has developed.

Supported by the EU's preparedness capacity-building tools, the EUMA series represents a renewed drive to bring research, innovation, and practical action closer together. It reflects the European Commission's commitment to embedding knowledge-based strategies into preparedness and response, and demonstrates the concrete value of EU programmes that strengthen our collective resilience.

The Preparedness Union Strategy is our compass—guiding us towards a new level of collective readiness that is proactive, interconnected, and truly integrated.

This book series supports one of its key actions: bringing preparedness into education. By focussing on higher education and developing a robust Master's programme, the EUMA project has helped build a holistic approach to preparedness—one that equips future generations with the knowledge and skills needed to manage disaster risks effectively.

I want to warmly congratulate all those who contributed to this series. I am confident that your work will offer valuable insights for our shared mission—a safer and better-prepared Europe.

As the risks we face become ever more complex, we remain committed to deepening partnerships with academic and research institutions, and to promoting lifelong learning. Together, we can harness knowledge and innovation to build a resilient Europe—one that is always ready for what lies ahead.



Brussels, Belgium

Hadja Lahbib
European Commissioner for Equality
Preparedness and Crisis Management

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The publication of this volume has only been made possible through the generous support of this programme.

Within the framework of the EUMA project, a curriculum for a new international Master's programme (M.Sc.) has been developed. The postgraduate Master programme, entitled **"International Disaster Management and Civil Protection"**, will be launched in **October 2026** at the **Postgraduate Center of the University of Vienna**.

Building on the outcomes of EUMA, the follow-up project **EUMAplus—"Creating Open Access Digital Educational Material in Disaster Risk Management and Civil Protection" (2026–2027)** is developing open access teaching and learning materials.

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Outlook

The EUMA Master's Programme is expected to be formally established at the University of Vienna from October 2026, marking a key milestone in expanding European education in Disaster Risk Management and Civil Protection. Further updates are available at https://postgraduatecenter.univie.ac.at/en/euma.

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Introduction to Natural Hazards in Disaster Risk Management

1

Thomas Glade, Sophia Sternath, Annika Fröwis, and Philipp Marr

Abstract

Natural hazards and disasters occur constantly in many regions of the world. A multitude of natural phenomena have exerted a profound influence on the evolution of our planet over the course of millions of years. These include, but are not limited to, earthquakes, volcanic eruptions, windstorms, droughts, tsunamis, wildfires, soil erosion, and landslides. However, these phenomena become hazards and risks only in the presence of human populations. As societies are increasingly affected by such hazards, the need for effective management continues to grow. Recent developments in disaster risk management increasingly emphasise preparedness, prevention, and anticipatory governance as key components of effective risk reduction strategies. In particular, policy frameworks at the European level increasingly frame investments in preparedness and capacity-building as long-term contributions to resilience rather than short-term costs. Many management options are available, ranging from simple local countermeasures to sophisticated early warning systems based on numerical modelling. The present chapter offers a general introduction to the subject. In addition, the text introduces several key terms. The objective of this study is not to provide a single, definitive definition for each term; rather, this contribution seeks to present the various terms and definitions, with a particular focus on the official United Nations Disaster Risk Reduction (UNDRR) terminology. However, it should be noted that other authors with differing scientific backgrounds or institutions may employ the same terms in different ways.

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Keywords

Trends in disaster risk management • Key terminology • Challenges in natural hazards and disaster risk management

1.1 Trends in Europe and Worldwide

The planet Earth includes a diversity of geographical features, encompassing islands, coastal zones, extensive plains and elevated alpine mountain ranges, in addition to submarine terrain. The topographic forms of these landscapes are defined by the materials upon which they are built and the processes that operate on these surfaces and shape their forms. These dynamic processes operate continuously, albeit with varying intensity, over billions of years.

As the human population has expanded over time, particularly in the last century, landscapes and natural processes have experienced mounting pressure. It is becoming increasingly evident that a multitude of societies are exposed to these processes, which can transform into natural hazards. The assessment of the impacts of natural hazards on at-risk societal elements (e.g. roads, houses, agricultural land and the population itself) is of paramount importance. This assessment can be conducted qualitatively or quantitatively, and the results indicate the level of risk posed by a natural hazard. In particular over the last few decades, the impact of these hazards has increased continuously due to changes in the hazards themselves, as well as in relation to the exposure of societies (Fig. 1.1).

In Europe, these developments have been accompanied by a gradual shift in disaster risk management policies from a predominantly response-oriented approach towards a stronger focus on preparedness, prevention and resilience-building. This shift is reflected in recent policy debates and strategic documents that increasingly highlight the economic and societal benefits of investing in preparedness, including reduced long-term losses, lower recovery expenditures, and enhanced institutional capacity to manage complex and cascading risks (European Commission n.d).

1.2 Some Basic Definitions

The following section aims to provide a concise overview of the key terminology employed in this volume, thereby establishing a framework for the subsequent discussion. The present text refers to the definitions provided by the United Nations Disaster Risk Reduction (UNDRR) glossary (UNDRR n.d.a.) to delineate the specific reference.

Natural event: A natural event is defined as an occurrence caused exclusively by non-human forces. The occurrence of these phenomena may be considered discrete or interconnected with other events. The fundamental principle is that natural events do not engender any consequences for societies.

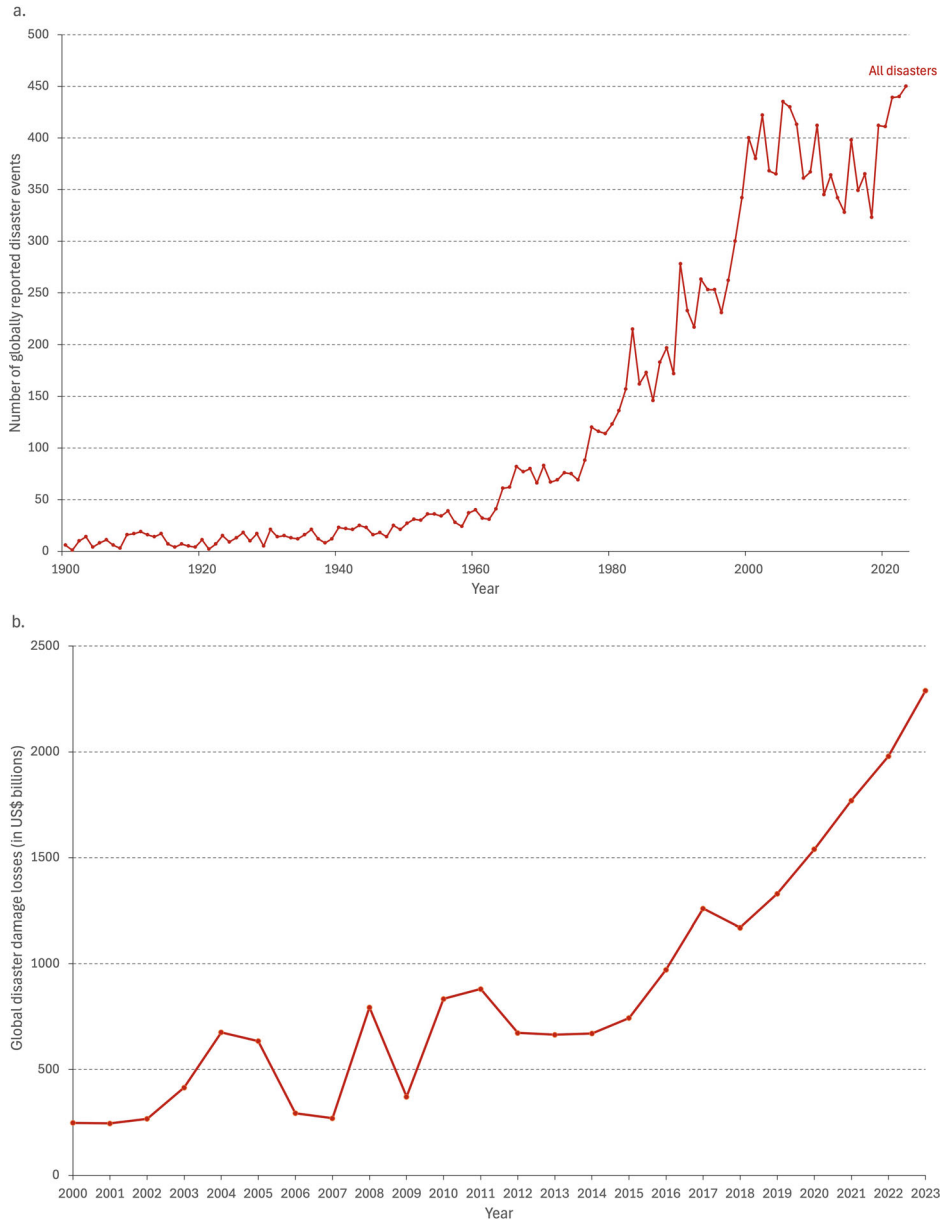


Fig. 1.1 Trends of **a** recorded disasters (Data: EM-DAT) and **b** respective consequences to societies. (Data: UNDRR) Both graphs display data up to 2023, with graph **b** available from 2000 onward due to data availability. (Own figure)

Natural hazard: These are processes and phenomena that have the potential to cause consequences, e.g. loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation (UNDRR 2017a). The occurrence of natural hazards within a specified area or region is characterised by a defined frequency and magnitude.

Vulnerability: This term is used manifold in different disciplines and commonly includes "characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" (UNISDR 2009: 12). This concept is expanded within the Sendai Framework for Disaster Risk Reduction (UNISDR 2015) to "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards" (UNDRR 2017b). Chapter 5 provides more background and explores this term also from physical, social, economic, institutional, and environmental dimensions.

Resilience: In recent years, the term 'vulnerability' has been accompanied by the term 'resilience'. According to the Sendai Framework Terminology on Disaster Risk Reduction, the term resilience refers to "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (UNDRR 2017c). Hence, while vulnerability refers to the missing capacities often resulting in damage and loss, resilience rather points to the capacities to buffer impacts and recover and build back after a disastrous event.

Risk: Similarly, the term 'risk' is understood in a variety of ways in different academic disciplines. In the disciplines of e.g. natural science, engineering, economics and insurance, risk is generally understood to be the outcome of the interplay between hazards as well as their ramifications. This concept encompasses the elements of risk, including their exposure and damage characteristics, as well as the vulnerability of each element at risk to a specific hazard dimension. In recent studies, the concept of resilience and adaptation capacities has also been incorporated (Galaitsi et al. 2024; Henud et al. 2024; Peroni and Pappalardo 2024). The prevailing paradigm perceives risk as being inextricably linked to adverse outcomes. Nevertheless, a more expansive interpretation of risk can be posited by including the potential for positive outcomes. The categorisation of risk can be approached in numerous ways. One can differentiate between individual and collective risk, or tangible and intangible risk. Another possibility is to distinguish between risk that is accepted and risk that is tolerated. Furthermore, residual risk refers to risk conditions which always remain, independent of any countermeasures.

Risk Management: This is defined by UNISDR (2009) as "the systematic approach and practice of managing uncertainty to minimise potential harm and loss". Such a systematic process involves the application of administrative directives, organisations, and operational skills and capacities to implement strategies, policies, and improved coping capacities to lessen the adverse impacts of hazards and thus the possibility of disaster. Against this background, preparedness and prevention can be understood as cross-cutting elements that link concepts such as vulnerability, resilience, risk management, and governance, as they aim to reduce future impacts before hazardous events materialise (EC n.d.; UNDRR n.d.a.).

Disaster: Within UNDRR (2017d), disasters are characterised as "a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts".

Disaster Risk Management (DRM): The major extension to Risk Management refers to the concept that the consequences must be considered and provides the basis for any further action (UNDRR 2017e). This becomes evident in the first of the four Sendai Framework priorities for action, which states that "disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment" (UNDRR n.d.b.).

Risk Governance: In addition to the management of risk and disaster risk management, risk governance can be defined as a process in which risk information is collected, analysed, communicated and taken into account in the decision-making process by all stakeholders involved (Greiving and Glade 2013). The term 'governance' hereby includes the ability of stakeholders, social groups and participating institutions to reach an agreement in which a common goal is established. Based on this, the individual contributions of the respective partners are defined.

The definitions outlined above are of particular relevance to this book. It should be noted that throughout the following chapters, these terms will be utilised, defined, and occasionally accompanied by different connotations. This does not constitute an error; rather, it is indicative of the prevailing reality. It is apparent that a multitude of academic disciplines are engaged in the study of natural hazards, disasters, and risk. However, it is important to acknowledge that these fields may sometimes present a divergence in their detailed understandings. It is therefore vital to establish a shared foundation for this book series.

1.3 Some Key Topics Covered in This Book

This book provides an overview of key concepts, applications, and future trends in the context of natural hazards and risks within disaster risk management. It is structured in nine chapters including an introduction to natural hazards in disaster risk management (this Chapter), natural processes and single-hazard approaches (Chap. 2), overview of past and current situations and expected future trends in natural disaster risk management (Chap. 3), institutional environments in DRM (Chap. 4), framing vulnerability (Chap. 5), socio-economic aspects of disaster and climate change risk management (Chap. 6), psycho-social support mechanisms within disasters (Chap. 7), Impact Chains (Chap. 8) and finally, synthesis and perspectives (Chap. 9). The respective themes are deepened within the different chapters and introduce the book topic in some basic terms.

1.4 Prevailing Challenges

It is evident that an edited book of this nature cannot address the full range of pertinent subjects. In the context of each individual topic, many publications, characterised by their high degree of specialisation, are available for study. These publications must be consulted when undertaking a more in-depth examination of the respective field.

Furthermore, there are numerous other topics of equal importance dealing with concepts, applications, and future trends of natural hazards and risks within disaster risk management. The following exemplary themes are already familiar to us: multi-hazard risks, extreme events and the role of social media. It is also imperative to maintain an openness to novel developments with which we are not yet acquainted. For instance, one such development is artificial intelligence. Alongside its undesirable consequences, the field of artificial intelligence has the potential to facilitate significant advancements that have historically been overlooked or under-researched in the context of previous conceptual frameworks and policy measures.

Key Sentences

- Hazards and disasters have increased significantly in recent decades in terms of probability of occurrence and consequences.
- Key terms are defined and used differently within a variety of disciplines; therefore, it is important to provide a common ground.
- Preparedness and prevention are increasingly recognised as cost-effective and future-oriented components of disaster risk management, particularly in the context of climate-related risks.

- The chapters provided in this book offer a first introduction to the topic but need further exploration and expansion in the future.

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Natural Processes and Single-Hazard Approaches

2

Philipp Marr, Thomas Glade, Rainer Bell, and Lothar Schrott

Abstract

A natural event is a naturally-occurring physical phenomenon, while a natural hazard refers to such an event when it has the potential to cause harm to human life, property, or the environment. However, there are many ways to define these terms. Climate-related hazards, including floods, droughts, and heatwaves, are characterised by an increased frequency and magnitude due to global change, posing significant threats to public health and economic stability. Natural hazards can be characterised using core parameters such as magnitude, frequency, speed of onset, duration, and spatial extent, features which are crucial for understanding hazard dynamics and classification. Analysing single hazards in isolation allows for a more detailed understanding of their underlying physical processes. However, by focussing solely on single hazards, important synergies, interactions between hazards and their cascading effects may be overlooked, potentially underestimating the true extent of risk. A regular update of single-hazard characteristics due to global change is necessary for effective, risk-based decision-making, as they are the basis for multi-hazard approaches.

Keywords

Natural processes • Single hazards • Global change • Hazard characteristics • Hazard classifications

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2.1 Introduction

The occurrence of natural hazards impacting human populations is increasing in many regions worldwide. In 2024, the Emergency Events Database (EM-DAT) registered 393 disasters related to natural hazards, resulting in 16,753 fatalities and affecting approximately 167.2 million people. The total estimated economic losses amounted to US$241.95 billion, making 2024 more costly in terms of disaster-related damages than the average year over the past two decades. However, the number of reported fatalities remained well below the 2004–2023 annual average of 65,566 deaths, largely due to the absence of large-scale, high-fatality events (CRED 2025).

Driven by factors connected to global change, such as population growth, urbanisation, as well as the impacts of anthropogenically-induced climate change, exposure to natural hazards has increased, and the impacts of these events have risen sharply over the past half-century (Pörtner et al. 2022; Ward et al. 2022). Various regions around the world are increasingly confronted with the simultaneous or sequential occurrence of multiple types of natural hazards (Lee et al. 2024; Pörtner et al. 2022). This trend is further intensified by globalisation and is projected to continue with increasing frequency and intensity of many climate-related hazards in the twenty-first century (Poljanšek et al. 2017). Traditional risk assessments have typically approached hazards as isolated phenomena (Kappes et al. 2012; Ward et al. 2022). However, natural hazards frequently occur simultaneously or in close succession (Gill and Malamud 2014).

Single-hazard approaches, which assess hazard potential by treating each hazard as an isolated and independent phenomenon, remain widespread in both research and practice. However, their continued use can lead to distorted risk management priorities, an underestimation of actual risk, or heightened vulnerability to other relevant hazards within the same area (Budimir et al. 2014; Kappes et al. 2010). Furthermore, the quantification of single hazards is getting increasingly complex, in particular also under global change.

This book chapter aims to provide a comprehensive introduction to natural processes and single-hazard approaches, by introducing foundational terminology and exploring hazard characteristics. The chapter then explores how global change, including climate variability and socio-environmental transformations, is influencing the frequency, intensity, and distribution of natural hazards. Finally, the chapter reflects on the strengths and limitations of single-hazard assessments and provides future perspectives.

2.2 Definitions

Within a global perspective, there is a wide variety of natural processes and single hazards. Likewise, there are manifold definitions of natural processes or events, as well as categorisations of single-hazard approaches. In order to address the domains of natural processes and single hazards within, and especially across disciplines, clear definitions

of key terms are required. The key definitions are summarised in Box 1. These are also based on the Disaster Risk Reduction terminology provided by the UNDRR (2025).

Natural hazards are fundamentally part of the Earth system and can be broadly classified based on their origin into endogenous (internal) and exogenous (external) processes. They may arise from a range of causes, including geological–geophysical, geomorphological, meteorological–climatological, hydrological–cryological, biological, extraterrestrial or often combined/complex causes (please refer to UNDRR and ISC 2020 for more details). In addition to these natural phenomena, there are hazards resulting from environmental degradation and technological processes, which are typically referred to as anthropogenic, human-induced, or man-made hazards (Murray et al. 2022; UNDRR 2025; UNDRR and ISC 2020). The intensity and frequency of such hazards vary depending on geographical location, climatic conditions and tectonic processes.

A **natural process** or **event** is a physical phenomenon that occurs without human intervention or harm, such as earthquakes, storms, or floods. These processes are occurring under natural conditions, thus neither are they preconditioned or triggered by human activity, nor do they affect society by direct and/or indirect means.

A **natural hazard** is predominantly associated with a natural process and phenomena potentially causing consequences to society (UNDRR 2017). It is a natural process that is occurring with a given magnitude, a specific frequency and in a predefined space and may potentially affect society, either via direct impact (e.g. damage to a road) or indirect consequences (e.g. interruption of a critical lifeline).

Elements at risk are all assets that may potentially be affected by the occurrence of a natural hazard. These elements at risk can be classified in points (e.g. a house), in lines (e.g. a road), or in areas (e.g. agricultural land). These can be fixed and stationary (e.g. a bridge) or mobile (e.g. moving persons). Besides their geographical position, a value of the total damage caused to selected objects can be assigned, which refers to the total costs of replacement. In addition to these direct costs for replacement, indirect costs may be calculated (e.g. the cost of a one-week interruption of a major railway track).

The **exposure** purely defines the extent to which an asset is exposed to a given natural hazard. Often, maps of characterised elements at risk are purely overlayed with a map of natural hazards.

The general **vulnerability** refers to conditions determined by physical, social, economic, institutional, and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards (UNDRR 2017). Physical vulnerability of an element at risk is generally defined by the magnitude of impact of a natural hazard onto an element at risk and the respective consequences. It is commonly expressed as percentage of the total cost of damage and loss, ranging between 0 and 100%, or as a dimensionless value between 0 and 1. It must be noted that vulnerability here refers to physical dimensions only. Other types of vulnerability are explored in Chap. 5.

Within a **natural risk**, the direct or indirect impact or consequence for all elements at risk is addressed. If quantified, natural risk is commonly expressed as potential damage in €/unit (e.g. unit might be m^2, year, loss of income, etc.). The risk can thus be indicated for single objects or a larger area (e.g. a given slope or an administrative boundary such as a municipality). The natural risk is often expressed as a function of the natural hazards and the potential consequences (commonly the chances of losses), which include the elements at risk and their vulnerability. In recent studies, coping and adaptation measures have also been considered (Pörtner et al. 2022).

2.3 Natural Hazards and Risks Due to Global Change

According to the International Geosphere–Biosphere Programme (n.d.) global change can be referred to as

> … planetary-scale changes in the Earth system. More completely, the term 'global change' encompasses: planetary scale changes to atmospheric circulation, ocean circulation, climate, the carbon cycle, the nitrogen cycle, the water cycle and other cycles, sea-ice changes, sea-level changes, food webs, biological diversity, pollution, health, fish stocks, and more. Civilisation is now a large driver of Global Change so the term includes population, the economy, resource use, energy, development, transport, communication, land use and land cover, urbanisation, globalisation.

Climate-related hazards such as floods, droughts, and heatwaves are increasing in intensity, duration, and frequency due to the influences of global change. These hazards pose substantial risks to both public health and economic stability (Pörtner et al. 2022). These challenges unfold within the context of a rapidly globalising and interconnected world, where growing spatial pressures and climate change are driving unprecedented shifts in the magnitude and frequency of both single- and multi-hazard events (Vogel et al. 2019). Nevertheless, the overall impact of both climate-related and non-climate-related disasters has risen. This is largely attributed to growing societal exposure and complexity, which in turn increases vulnerability, as well as to the rising frequency, magnitude, and interconnected nature of hazards within multi-hazard scenarios (see López-Saavedra and Martí 2023).

While natural processes such as precipitation, wind, or tectonic activity are governed by physical laws that remain constant over time, their patterns, intensity, and impacts can be significantly influenced by global change. For example, the physical mechanism by which rainfall occurs has not changed—moisture condenses in the atmosphere and falls due to gravity—but climate change alters the atmospheric conditions under which this process takes place. Warmer temperatures can increase the moisture-holding capacity of the atmosphere, leading to heavier and more intense rainfall events in some regions and prolonged droughts in others. In this sense, global change does not modify the basic physics

of natural processes but shifts the spatial and temporal patterns in which they occur and amplifies or modifies their consequences through increased exposure and vulnerability.

2.4 Characterisation of Different Natural Hazards

As introduced, there are different approaches to define natural processes and hazards, the same is true concerning their characterisation. A hazard is described as a potentially damaging natural event that can be characterised by key parameters, which are related, such as magnitude (e.g. impact size, released energy, deposit volume, flood discharge), frequency of occurrence (e.g. annual, decadal). Additional factors are speed of onset, duration (e.g. seconds, weeks), spatial extent (e.g. catchment scale), and intensity. Disastrous events arising from the interaction of multiple hazards rather than isolated occurrences is an interaction that accounts for a significant proportion of global losses (Lee et al. 2024). These hazard characteristics are fundamental in comprehending their dynamics and dimensions of a specific hazard type. In general, the more thoroughly these five core attributes, magnitude, frequency, speed of onset, duration, and spatial extent, are documented and understood, the more reliably a hazard can be identified and assigned to a particular type.

Investigating these characteristics is therefore of central importance for scientific analyses as well as further applications, e.g. developing adaptation strategies. However, the quality of the investigation is contingent on the data quality and availability, which is highly dependent on the respective hazard (for more detail see in this series the book volume: Geospatial Innovations in Disaster Management). Long-term time series and spatially-dense observation and/or monitoring networks significantly contribute to a more comprehensive understanding of the nature and dynamics of various natural hazards. Large datasets can be beneficial for applying Artificial Intelligence for identifying underlying patterns of natural hazards. Additionally, applying scenario-based modelling of potential future developments can contribute to reduced vulnerability in a long-term perspective (Sternath et al. 2026; UNDRR 2017). Moreover, the process characteristics, magnitude, frequency of occurrence, speed of onset, duration, as well as spatial extent, are highly relevant. This is the case for different applications, such as for forecasting and prediction, for the development of early warning systems, for spatial planning, for designing protective measures, and for shaping response strategies (e.g. “How quickly assistance can be provided without endangering the responders themselves?”) in the context of risk and disaster management (e.g. Burton 1993; Schrott and Hufschmidt 2017). The implementation of effective early warning systems, in particular, requires in-depth knowledge of the underlying hazard processes.

Many single natural hazard events are reasonably well understood and documented, allowing the correct assignment to a particular hazard type, such as snow avalanches, rock falls, river floods, or droughts. However, there is also a growing number of partly

understudied, less documented and new evolving hazards such as permafrost degradation, glacial lake outburst floods (GLOFs), submarine hazards, extraterrestrial hazards, flash floods or heatwaves. As these hazards are expected to intensify in the wake of ongoing anthropogenically-induced climate change, research on these has gained more attention recently (Hock et al. 2019; Parmesan et al. 2023; Zhang et al. 2021). The UNDRR and ISC (2020) also highlight extraterrestrial, submarine and biological hazards (e.g. pandemics), as well as technological hazards such as cyber hazards or societal hazards, including armed conflicts or terrorism, however a consideration of these hazards is beyond the scope of this volume.

Based on a classification proposed by the United Nations Office for Disaster Risk Reduction (UNDRR), natural hazards can be differentiated according to their origin or the underlying processes. Depending on the intended application, such as geographical analyses, hazard databases, or use by reinsurance companies, various categorization schemes have been developed (Dikau et al. 2020; Murray et al. 2022; Schrott and Hufschmidt 2017).

Numerous examples can be associated with the various hazard types (see Table 2.1), including earthquakes, floods, landslides, avalanches, droughts, wildfires, and storms. For certain events such as earthquakes (geological–geomorphological) or storms (meteorological–climatological), the underlying triggers can be clearly identified. In contrast, hazards like landslides may result from multiple interacting triggers, such as intense precipitation (a meteorological factor) and/or seismic activity (geological factor). There are many different classifications systems available, e.g. from EM-DAT or DesInventar.

The most comprehensive classification system to date is provided by UNDRR and ISC (2020), which defines eight overarching hazard categories encompassing 49 clusters and a total of 302 specific hazard types.

Despite this structured approach, no universally accepted scientific consensus has yet been reached regarding hazard categorisation. The UNDRR technical report on hazard definitions and classification review (Murray et al. 2022; UNDRR and ISC 2020) identified four major challenges related to the current classification system (see Fig. 2.1):

(1) Unclear distinctions between hazard sources, vulnerabilities, exposures, and risks;
(2) Broad terminology in some cases;
(3) Inconsistent levels of detail across categories;
(4) Misclassification of certain hazards.

Nonetheless, hazard classification remains a valuable tool for distinguishing, documenting, and causally describing hazardous processes. It is important to adopt a uniform classification of hazards, including the multi-hazard aspects, for proper damage and loss databases as well as for better hazard and risk assessments. Statistical analyses in particular rely on standardised classification systems, enabling comparisons across countries, regions, or time periods. UNDRR and ISC (2020) and UNDRR (2020, 2025) advocate

Table 2.1 Hazard categories based on main causal relationships and associated examples. Modified after Schrott and Hufschmidt (2017)

Main cause	Example of (natural) hazard
Geological–geomorphological hazards *Natural processes or phenomena of the earth 's crust (lithosphere) or the earth's surface (reliefsphere)*	• Earthquakes • Volcanic eruptions • Landslides • Tsunamis
Hydrological-cryogenic hazards *Natural processes or phenomena of the hydrosphere and cryosphere*	• Flooding • Flash floods • Snow avalanches • Glacial ice avalanches, glacial lake outburst floods • Permafrost degradation (subsidence, deformation, rock falls)
Meteorological–climatological hazards *Natural processes or phenomena of the atmosphere*	• Extreme precipitation • Heat waves, cold spells • Hurricanes, tornadoes • Extreme climate fluctuations
Biological hazards *Processes of the biosphere including transmissions between organisms*	• Infectious diseases in humans • Diseases in plants and animals • Plagues of insects
Extraterrestrial hazards	• Meteor strike
Technological hazards *Technological/industrial accidents and waste, often termed "man-made" or "human-induced"*	• Contamination of humans and the environment by chemical, biological, radiological or nuclear substances, radiation or energy (CBRN-hazards) • NaTech hazards
Hazards caused by environmental destruction *Human-induced processes destroying or negatively changing natural resources*	• Soil erosion/degradation • Deforestation • Loss of biodiversity • Climate change • Sea level rise
Criminal hazards *Purposely induced processes with criminal motivation and negative impacts on humans and the environment*	• Terror attacks • Mass shootings • Sabotage • Armed conflicts

for a shift towards more context-specific definitions of hazards, emphasising the need for a deeper understanding of complex interactions, including vulnerabilities, exposures, and capacities. This implies a closer alignment with the systemic risk framework (for details see Renn et al. 2022). Additionally, the report calls for the development of a multi-hazard information system grounded in online accessibility and open-science principles.

2.5 Strengths and Limitations of the Single-Hazard Approaches

Single-hazard approaches have their strengths and limitations. The example of the different triggering mechanisms of landslides described in the previous chapter also applies to other hazards such as rock fall processes in high mountain areas. Here, the exact triggering factor is difficult to determine, with possibilities ranging from heavy rainfall, earthquakes or permafrost degradation (McColl 2012). In addition, many hazards cannot be clearly assigned to a single-hazard category, as they frequently occur in combination, interact with each other or as part of cascading process chains (Tilloy et al. 2019; Wenzel et al. 2026). These examples highlight both the benefits and limitations of single-hazard classification systems.

On the one hand, categorisation (see Fig. 2.1) supports systematic documentation (e.g. in databases) and statistical analysis, enabling spatio-temporal differentiation, the identification of hazard hotspots (important of spatial planning, first and second responders or insurance companies) and recognition of recurring patterns or periods (e.g. hurricane season). Analysing hazards in isolation helps to understand the physical processes of a particular hazard in greater detail.

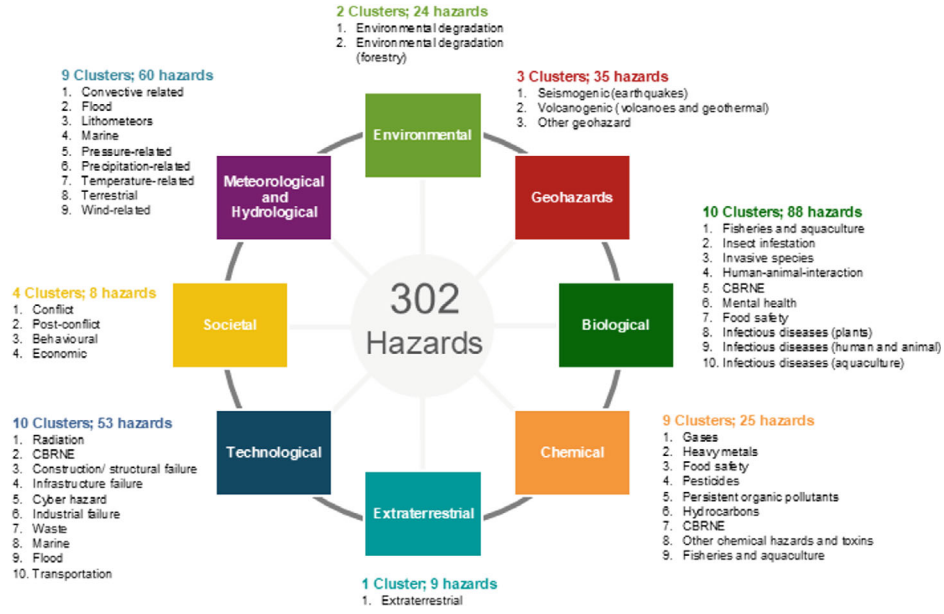


Fig. 2.1 Hazard type categories and subdivided clusters according to UNDRR and ISC hazard information profiles. A total of 302 hazard types are compiled in the technical report on hazard definition and classification review. Modified from Murray et al. (2022); UNDRR and ISC (2020)

This understanding is one basis for multi-hazard approaches which will be further elaborated in another book volume of this series (Schrott et al. 2026). Single-hazard approaches present a number of advantages, some of them described below for each of for exemplary process domains with illustrative settings:

1. Earthquakes can cause human casualties, economic losses and destroy infrastructure. By assessing the environmental conditions as well as the damage caused by past earthquakes and collecting seismic data, it is possible to develop strategies to enhance the safety of inhabitants. This is done for instance via the development of more earthquake-resistant building codes (Stucchi et al. 2011; Zhang et al. 2022).
2. Single-hazard approaches concerning landslides have been utilised in various ways in the past. For example, landslide inventories can be used to develop landslide susceptibility or even hazard maps which can be used by authorities to adjust their spatial planning strategies (Petschko et al. 2013, 2014).
3. Single-hazard approaches concerning floods have been applied in a variety of ways. For example, flood event records can be used to develop flood hazard and susceptibility maps, which serve as an important basis for authorities to refine land-use decisions and integrate risk considerations into planning processes (e.g. Maranzoni et al. 2023).
4. The spatial distribution of past snow avalanches, the assessment of the environmental circumstances of their occurrence and the application of models led to important steps forward in forecasting and mitigation strategies (Ortner et al. 2023; Stethem et al. 2003).

On the other hand, the varying nature and heterogeneous spatio-temporal characteristics of different hazard types result in substantial differences in how they are documented, assessed, and addressed through mitigation or/and adaptation efforts. The categorisation from Fig. 2.1 has some limitations. For instance, the category of environmental hazards, listed alongside biological, geohazards, meteorological, or hydrological hazards, does not appear very convincing. The term is often poorly-defined and tends to include very different processes or hazards that are already covered by other categories. This lack of clarity reduces its analytical value and can even create confusion, especially when hazard classifications are used for research, risk assessment, planning or decision-making.

Another important drawback of single-hazard classifications is that their failure to account for interactions among multiple hazards—as well as their interplay with key factors such as exposure and vulnerability—can result in significant underestimation or overestimation of actual risk levels (Lee et al. 2024). In response, numerous studies have emphasised the urgent need to develop conceptual and analytical frameworks capable of capturing multi-hazard interactions (Gill and Malamud 2014; Tilloy et al. 2019). Over the past few decades, awareness of the complexity and significance of multi-hazard events has steadily increased within both the scientific and policy communities. In summary, the

dynamic interplay between different single hazards can give rise to complex and unforeseen consequences that often cannot be handled by traditional single-hazard assessment frameworks. By focussing solely on individual hazard types, important synergies and cascading effects may be overlooked, potentially underestimating the true extent of risk (Kappes et al. 2012).

While single hazards remain important, multi-hazard scenarios often pose greater risks, as their co-occurrence, consecutive or cascading effects can lead to more severe consequences, including higher economic losses and increased mortality should not be overlooked (Kappes et al. 2012; Zscheischler et al. 2020).

2.6 Future Perspectives

In contexts where communities are exposed to multiple hazards, it is essential for decision-making processes to account for the varying nature and magnitude of risk posed by each hazard—not merely as separate threats, but in terms of their potential interactions. Overlooking these interactions and focussing narrowly on single elements of the Earth system can result in decisions that unintentionally increase vulnerability to other, neglected hazards. For instance, constructing retention basins for flood protection might be successful in reducing fluvial flood risk, but if the design does not consider heavy rainfall events on adjacent slopes, the intervention can inadvertently increase the likelihood of landslides. In this case, managing one hazard in isolation (river flooding) unintentionally amplifies vulnerability to another (slope instability), illustrating the importance of an integrated multi-hazard perspective. Developing more integrated multi-hazard risk approaches that consider the full complexity of hazard interrelations, alongside exposure and vulnerability, presents a critical opportunity for the disaster risk reduction community to improve planning and reduce future losses (Gill and Malamud 2014).

Based on the findings of Murray et al. (2022) some recommendations concerning single-hazard approaches can be given:

(1) A regularly reviewed and updated hazard classification system is essential for effective, risk-based decision-making. The process should involve end-users from the disaster risk reduction, emergency management, climate policy, and sustainable development sectors, aligning with the all-of-society and all-of-State Institutions approach of the Sendai Framework. Special attention should be given to underrepresented hazard types, such as societal hazards, through detailed scientific reviews. Maintaining and updating Hazard Information Profiles, including clear definitions and scientific descriptions, is crucial. This requires coordinated intergovernmental processes and continuous engagement with the scientific community to ensure definitions evolve with the dynamic nature of risk. A further step towards this are the Hazard Information Profiles (UNDRR 2025).

(2) Improving hazard classification and ensuring easy access to clear definitions and descriptions is essential. Future efforts should focus on developing online, linked-data-based hazard definitions that follow open-science principles (UNDRR 2025). This requires a structured scheme that captures key elements such as preferred and alternative terms, inter-hazard relationships, and source references.
(3) Further development of hazard definitions requires active engagement with a wide range of users and stakeholders, including those in disaster risk reduction, emergency management, climate change, and sustainable development. Sharing and promoting the hazard terminology report will help assess its relevance and usability across different user groups. The Hazard Information Profiles can also support the work of the UN Statistics Division and national statistical offices by enabling standardised and interoperable hazard definitions.
(4) Countries are encouraged to use the hazard list and Hazard Information Profiles as tools to identify context-specific sources of risk, supported by tailored guidance for end-users. This guidance would help UN Member States apply the hazard list effectively in implementing, monitoring, and reporting on the Sendai Framework and disaster risk-related Sustainable Development Goals. Key activities may include strengthening the science-policy interface, investing in open-science research, and enacting evidence-based legislation. Additional measures involve conducting risk and capacity assessments, planning, simulations, infrastructure development, public engagement, education, and other capacity-building efforts.
(5) This work complements the hazard definition process by highlighting the need to address exposure and vulnerability, core components of risk alongside hazards. Although significant progress has been made in defining exposure and vulnerability for certain hazard types, there is still no universally accepted set of parameters applicable across the full range of hazards. Addressing this gap could be a key task for the newly established Working Group on Vulnerability and Exposure under the Global Risk Assessment Framework (GRAF).
(6) There is an urgent need to systematically explore the direct and indirect linkages among natural, technological, and human-induced hazards to better identify and understand cascading and complex risks. Adopting a broader, context-specific understanding of hazards requires a comprehensive risk framework that integrates hazard, vulnerability, exposure, and capacity, along with their interactions.

Therefore, it is of major importance to continue the research on natural processes and single-hazard approaches. Only a fundamental understanding of the single-hazard process and the underlying changes in space and time allows us to improve our knowledge, resulting consequently in better understanding of any interconnections within mutli-hazards. Therefore, future work must include (but not be limited to) the following directions:

- Studying individual processes in detail. This includes continuous monitoring, assessment of past developments under respective conditions, which could potentially help to upscale these finding.
- Developing different types of models for retrospective analysis of past events, but also, and in particular, for scenario modelling in order to approximate future events.
- Establishing profound knowledge on the predisposing, the triggering and the controlling factors determining the occurrence of natural events, hazards and risks.
- Investigating the already visible or potential effect of global changes on the events, the hazards and risks.
- Engagement in horizon-scanning to aid anticipation of unforeseen events, many of which may never have been experienced in type or magnitude either generally or in a given geographical space.
- Moving forward from stationary analysis and conditions to the assessment and visualisation of spatio-temporal dynamics.
- Providing open-access databases to be utilised for individual research and applications
- Embedding scientific achievements into practice in forms such that the scientific knowledge can be understood, and therefore utilised, by the public and decision makers.
- And finally, to continuously reflect whether the available concepts and methods remain applicable and whether the underlying modelling assumptions are still valid.

2.7 Summary

The occurrence of natural hazards affecting human populations and livelihoods continues to rise in many parts of the world. In recent decades, disasters caused by natural hazards led to substantial economic losses and widespread impacts. A focus on single-hazard approaches to tackle these issues has characterised the research in this field in the past. Based on this, several definitions were developed concerning natural processes and hazards. These definitions and hazard characterisations help to find a common language as well as to better understand the respective single-hazards which are investigated. This knowledge is key for a single-hazard understanding and is the basis for a multi-hazard approach which accounts for hazard interactions. In the context of global change, it is of great importance to consider these dynamic changes for future (multi-)hazard risk assessments.

These perspectives are particularly vital to enhance disaster risk reduction and planning and to support coping and adaptation strategies to increase environmental and societal resilience.

Key Sentences

- The terms "natural process" and "natural hazard" did not have a standardised definition, which was commonly applied. However, there are approaches such as the Hazard Information Profiles, which were introduced by the UNDRR to fill this gap.
- The frequency and magnitude of certain hazard types, particularly weather-related events, has increased due to global change.
- A hazard is described as a potentially damaging natural event that can be characterised by key parameters such as magnitude, frequency of occurrence, speed of onset, duration, spatial extent, and intensity.
- Single-hazard approaches, which treat each hazard as isolated and independent, remain common in research and practice and are valuable in understanding single hazards more thoroughly.
- By focussing solely on single-hazards, important synergies, interactions between hazards and their cascading effects may be overlooked, potentially underestimating the true extent of risk.
- In areas exposed to multiple hazards, decision-making must consider not only the distinct nature and magnitude of each single hazard but also their potential interactions, highlighting the need for integrated multi-hazard risk approaches that account for hazard dynamics, exposure, and vulnerability to enhance disaster risk reduction and planning.

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Past, Present and Future Trends in Disaster Risk Management

3

Thomas Glade, Sophia Sternath, and David E. Alexander

Abstract

Disaster Risk Management (DRM) is the systematic process of applying policies and strategies to prevent, mitigate, and cope with the adverse impacts of hazards and risks to avoid or reduce losses and build resilience. DRM strategies have a long history in human life. Even thousands of years ago, preventive measures were created to protect society. DRM evolved with the increasing sophistication of institutional settings. These efforts were often driven by both technological and political factors. Although they have evolved into a variety of DRM concepts and approaches, their degree of implementation varies substantially around the world. In the future, DRM must address many challenges. These include extreme events and climate change. They involve coping with social media and systemic and emerging risks. It will also be challenging to make use of serious games, social simulation, big data and artificial intelligence. Many of the challenges are driven by a combination of societal change and the advancement of technology (with the latter contributing greatly to the former). Consequently, existing DRM concepts and approaches must constantly adapt to new challenges.

Keywords

Historical trends • Extreme events • Social media • Serious games—Social simulations • Big data and AI • Systemic risks • Emerging risks

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3.1 Historical Review of Trends

Throughout history the management of hazards and their potential consequences has been an inherent feature of human existence. Initially, the emphasis was placed on the lives of individuals, their families and the communities with which they were closely associated. The primary objective was to ensure the survival of the group. Over time, the management of disaster risk has become institutionalised, facilitated by the development of institutions. Programmes have often been tailored to the management of hazards and associated risks for specific social groups. It is only in the last 150 years that the management of disaster risks has become the responsibility of leaders and governments, and the scope of their duties has been adapted. Moreover, it is only during the last 400 years that concepts such as "identity", "sovereignty" and "human rights" have assumed their modern connotations.

In recent decades, a considerable number of studies have been conducted that explore the broad concepts of disasters and catastrophes (Alexander 2000) and that endeavour to define the principles of emergency planning and management (Alexander 2002). Certain approaches concentrate on emergency response and disaster planning for specific groups, such as corporate and municipal managers (Erickson 2006) or facility managers (Gustin 2013). Other concepts address the essentials of emergency management within an all-hazards approach (Gallant 2008). Moreover, disaster management has been described as "organising chaos" (Kirschenbaum 2004). Some scholars have sought to develop a comprehensive overview, as exemplified by Handmer and Dovers (2007) in their *Handbook of Disaster and Emergency Policies and Institutions.*

3.2 Current Challenges

A variety of different DRM approaches and concepts are available. The design process, its implementation in institutional settings, and the potential duties and responsibilities that accompany it vary widely. Involvement may vary from a limited scope encompassing only an inner cycle to a more extensive one that involves comprehensive societal engagement with all social groups. The role of institutions within DRM varies worldwide and therefore so do their approaches to DRM. However, in addition to institutional resources, the issue pertains to the availability of human and financial resources. Furthermore, the integration of these findings into authentic disaster risk management policies remains a significant challenge (Fan et al. 2025; Marchezini et al. 2025).

Recent advancements have begun to utilise an impact-based management approach that focusses on the potential consequences of disaster and how to manage them. Therefore, a classical natural hazards assessment, delineating potentially endangered areas and including information on magnitude and frequency, is often regarded as insufficient. It is evident that the absence of pertinent information, particularly that pertaining to the potential consequences, is a salient issue. The UN Sendai Framework calls for a risk-based approach

to disaster management. This refers to the information not only on the hazards and their expected characteristics, but also on the potential consequences. This necessitates a focus on vulnerability rather than hazard (Birkmann 2013). Furthermore, within the domain of early warning systems, there is a need to progress towards impact-based early warning.

There is a trend towards a more inclusive, all-of-society approach to DRM. This involves a system of decision-making that includes the individuals vested with authority, the processes to be followed, and the individuals who are accountable for the execution of these processes. It also requires the beneficiaries to be consulted. In this manner, risk management is integrated into an organisation's strategies and objectives. Some key components of risk governance are:

- **Decision-Making Framework**: Risk governance clarifies who decides what risks to take, on what basis, and to whom they are accountable.
- **Risk Appetite and Tolerance**: This defines the level of risk an organisation is willing to accept in pursuit of its objectives.
- **Integration with Strategy**: This connects risk management evaluations and decisions directly to the organisation's overall strategies and goals.
- **Accountability and Oversight**: This establishes clear lines of responsibility and oversight for managing risk, ensuring transparency and accountability.
- **Stakeholder Involvement**: In many contexts, risk governance involves the participation of various stakeholders by considering broader legal, political, and social factors.
- **Risk Culture**: This aims to build a culture in which risk awareness is everyone's business.

To implement a risk governance approach, institutional settings, responsibilities, human resources and financial allocations must be taken into account. Including risk governance principles is an essential way of ensuring that DRM is long-lasting and sustainable.

3.2.1 Extreme Events

When practising DRM, it is important to recognise that not all disaster impacts are moderate and predictable. Systems must demonstrate resilience to high-impact, low-probability events as well as to more common ones of lesser impact (Tellman and Eakin 2022). This is particularly important with respect to the ongoing debate on the effects of climate change (Glaus et al. 2024; IPCC 2012). It is thus essential to expand hazard assessments beyond conventional limits in order to account for the increasing magnitude and frequency of extreme events produced by weather and climate. The model of risk must emphasise the interplay of hazard, exposure and vulnerability. An extreme event only becomes a disaster when exposed systems are vulnerable. Thus, it is important to reduce exposure

and strengthen coping and adaptation capacity. Furthermore, rather than relying purely on historical "most likely" scenarios, adaptive mitigation measures are required, such as robust design codes, redundancy and extra capacity in infrastructure. Rather than treating hazards in isolation, preparedness and early-warning systems must anticipate compound and cascading events (for example, a heatwave leading to wildfire and then degraded air quality). In a cascade of consequences, secondary impacts can sometimes be more serious than primary ones (Pescaroli and Alexander 2018).

It is imperative that recovery and resilience planning acknowledge the possibility that the magnitude of an impact may surpass the conventional capacity to absorb it. This necessitates the implementation of surge capabilities, flexible funding, and planning for worst-case scenarios. Training and governance should engender a culture of enquiry, whereby "what if?" is investigated rather than merely "what has been?". To estimate the likelihood and impact of rare but catastrophic events, monitoring and modelling processes should investigate so-called "fat tailed" distributions and statistical extremes, as exemplified by extreme-value theory.

Investment in risk financing (i.e. insurance, contingency funds, and public–private partnerships) must reflect the potential losses from extremes and, as far as possible, ensure mechanisms are in place to absorb shocks (Deng et al. 2025). Social equity should be prioritised, given that marginalised or vulnerable populations are often disproportionately impacted. Ultimately, the incorporation of extreme events into DRM is congruent with sustainable development objectives (Glaus et al. 2024). This ensures that development pathways are constructed in a manner that fosters resilience rather than allowing risk to accumulate.

3.2.2 Social Media

The integration of social media into DRM (Alexander 2014) has been shown to enhance all phases of the disaster cycle by facilitating dynamic communication, real-time data flows and community engagement (Nielsen et al. 2024). However, many challenges have been identified (Seneviratne et al. 2024). Social media channels enable authorities to disseminate early warnings and preparedness guidance across extensive user networks, thereby augmenting the reach and awareness of such messages among vulnerable communities (Kankanamge et al. 2020). Social media platforms such as X or Facebook can provide crowd-sourced situational information, requests for help from victims, and evidence of emerging hazards. This improves situational awareness and aids coordination.

Social media data can be utilised as a valuable source of impact assessment and monitoring (Ilyas and Sharifi 2025). The analysis of posts, geolocations and sentiments can facilitate the identification of affected areas with greater rapidity in comparison to the utilisation of traditional monitoring systems (Demiroz 2020). Within the phase of recovery and resilience-building, social media facilitates community cohesion, the organisation

of donation appeals, the mobilisation of volunteers and communication between citizens and authorities. To exploit social media a participatory model is needed. In this model, individuals function as both producers and consumers of information, thereby reinforcing bottom-up engagement in DRM initiatives.

However, this integration poses several challenges. These include the potential for misinformation, unequal access (including the so-called "digital divide") and issues of data reliability, all of which may reduce the effectiveness of strategies driven by social media (Ilyas and Sharifi 2025). It is imperative that DRM organisations develop the capacity to monitor, validate and engage with social media. It is essential that they establish trust and manage information flows in a structured manner.

Strategies for the utilisation of social media must formulate messages with care, select an appropriate platform, and employ language that is intelligible to diverse user communities (Ramakrishnan et al. 2022). Factors such as age group, digital literacy and the prevailing local context must be taken into consideration. In order to cross-check the acceptability of a given DRM application, analytics derived from social media can be used to foster adaptive decision-making. Insights from user behaviour and sentiment can help authorities to refine response tactics and allocate resources efficiently (Stolero et al. 2024).

Embedding social media in DRM is now part of risk governance (Erokhin and Komendantova 2024). It acknowledges the distributed nature of information flows. It empowers communities and supports resilience through bi-directional communication, rather than relying entirely on top-down directives.

3.2.3 Serious Games—Social Simulations

Social and policy simulations, including serious games, are participatory approaches through which diverse stakeholders collectively explore complex challenges (Fleming et al. 2020). Drawing on insights from both social and natural sciences, they foster experiential learning and a deeper understanding of interconnections, dynamics and diversity. These tools help inform policy processes in complex contexts, such as sustainable development, climate change adaptation, and disaster risk reduction.

Within DRM, serious games and simulations create interactive environments that allow participants to learn how to make hazard, exposure and vulnerability decisions in a risk-free setting. By exposing conflicting interests and coordination challenges, they enhance social learning, reflection and collaboration. Moreover, simulations help understand cascading and multi-hazard scenarios, improve prevention and preparedness and adapt to situations (Solinska-Nowak et al. 2018). Through experiential learning, they contribute to heightened risk awareness, empathy and resilience (Vazquez-Vilchez et al. 2025). They also provide training for emergency drills, resource allocation, evacuation planning, post-disaster recovery strategies and early warning (Weyrich et al. 2021). However, their

effectiveness depends on careful design, alignment with DRM objectives, and evaluation of the learning and behavioural outcomes. These tools should complement rather than replace traditional DRM approaches, as empirical evidence of their long-term real-world impact remains limited.

3.2.4 Big Data and AI

The integration of big data and artificial intelligence (AI) into DRM can transform the disaster readiness, response and recovery (Qin et al. 2024). A vital characteristic of big data is its integration of extensive and varied datasets, such as satellite imagery, the Internet of Things (IoT), social media streams and historical disaster records (Abdalla 2025; Pundit and Noy 2024). This improves the characterisation and mapping of hazard and exposure, enabling risk managers to go beyond static scenarios to provide dynamic situational awareness. AI algorithms, including machine learning and deep learning, process these extensive data streams to detect patterns, identify anomalies, predict evolving threats and optimise resource allocation under uncertainty (Gevaert et al. 2021).

The combination of big data and AI facilitates the development of advanced early warning systems. These gains enhanced sensitivity and increased speed of operation, thereby increasing the time available for decision-making. This has the potential to reduce the number of casualties and the magnitude of damage. In addition to forecasting, these technologies have the capacity to facilitate real-time decision-support. AI-driven dashboards have been shown to aggregate heterogeneous data, visualise critical metrics, evaluate options and suggest action plans. This can improve coordination among stakeholders.

In the recovery phase, the utilisation of big-data analytics with AI can facilitate the assessment of damage. It can help monitor the progress of reconstruction and the identification of emerging vulnerabilities or cascading risks before they can escalate. However, the integration of big data and AI into DRM poses significant challenges (Ghaffarian et al. 2023). There are concerns about the quality and interoperability of data, the transparency of models (referred to as the "black-box" risk), ethical and privacy issues, the potential for algorithmic bias, and varying levels of access to different kinds of information.

In order to ensure that technologies serve resilience rather than introducing new fragilities, institutions must adapt. To achieve this, they must acquire technical tools and ensure human oversight of AI, governance frameworks, and continuous learning. It is essential to align these technologies with the fundamental principles of risk science (hazard–exposure–vulnerability) to ensure that predictions and recommendations are grounded in the realities of affected communities.

In essence, the integration of big data and AI into DRM represents a paradigm shift from a reactive mitigation approach to a proactive and adaptive resilience strategy (Velev

and Zlateva 2023). However, the technical capabilities must be complemented by adequate capacity, effective governance and robust ethical safeguards.

3.2.5 Systemic Risks

If DRM is to tackle systemic risks there must be a change from single-hazard, event-centric approaches to frameworks that recognise interdependencies, cascading failures (Alexander and Pescaroli 2019), and the potential for localised shocks to propagate across infrastructures, economies and social systems. Systemic risk thinking emphasises the web of connections such as physical networks, supply chains, financial systems, and governance arrangements through which a failure in one place can generate disproportionate, nonlinear impacts elsewhere.

Embedding systemic risk into DRM means developing multi-layered risk assessments that map dependencies and feedback rather than treating hazards, assets and sectors in isolation. It requires scenario exercises and modelling (including network, copula and agent-based approaches) that explicitly capture dependency structures, high impact-low probability events and the likelihood of cascading events. Governance must be adaptive and anticipatory (Hochrainer-Stigler et al. 2024). Cross-sector coordination, joint contingency planning and rapid resource mobilisation are essential if localised failures are to be prevented from becoming systemic crises.

Investments in preparedness and resilience should prioritise critical nodes and buffers that reduce propagation pathways and protect socially vulnerable groups who are most likely to suffer disproportionate harms (Maskrey et al. 2023). The buffers include redundancy, decentralisation and fiscal backstops. Monitoring and early warning must go beyond hazard detection to include indicators of system health that can reveal escalations in systemic stress. Examples include stress in supply chains, critical infrastructure loads and liquidity signals.

Risk financing and insurance need to be recast in a systemic context. Standard indemnity products may fail when losses are connected across portfolios. Hence, diversified financing instruments and contingent credit lines are important. Integrating systemic risk demands greater stakeholder engagement and transparency so that trade-offs in risk transfer, mitigation and development are negotiated openly and equitably (Hochrainer-Stigler 2020; Pescaroli et al. 2023). Ultimately, treating systemic risk as central to disaster risk management makes DRM a better reflection of a highly interconnected world and helps align risk reduction with pathways towards resilient development (Mitra and Shaw 2023).

3.2.6 Emerging Risks

Incorporating emerging risks into DRM means recognising that hazards are not static and that new or rapidly evolving threats can change the risk landscape in ways that are difficult to predict. Emerging risks often arise from novel technologies, shifting climate conditions, changing socio-economic patterns or interconnected systems. They cannot always be addressed by conventional risk-management frameworks (Aven 2017). Because their likelihoods, trajectories or consequences are poorly understood, these risks may be difficult to assess, yet their impact potential may be substantial. Hence, proactive anticipation is essential.

DRM systems must incorporate horizon scanning and early-warning processes that specifically aim to identify emerging risks, such as proliferating technological failure, climate variations and biosecurity events. There must also be flexible, adaptive governance arrangements and stakeholder networks that can respond to unknown or poorly defined threats rather than the typical hazard-vulnerability-exposure profiles.

Capacity-building needs to include scenario planning, simulation of rare events and rapid learning loops so that when emerging risks materialise, systems can respond effectively. As novelty and surprise can accompany emerging risks, resource allocation processes must account for the "premium of uncertainty", investing in resilience and redundancy rather than purely in efficiency. Data systems must be upgraded to collect and integrate diverse signals associated with, for example, technological failures, supply-chain disruptions and climatic extremes. Information on these must be fed into analytical frameworks that can make sense of early signals and emerging threats. Communication strategies should build adaptive mindsets among practitioners and communities. They should frame DRM as a process of managing change and novelty rather than merely one of responding to well-known events. Emerging risk thinking can ensure that DRM remains relevant in a fast-changing world. It can encourage the transition from reactive mitigation to forward-looking resilience and adaptability.

3.3 Future Dimensions

Future decades will face disaster risk management with a rapidly evolving hazard landscape in which climate change, demographic and societal shifts, and urban expansion amplify both the frequency and complexity of events. This will render traditional single-hazard, sectoral responses outdated (Wen et al. 2023). Multi-hazard interactions and cascading systemic risks demand a system-of-systems perspective that can capture interdependencies across sectors, scales and infrastructures rather than creating isolated hazard assessments (Hochrainer-Stigler et al. 2023). Concurrently, the rise of big data and artificial intelligence can improve early warning, situational awareness and resource allocation,

but also raises acute concerns about data quality, algorithmic bias, transparency, and the compatibility of heterogeneous data streams (Erokhin et al. 2024; Khan et al. 2023).

Governance and institutional capacity will be tested, as DRM must be integrated with climate change adaptation, the maintenance of public health, and planning for development. This will require new legal frameworks, financial instruments and multi-level coordination mechanisms (Sandoval et al. 2023). Equity and social vulnerability will remain central challenges because technical advances alone cannot redress uneven exposure, adaptive capacity or the political drivers that differentiate losses socially (Wen et al. 2023). If multi-hazard and systemic risk frameworks are to be turned into usable decision support tools for practitioners, methodological advances in modelling, scenario development and the communication of uncertainty will be required (Hochrainer-Stigler et al. 2023).

The dependency of critical lifelines on complex supply chains and digital infrastructure increases the potential for cascading failures and creates new priorities for resilience planning, redundancy and recovery (Khan et al. 2023). Participatory data, including those derived from social media, offer opportunities for faster, community-level responses but simultaneously impose ethical and privacy limitations and challenges for responding to misinformation (Erokhin et al. 2024).

To connect DRM with measurable development and health outcomes, monitoring, evaluation and the synthesis of evidence must be improved. Under constrained budgets, evidence-based decision making must take priority (Sandoval et al. 2023). Research must be translated into policy in ways that connect academic innovation and operational practice. This will require co-production, capacity building and investment in locally grounded pilot projects that can be used globally as well as locally (Khan et al. 2023; Sandoval et al. 2023).

Some key challenges include:

- **Systemic and Cascading Risks:** modelling, governance and decision-making of interdependent failure potential.
- **Integrating Multi-Hazard and Multi-Risk Assessments** into planning and operational practice.
- **Data Governance**, AI ethics and algorithmic transparency for the application of big data.
- **Interoperability of Data Systems and Technical Standards** across organisations and sectors.
- **Addressing Social Aspects** such as vulnerability, equity and inclusivity in DRM policies.
- **Strengthening Institutional Capacity,** including improved financial mechanisms and polycentric coordination.
- **Securing Critical Infrastructure** and supply-chain resilience against cascading disruption.

- **Managing the Quality of Information**, privacy concerns and misinformation from social media sources (Erokhin et al. 2024).
- **Improving Monitoring, Evaluation** and evidence translation to inform policy and investment.
- **Translating Research into Practice** through co-production and practitioner training.

Disaster risk management faces a convergence of technical, social and governance challenges driven by the increasing complexity of threats and hazards. This is compounded by the transition to a digital world and by persistent social inequity. Addressing these challenges requires integrated multi-hazard frameworks, ethical and interoperable data systems, strengthened institutions and careful attention to local co-production. Prioritising operational research, transparent governance of AI and multi-level finance will be essential if DRM is to be made both scientifically robust and socially legitimate.

Key Sentences

- DRM has evolved from single, individual and family concerns over community units to national and international dimensions.
- Risk governance is a major advance towards an integrative and sustainable DRM.
- Current challenges in DRM include extreme events, social media, serious games and social simulations, big data and AI, systemic risks, and emerging risks.

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Institutional Environments in Disaster Risk Management

4

Annika Fröwis and Sophia Sternath

Abstract

Since the earliest stages of human history, societies across diverse cultures have found themselves confronted with a wide range of natural hazards, resulting damages, and disasters. In response, diverse strategies, capacities and institutional frameworks to mitigate or even prevent potential damage have been developed. Over time, formal organisations and administrative structures have emerged at multiple spatial and governance levels to assume specific roles within disaster risk management (DRM) processes. This chapter provides an overview of the historical evolution of DRM, followed by an examination of contemporary institutional frameworks and key organisations currently involved in disaster preparedness, response and recovery. Finally, it discusses emerging perspectives shaping the future of institutional environments in disaster risk management: In recent years, institutional debates have increasingly highlighted preparedness, prevention and anticipatory governance as central components of effective DRM. In this context, institutions are progressively expected not only to coordinate response and recovery, but also to enable long-term investments in resilience and capacity-building across sectors and governance levels.

Keywords

Disaster risk reduction • Risk governance • Hyogo framework • Sendai framework • UNDRR

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4.1 Introduction

Over recent decades, disaster risk reduction (DRR) has evolved from a specialised technical discipline into a global, interdisciplinary endeavour that aligns closely with sustainable development objectives (IPCC 2023; Pelling 2011; Wen et al. 2023). The increasing frequency and severity of disasters, alongside a rising number of individuals exposed to and affected by natural hazards, have triggered growing recognition among governments, institutions and communities that disaster resilience must be a fundamental pillar of development strategies (UNDRR 2025). As a result, frameworks, policies and institutions have progressively been developed to provide structure and coherence to DRM systems, both globally and regionally (Boin and Lodge 2016; Tierney 2019; UNISDR 2015). Against this backdrop, in this chapter we examine how institutional environments have shaped approaches to DRM and trace their historical development from the earliest stages of human history to the twenty-first century. It must be noted that only a general overview can be provided in this chapter. For a more detailed discussion of this topic, please refer to the book entitled "*International Legal and Institutional Frameworks for Disaster Risk Management*" by Sommario and Billing (2026), which is also part of this book series. In addition, Quevauviller et al. (2026) provide a comprehensive overview of EU disaster risk reduction policies in their book "*EU Research and Community Building in the Area of Disaster Resilient Societies—A 10-Years Legacy*".

4.2 The Role of Institutional Environments in DRM

Institutional environments form the foundation of effective DRM by establishing the norms, rules, and organisational capacities necessary for preventing disasters, preparing for hazardous events, as well as responding to and recovering from their impacts. These environments are dynamic and continuously shaped by changing socio-political contexts, historical developments and evolving risk landscapes. Institutions operate across multiple levels, from local and national to multinational, such as European or global bodies, requiring coordination both within and across borders to address increasingly complex disaster risks (UNDP 2015).

A resilient institutional environment supports evidence-based policymaking, coordination among diverse actors, investments in preparedness, and adaptive governance. Thus, frameworks and organisations play a critical role in translating scientific knowledge into actionable strategies, ensuring DRR is integrated across sectors and scales. The concept of risk governance underscores the necessity of key pillars functioning harmoniously, including human and financial resources, and a robust institutional setting; without these elements, institutional effectiveness remains constrained (IRGC 2019; Klinke and Renn 2010).

Institutions are not merely formal organisations, but assemblages of norms, practices, and expectations that evolve through crisis and reform (Tierney 2019). Their capacity to learn, adapt, and incorporate new knowledge and actors is crucial for sustaining long-term resilience. As Boin and Lodge (2016) argue, crises test not only technical capacities but also the legitimacy and adaptive flexibility of governance systems. Institutions must navigate the complexities of so-called "wicked problems", characterised by contested causes, interdependencies, and the absence of definitive solutions. This requires adaptive governance mechanisms which integrate diverse knowledge systems and foster resilience through iterative learning and inclusive stakeholder engagement (Pahl-Wostl et al. 2012; Rittel and Webber 1973; Sharman and Perkins 2017). Pelling (2011) further highlights that institutions' adaptive capacity is crucial for managing disaster risks in contexts of social vulnerability and climate change, advocating for governance approaches that are both flexible and transformative.

4.3 Historical Pathways of Disaster Risk Management

Throughout human history, societies have faced a myriad of disasters ranging from famine and diseases to floods and earthquakes. Early responses were often embedded in spiritual or cosmological worldviews, with disasters interpreted as divine punishment or natural cycles (Steinberg 2006). Nevertheless, archaeological and historical evidence suggests that even prehistoric communities took deliberate steps to reduce their exposure to hazards. For example, they chose settlement locations strategically, moved seasonally during periods of scarcity, and developed warning systems based on environmental cues—reflecting early forms of hazard awareness and risk mitigation (Coppola 2015).

Cultural narratives such as the biblical story of Noah's Ark—although mythological—illustrate symbolic responses to perceived warnings and are echoed in flood myths across cultures, including the Mesopotamian Epic of Gilgamesh and the Manu flood story in Hindu mythology. These stories reveal a shared human concern with preparedness and survival. More concrete evidence of early disaster governance can be found in Ancient Egypt, where the 12th dynasty Pharaoh Amenemhet III implemented a large-scale hydraulic project to control Nile flooding and improve agricultural resilience, a precursor to structural river management (Coppola 2015; Quarantelli 2000).

DRM systems have developed divergently across regions, shaped by specific environmental conditions, societal structures, and cultural worldviews. For instance, the Inca Empire in the Andes maintained extensive food storage and terracing systems to manage drought and landslides, while in ancient China, state-managed flood control was central to imperial authority (Coppola 2015). These variations in approach laid the foundation for distinct institutional traditions in managing hazards.

A significant turning point occurred in the mid-twentieth century with the emergence of civil defence systems in industrialised nations, developed primarily in response to

wartime threats such as aerial bombing and nuclear attacks. These systems featured shelters, warning infrastructure and emergency protocols. Though initially military in nature, these structures constitute the basis for today's emergency management institutions (Coppola 2015). Although only a small number of civil defence units were gradually transformed into broader disaster management organisations (Quarantelli 1995), the legal structures established for them persisted and became the foundation of modern disaster and emergency management systems.

In the 1970s and 1980s, increasing awareness of disasters' socio-economic consequences led to a shift towards proactive risk management. This period saw major international initiatives, including a landmark UN conference in 1979 that promoted vulnerability assessments and paved the way for coordinated global action in disaster risk reduction (UNDRR 2025; Zentel and Glade 2013).

4.4 The International Decade for Natural Disaster Reduction (1990–1999)

Prompted by rising disaster impacts, the United Nations declared the 1990s the International Decade for Natural Disaster Reduction (IDNDR). The initiative aimed to reduce loss of life, property damage, and social and economic disruption, particularly in low-income countries, promoting a shift from reactive responses to proactive, risk-informed strategies (UNDRR 2025; UNGA 1990). Five key goals were identified:

1. Strengthening national capacities for rapid and effective response, particularly in developing countries;
2. Developing guidelines and strategies based on scientific and technological knowledge, while respecting cultural and economic diversity;
3. Promoting research to close knowledge gaps;
4. Disseminating existing and new technical information;
5. Designing and evaluating risk reduction programmes through international cooperation.

The IDNDR marked a paradigm shift in international disaster policy. It reframed disasters not as isolated "natural" events but as the outcomes of complex interactions between hazards, exposure and societal vulnerabilities. This understanding gave rise to the concept of disaster risk, which later formed the foundation for integrated risk governance (Oliver-Smith et al. 2017).

Moreover, the IDNDR helped to institutionalise DRR within the UN system and national policy arenas. It supported early warning systems, knowledge networks, and the development of national platforms. Nevertheless, evaluations of the Decade revealed persistent shortcomings: fragmented institutional responsibilities; weak integration into

broader development agendas; and insufficient long-term financing (UNDRR 2025; Zentel and Glade 2013).

Despite these limitations, the IDNDR also laid the groundwork for more permanent institutional frameworks, notably the creation of the UN International Strategy for Disaster Reduction (UNISDR) in 1999. It additionally paved the way for subsequent global policy frameworks such as the Hyogo Framework for Action (2005–2015) and the Sendai Framework for Disaster Risk Reduction (2015–2030) (Coppola 2015; UNISDR 2015).

4.5 Institutionalisation: From UNISDR to UNDRR

Building on the momentum of the IDNDR, the UN established the International Strategy for Disaster Reduction (UNISDR) in 1999 to support disaster risk reduction through strategic coordination and policy guidance (Zentel and Glade 2013). The ISDR introduced national platforms, promoted knowledge exchange and began aligning DRR with climate and development agendas. In 2019, UNISDR was restructured as the United Nations Office for Disaster Risk Reduction (UNDRR). Its mandate now includes supporting the implementation of the Sendai Framework, facilitating global reporting through tools like the Sendai Monitor, and promoting coherence across the 2030 Agenda and the Paris Agreement (IPCC 2023; UNDRR 2025).

4.6 Global Frameworks: Hyogo and Sendai

Alongside these earlier developments, other significant initiatives emerged (UNISDR 2015). In 2005, the Hyogo Framework for Action (HFA) was adopted by 168 countries at the World Conference on Disaster Reduction in Kobe, Japan (UNISDR 2007). The HFA provided the first detailed international blueprint for DRR over a ten-year period (UNDRR 2007). Its priorities included:

- Making DRR a national and local priority;
- Identifying, assessing and monitoring risk; improving early warning systems;
- Using education and knowledge to build a culture of safety;
- Reducing underlying risk factors;
- Strengthening disaster preparedness at all levels (UNDRR 2007).

While the HFA spurred institutional growth and awareness, it struggled to reduce disaster losses effectively, particularly due to weak integration into broader development agendas—a limitation already highlighted by Alexander and Davis (2012) and later reaffirmed by UNISDR (2015). Its successor, the Sendai Framework for Disaster Risk

Reduction (2015–2030), marked a shift from disaster management to risk governance. It broadened the scope by:

- Addressing all hazards and systemic risks;
- Emphasising accountability, inclusivity and resilience;
- Aligning with the Sustainable Development Goals, Paris Agreement, and New Urban Agenda.

The Sendai Framework highlights the role of governance, data, and cross-sector coordination, establishing a forward-looking agenda for building resilient societies (IPCC 2023; UNDRR 2025).

4.7 European Union Initiatives

Beyond regulatory frameworks, the EU has established a broad portfolio of funding and capacity-building programmes supporting disaster risk management, including preparedness, prevention, training and knowledge exchange. These instruments help embed preparedness within institutional practice by linking policy objectives, financial resources, and operational capacities across governance levels (European Commission 2025c).

At regional level, the European Union has developed a robust institutional architecture for DRM. The EU has progressively expanded its role in DRM since the 1990s. The Union Civil Protection Mechanism (UCPM), coordinated by the Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG-ECHO), supports disaster preparedness, facilitates mutual assistance among member states and coordinates joint responses to large-scale emergencies (European Commission 2025a). Following initial cooperative efforts, the UCPM was established in 2001 to systematically enhance collaboration among member states during disaster events. Since then, the mechanism has undergone several reforms and expansions to address increasingly complex and cross-border risks, ensuring coordinated and effective responses to emergencies (Boin and Lodge 2016; European Commission 2025b).

Key institutional tools and networks complement the UCPM:

- The Disaster Risk Management Knowledge Centre (DRMKC) supports evidence-based policy through data, modelling, and risk assessment (DRMKC 2025).
- The Union Civil Protection Knowledge Network (UCPKN) promotes exchange between researchers, practitioners, and policymakers (European Commission 2025b).
- The Joint Research Centre (JRC) in Ispra hosts the European Crisis Management Laboratory (ECML), which develops analytical tools for risk monitoring, early warning, and impact forecasting (European Commission JRC 2025).

Together, these instruments enhance the EU's ability to anticipate, coordinate, and respond to complex and transboundary risks and disasters, while also fostering long-term resilience through science-policy integration.

The proposed EU Multiannual Financial Framework (2027–2034) reflects this evolving understanding by placing greater emphasis on preparedness, crisis management, and institutional capacity-building. Policy documents and accompanying factsheets indicate a deliberate effort to strengthen anticipatory action, preparedness planning and resilience-oriented investments across EU disaster risk management instruments (European Commission 2025d).

4.8 Broader International and Multilateral Actors

Beyond the UN and EU frameworks, numerous international organisations contribute to shaping institutional environments. The Global Facility for Disaster Reduction and Recovery (GFDRR) works to mainstream DRR in development planning, especially in vulnerable countries. The OECD, notably through the G20, supports policy alignment in disaster resilience. The International Federation of Red Cross and Red Crescent Societies (IFRC) plays a crucial role in community-based disaster preparedness and response.

National institutions with global influence, such as FEMA in the United States and Japan's Cabinet Office Disaster Management, illustrate the multi-scalar nature of institutional approaches to DRM. Additionally, research-driven entities like the United Nations University Institute for Environment and Human Security (UNU-EHS) in Bonn provide essential interdisciplinary expertise that supports the evolution of DRM frameworks worldwide (UNU-EHS 2025).

Other crucial actors include the World Bank's Global Crisis Risk Platform (GCRP), established in 2018 to monitor and manage compound risks, from climate and natural hazards to conflict, fragility, and food insecurity, through integrated analytics and preparedness strategies in vulnerable countries. Climate-specific disaster risks, in turn, are addressed within the United Nations Framework Convention on Climate Change (UNFCCC), particularly under its adaptation agenda, which aims to enhance resilience, adaptive capacity, and climate-informed development planning (UNFCCC 2025; World Bank Group 2026).

4.9 Synthesis

DRM has undergone a dynamic evolution shaped by historical experience, scientific advancement, and institutional innovation. From ancient flood control measures to modern multilateral agreements, the institutionalisation of DRM reflects a collective global

effort to anticipate, mitigate, and recover from disasters. The gradual shift from reactive approaches towards proactive, integrated strategies has enabled more coherent and collaborative responses.

Risk governance, encompassing legal frameworks, governance structures, and collaborative mechanisms, is essential in embedding risk reduction as a central development concern rather than a peripheral emergency response. As Tierney (2019) emphasises, institutions are not merely formal organisations but assemblages of norms, practices, and expectations evolving through crises and reform. Their capacity to learn, adapt, and integrate new knowledge and diverse actors is crucial for sustaining long-term resilience.

Moreover, DRR is now more deeply embedded in a broader political and economic landscape. As Boin and Lodge (2016) observe, crises often test not only technical capacities but also the legitimacy and adaptive flexibility of governance systems. Effectively addressing disaster risk therefore requires institutional arrangements capable of balancing immediate response with long-term structural transformation, especially in the face of so-called "wicked problems", characterised by contested causes, high interdependencies, and complex solutions.

4.10 Perspectives

Looking ahead, several challenges and opportunities will shape the future of institutional DRM. While the benefits of anticipatory approaches are increasingly acknowledged, translating this recognition into sustained institutional practice, long-term funding, and coordinated governance across sectors and scales continues to require political commitment and adaptive institutional design (European Commission n.d.; UNDRR 2025).

First, the increasing complexity of disasters, fuelled by climate change, urbanisation, geopolitical instability, and cascading risks, requires adaptive, anticipatory and inclusive institutions (Alexander and Davis 2012; IPCC 2023; UNDRR 2025).

Second, the institutional mainstreaming of DRR across sectors, particularly in finance, infrastructure, education, and health remains uneven, especially at the interface between national and local governance levels (Tierney 2019; UNDP 2015; Weichselgartner and Pigeon 2015).

Third, the co-production of knowledge, linking scientific data, local insights, and policy priorities, is increasingly recognised as essential for effective risk governance (Pahl-Wostl et al. 2012; Weichselgartner and Pigeon 2015). Stronger efforts are also needed to address inequalities and ensure participation from marginalised groups, whose vulnerabilities are often most acute (Oliver-Smith et al. 2017; Pelling 2011).

Further considerations include:

- The growing role of digital technologies, including social media and artificial intelligence, across all stages of DRM (DRMKC 2025; European Commission 2025a).

- Education as a tool to build resilient societies (UNDRR 2025).
- Systemic risks and Impact Chains requiring integrated institutional responses (IRGC 2019; World Bank—GCRP 2018).
- Emerging hazards and their implications for institutional arrangements (Boin and Lodge 2016; IPCC 2023).
- Cross-border disaster dynamics, whether through the event itself (e.g. earthquakes affecting multiple countries) or through global ripple effects (e.g. supply chain disruptions, impacts on tourists) (Boin and Lodge 2016; European Commission—JRC 2025).
- Multi-hazard and interconnected risks necessitating coordinated governance (UNDRR 2025; Wen et al. 2023).
- Institutional vulnerabilities arising from political shifts, such as the weakening of FEMA or USAID in recent years (Alexander and Davis 2012; Tierney 2019).

These challenges highlight the enduring importance of robust but flexible institutional environments in DRM. Digital technologies, integrated data systems, and transnational knowledge exchange will shape the next generation of institutional frameworks, which must also contend with political volatility, trust deficits, and capacity disparities. Policymakers must ensure DRR remains a sustained political priority, underpinned by evidence, long-term funding, and multidisciplinary collaboration across borders.

Key Sentences

- Institutional environments form the foundation of DRM by establishing norms and have evolved historically from spiritual interpretations to modern, risk-informed governance structures—decisively shaped by international decades and global frameworks such as the Hyogo and Sendai Frameworks.
- Global and regional actors (including UNDRR, GFDRR, IFRC, and EU mechanisms) underscore the multi-scalar nature of DRM and promote coordinated, cross-border risk governance.
- The paradigmatic shift from reactive disaster response to proactive risk governance places prevention and preparedness at the centre of institutional functions, requiring stable governance arrangements, long-term investment, and cross-sectoral coordination.
- In light of climate change, systemic risks, and political volatility, future-oriented institutions must embrace adaptive, inclusive, and anticipatory approaches, supported by digital technologies and transnational cooperation.

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Framing Vulnerability

5

Sophia Sternath, Thomas Glade, and Sven Fuchs

Abstract

Vulnerability is one of the key drivers of risk, along with information about the hazard and the elements at risk. The term vulnerability is, however, used by many disciplines and requires careful consideration, which is why it is defined here. Key vulnerability concepts of natural and social science are presented and embedded into an interdisciplinary approach. The different dimensions, including social, physical, economic, environmental and institutional vulnerability, are characterised and finally summarised in an overview table. Furthermore, the spatio-temporal dynamics of vulnerability are explored and complemented by some identified key future challenges of vulnerability research. It is concluded that a comprehensive understanding of vulnerability is essential for good governance in disaster risk management and reduction. This is of particular relevance for the development of tailor-made measures to strengthen the resilience of affected communities, which lead ultimately to increased disaster preparedness.

Keywords

Vulnerability concepts • Vulnerability dimensions • Measuring vulnerability • Vulnerability indicators • Spatio-temporal dynamics

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5.1 Introduction

Under the conditions of global environmental change as outlined in the 6th IPCC Assessment Report by WG II (Pörtner et al. 2022), the impacts of natural hazards on natural and human systems are manifesting themselves worldwide. Losses due to these hazards are reported to be increasing, even though considerable efforts have been made to reduce disaster risks at a global level as well as at the national level of the affected countries. Global trends show an increase in the number of natural hazards and hence in the losses from so-called disasters. Losses are the result of both the dynamics of the frequency and magnitude of hazardous events and of the exposure of society or elements at risk, such as buildings or infrastructure. Exposure to natural hazards is related to vulnerability and resilience, concepts that have (re)gained popularity in recent years, both from a scientific perspective (Fuchs and Thaler 2018a) and in policy development and disaster risk reduction (Birkmann 2013a; Zimmermann and Keiler 2015). Vulnerability is broadly defined by the UNDRR (2017) as "…conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards…". It commonly includes the potential for loss and comprises elements at risk (people, infrastructure, clean air, rare flora and fauna), sensitivity (the degree to which people, places, or infrastructure are harmed), and coping capacity (the skills, resources and opportunities of people and places to survive, absorb impacts, and cope with adverse outcomes).

Despite the growing number of studies published over the last decades (e.g. Birkmann et al. 2013; Menoni et al. 2012), current approaches are still driven by a divide between the natural and social sciences, although some attempts have been made to bridge this gap (e.g. Fuchs and Thaler 2018a). While social scientists tend to view vulnerability and resilience as the set of socio-economic factors that determine people's ability to cope with stress or change (e.g. Cutter et al. 2003; Fekete et al. 2014), natural scientists and engineers often view both terms as focussing on the occurrence likelihood of specific hazards and the associated impacts on the built environment (e.g. Papathoma-Köhle et al. 2017). Researchers from each discipline define vulnerability in a way that fits their individual disciplinary lens. However, within the academic discourse there is an interconnection and feedback between these different academic fields, which is an essential asset for understanding the broader context of vulnerability in natural hazard management (Gotham and Campanella 2011; Turner II 2010). Vulnerability reduction is one of the key drivers of risk reduction and thus sustainable development. Consequently, the topic is also addressed in international frameworks of the United Nations International Strategy for Disaster Reduction such as the Sendai Framework (UNISDR 2015) and its predecessor, the Hyogo Framework (UNISDR 2005).

This chapter first defines vulnerability and then discusses natural and social science concepts of vulnerability, including an interdisciplinary approach to vulnerability. The social, physical, economic, environmental and institutional dimensions of vulnerability

are then illustrated with examples. The spatio-temporal dynamics of vulnerability are discussed before the chapter concludes with an outlook on future challenges in the field.

5.2 Defining Vulnerability

The concept of "vulnerability" originates from the Latin terms *vulnerare* ("to wound" or "to injure") and *vulnus* ("wound"). While traditionally associated with human susceptibility to harm, in risk and disaster research, the term extends to objects, infrastructure, and even entire regions as well as to intangibles that are not strictly physical, such as clean air. Vulnerability is a central issue in hazard and risk studies, as well as in climate change research, and has been extensively debated and refined over the past four decades (e.g. Blaikie et al. 1994; Birkmann et al. 2013; Chambers 1989; Ciurean et al. 2013; Cutter 1996; Fuchs and Thaler 2018b; White 1945; Ziga-Abortta and Kruse 2023).

Discussions have fostered diverse perspectives, enriching the understanding and analytical frameworks of vulnerability, even as a single universally accepted definition remains elusive (Birkmann 2013a). The concept of vulnerability is adaptable across disciplines and contexts, reflecting its multi-faceted nature. Despite these variations, a shared understanding emerges within risk research, emphasising susceptibility to damage or injury (Blaikie et al. 1994; Wisner et al. 2004). In the "Encyclopedia of Natural Hazards", Cutter (2013: 1088) defines vulnerability as the "potential for harm or loss", applicable at both individual levels, such as persons, buildings, or roads, and collective levels, encompassing groups of people or infrastructure systems.

The former UNISDR (United Nations International Strategy for Disaster Reduction), now the UNDRR (United Nations Office for Disaster Risk Reduction), defines vulnerability as "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" (UNISDR 2009: 12). This perspective highlights the importance of pre-existing conditions (ex-ante) that influence the level of risk for a given element, while placing less emphasis on the impact of a hazard event itself (Fuchs et al. 2011, 2018). Additionally, the UNISDR (2009) clarifies that vulnerability, whether for individuals, communities, systems, or assets, exists independently of exposure. For instance, a building in a flood-prone area may have lower vulnerability than one outside a designated high-risk zone due to the implementation of preventive measures and resilient design. The Sendai Framework for Disaster Risk Reduction (2015) expands on this concept by defining vulnerability as "the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards" (UNDRR 2017). Rubin and Dahlberg (2017) further emphasise in the "Dictionary of Disaster Management" the multifunctional nature of vulnerability as a complex interplay of several factors,

which is responsible for the "diminished capacity of an individual or community to anticipate, cope with, resist, and recover from the impact of a hazard", and thus goes beyond the aspect of susceptibility.

These definitions illustrate how vulnerability can be assessed at both individual and collective levels, allowing for more targeted risk reduction strategies. Birkmann (2013a) underscores the role of social factors and structures in shaping risk and adaptation options. Cutter (2021) argues that vulnerability is a key determinant of disaster outcomes, helping explain disparities in risk levels across different social groups and risk elements. Fuchs and Thaler (2018b: 3) further refine the concept of vulnerability by identifying three interrelated components. First, "elements at risk" refer to the people, places, and infrastructure, such as buildings and transportation networks, that may be affected by hazards. Second, "sensitivity" describes the extent to which these elements experience harm. Third, "coping" encompasses the skills, resources, and adaptive strategies available to individuals and communities to manage, absorb, and recover from hazards.

Given the interdisciplinary nature of natural hazard and risk research, perspectives on vulnerability continue to evolve across various fields, including social sciences, environmental studies, insurance and engineering disciplines. The "*Atlas of Vulnerability and Resilience"* by Fekete and Hufschmidt (2016) integrates diverse spatial and disciplinary approaches, case studies, and conceptual frameworks, contributing to a more holistic and interdisciplinary understanding of vulnerability and resilience. The ongoing refinement of these approaches enhances the ability to develop effective risk reduction strategies and strengthen adaptive capacity across different contexts.

5.3 Key Concepts

5.3.1 Vulnerability in Natural Sciences

Engineering and natural sciences research on vulnerability primarily focuses on modelling the factors influencing vulnerability and their interdependencies through quantitative approaches. These disciplines seek to translate complex risk dynamics into mathematical frameworks that allow for objective assessment and predictive modelling (Fuchs et al. 2019). Hence, vulnerability is conceptualised as "the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total loss)" (UNDRO 1980). This definition suggests that vulnerability is equal to the degree of loss of an element at risk resulting from the occurrence of a natural process (ex-post) and, once the relationship between hazard impact and rate of destruction is known, allows an ex-ante assessment of possible future losses (Fuchs et al. 2018).

In the field of natural sciences, including engineering, vulnerability is often understood as part of a risk function and is, therefore, together with the hazard and the elements at

risk, equated with the risk. In this context, the elements at risk together with the vulnerability form the adverse consequences resulting from a hazardous event. Some approaches go further and require that "adaptation and coping capacities" are also taken into account (Cardona et al. 2012).

When calculating vulnerability, large variations in parameter values in particular must be openly communicated to avoid misinterpretation of the calculations. In the scientific discussion of vulnerability, this calculation is often realised in a relationship with the intensity of a natural event. The greater the intensity of a natural hazard, the greater the vulnerability of an object or person (or group) to that event. This is true up to an intensity of the natural event that completely destroys the object. Depending on the hazard type, there may also be a lower limit to the intensity of an event below which no damage occurs and an upper limit above which total damage is expected.

In natural sciences, four different approaches are used to calculate vulnerability: (1) empirical methods, based on past event data, damage reports and historical observations; (2) analytical methods, using numerical models and physics-based simulations to assess damage; (3) probabilistic approaches, using statistical models such as Monte Carlo simulations—these are closely linked to the first one; and (4) deterministic approaches, focussing for example on worst-case scenarios with predefined levels of hazard.

5.3.2 Vulnerability in Social Sciences

The social sciences conceptualise vulnerability as a dynamic, multidimensional condition shaped by social, economic and political factors. Unlike the natural science and engineering approach, which focuses on physical vulnerability, the social sciences emphasise human systems, inequalities and adaptive capacity. However, debate continues on this and other issues surrounding the concept of vulnerability, including if vulnerability is an outcome of a disaster perspective or a process, and whether or not vulnerability as a conceptual measure can exist independently of a hazard (Fekete and Montz 2018).

Robert Chambers, former director of the Institute of Development Studies (IDS) at the University of Sussex, greatly influenced vulnerability research in social sciences. His study in developing countries revealed that vulnerable groups develop complex methods for managing risks (Chambers 1989). He sees vulnerability as having two sides, an external side (risks, shocks and stress) and an internal side (defencelessness or lacking the means to cope), and he emphasises that social context determines vulnerability. Building on this, Bohle (2001) proposed the concept of the dual structure of vulnerability (Fig. 5.1). Watts and Bohle (1993) argued that vulnerability is shaped by socio-ecological, political-economic, and entitlement structures. Thus, social conditions, resource access, interdependencies, and power structures have a significant impact on vulnerabilities (Bohle and Glade 2008).

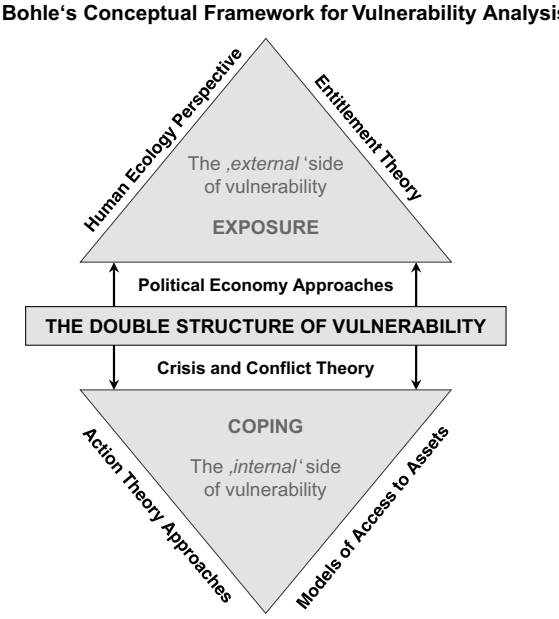


Fig. 5.1 The dual structure of vulnerability. Adapted from Bohle 2001

The concept of social vulnerability is also used in development research and cooperation. Chambers' work led to livelihoods research at the Institute for Development Studies at Sussex in the late 1990s. The *Sustainable Livelihoods Framework* has been developed to assess the vulnerability of marginalised groups (DFID 1999). It identifies vulnerability contexts and evaluates the assets that support livelihoods (natural, physical, financial, human, social capital). The distribution of and access to resources are shaped by policies, laws, and cultural norms. Critics argue that the framework is too static, lacks historical context, and ignores the drivers of power relations (Bohle and Glade 2008).

Early geographical hazards research examined society-environment interactions through vulnerability analysis (White 1945). Blaikie et al. (1994) introduced the *Pressure and Release Model*, which views disasters at the intersection of vulnerability-generating processes and physical hazard exposure. Pressure can be exerted on the affected person(s) from both sides. To release the pressure and mitigate the disaster, a reduction in vulnerability is necessary. Critics argue that the model overlooks exposure, the development from vulnerability to a disaster, and environmental aspects such as sustainability and human–environment relationships, and vulnerability to nature (Hammer et al. 2019).

The *Hazards of Place Model* introduced by Cutter (1996) takes a multi-hazard approach rather than considering only one hazard relevant to a specific location. Vulnerability is understood as the interaction of the biophysical risk and the social context in a specific geographical and temporal context. Cutter distinguishes between the geographical space in which vulnerable people are located and the social space in which vulnerable people act. In this approach, the components of vulnerability interact with each other to create the vulnerability of a given location and the people living there.

5.3.3 Interdisciplinary Approaches Towards Vulnerability

An interdisciplinary approach is required to ensure a holistic view of vulnerability. Alexander (2004) provided a conceptual link between natural and social science approaches and showed that social vulnerability can influence potential damage even more than the damaging event itself. He also argues that the disaster potential is highly dependent on societal change and the social and spatial differentiation of a society, and he emphasises the dynamic duality of vulnerability. He refers to the tension between social, risk-generating activities and human efforts to minimise risk. Thus, both the social science, actor- and action-orientated perspective and the natural-science, risk-related perspective are taken into account in the conceptualisation of vulnerability (Bohle and Glade 2008).

With the motivation of creating a multi-dimensional and holistic framework of vulnerability, Birkmann et al. (2013) developed the *MOVE framework*. Its aim is to consider the most important causal factors such as exposure, susceptibility, lack of resilience, as well as the various thematic dimensions of vulnerability (physical, social, environmental, economic, cultural, institutional). This framework also distinguishes between coping and adaptation. The *MOVE framework* emphasises the nonlinear, complex and emergent nature of disaster risk systems and their different processes (Birkmann et al. 2013).

5.4 Dimensions of Vulnerability

Commonly, five central dimensions of vulnerability are identified. It is important to stress that the boundaries between these dimensions are not clear-cut, but rather blurred and intertwined, and that they complement each other specifically in an interdisciplinary context of risk assessment. Nevertheless, this approach helps to provide a structured overview of the different dimensions of vulnerability.

5.4.1 Social Vulnerability

Social vulnerability refers to the vulnerability of societies, whether individuals or social groups, i.e. their susceptibility to injuries, loss and disruption of livelihoods, including fatalities. On the one hand, social vulnerability is the product of social inequalities that determine the susceptibility of groups of people to hazards and their ability to cope with disasters. On the other hand, according to Cutter (2006), vulnerability also includes the inequalities between places, which can be attributed to the degree of urbanisation, growth rates and the economic situation (Cutter et al. 2003). Social vulnerability is also influenced by access to resources (including information, knowledge, technology) and stable political representation, social capital (including social relationships and networks), beliefs and customs, the presence of physically disabled people, the condition and age of buildings, and the type and density of critical infrastructure. These broad concepts are in turn influenced by various variables such as age, gender, ethnicity and socio-economic status. No common ground has yet been found on the characteristics that describe people with special needs or those with limited or no access to social networks, which is necessary for a rapid and sustainable recovery in the event of a disaster (Morrow 1999). These include people with physical or mental disabilities, people with limited language skills, people experiencing homelessness and tourists. Hazards can entrench and reinforce pre-existing inequalities and injustices within social structures (Cutter 2006). Fothergill and Peek (2015) studied the impact of Hurricane Katrina on children and adolescents and found that disasters are particularly stressful for children from unstable backgrounds. For a deeper understanding of how to measure social vulnerability, refer to Burton et al. (2018).

5.4.2 Physical Vulnerability

While social vulnerability focuses on individuals or societies and their coping capacities in response to natural hazards, this becomes less important in the case of physical vulnerability. The role of the natural hazards themselves and their impacts become more relevant (Ciurean et al. 2013). The interactions between the hazard and the physical and built environment determine this vulnerability type. Physical vulnerability refers to the degree of susceptibility within the physical-material environment and thus to the negative impact on, for example, fixed structures such as buildings, transportation routes, or mobile objects such as vehicles. Despite significant differences in the definition of physical vulnerability across disciplines, two essential elements can always be identified. The first relates to the hazard itself—on the one hand, the characteristics of the hazard, such as its spatial extent, the magnitude or intensity and the frequency in a given period of time. The second key component refers to the characteristics of the physical or built environment, which

includes different areas such as societal assets (lifelines, agricultural resources, individual and community values, and the surrounding natural environment) (Fuchs et al. 2018). When determining physical vulnerability, both the exposure of an element at risk and the damage potential and sensitivity of the element at risk, i.e. buildings, infrastructure and population, to the potential impacts and physical demands of the hazard on the environment need to be considered. The assessment can be based on vulnerability matrices, indicators and curves (Papathoma-Köhle et al. 2017).

5.4.3 Economic Vulnerability

Assessing economic vulnerability is particularly important for scientists, practitioners and the private sector, especially (re)insurers. Especially in natural hazard and disaster risk management, it is important to determine the benefits of adaptation and mitigation measures and to compare costs to optimise management. It is also useful to identify the limits of adaptive capacity. In response to the need to identify measures to minimise damage and compare costs, stage-damage curves have been developed to show the relationship between the impact of an event and the resulting damage. Such curves also allow translation into monetary values and can then show the economic effects of loss. For a detailed description on creating stage-damage curves and related challenges, please refer to e.g. Thaler and Jongman (2018).

A distinction can be made between indirect and direct losses, as well as tangible (or monetary) and intangible (or non-monetary) losses. Direct tangible losses arise straight from the physical force of a hazard, such as damage to a building or household inventory, infrastructure, agricultural crops or livestock. In contrast, direct intangible losses are usually caused by the individual effect of an event, which can extend both temporally and spatially beyond its area of impact and may be difficult to measure. Examples include damage to cultural sites, environmental assets, health, life, trust in authorities, or memorabilia. For example, a road blocked by a landslide can damage a company by forcing it to stop production for a certain period of time due to a lack of resources or labour, without the company's building itself being destroyed. Negative effects are not only limited to occurring on the supply side but can also affect the demand side. The temporary closure of a company also reduces the demand for input factors, which can also lead to suppliers outside a road network or even on other continents having to reduce their production. Indirect losses are therefore usually calculated as the difference between total losses and direct losses, whereby the mechanism that triggered the effects is not taken into account (Thaler and Jongman 2018). Cochrane (2004) used the term "systemic risk" to expand the concept of indirect loss and attempted to develop a more holistic perspective. Instead of focussing solely on the negative effects on the production chain, systemic risk refers to the consequences for the financial system. From a long-term perspective,

indirect losses generally have more serious negative effects than direct losses (Thaler and Jongman 2018).

5.4.4 Environmental Vulnerability

Environmental vulnerability can be understood as the susceptibility of the natural environment to hazard processes. A distinction can be made between natural hazards, such as volcanic eruptions or earthquakes, and human-induced hazards such as the effects of human-induced climate change, soil erosion caused by agriculture, contamination of soil or water bodies or deforestation. The environment, and in particular ecosystems, are differently vulnerable to hazard processes and have different buffering capacities against them, i.e. small magnitudes of hazard processes have hardly any effect on the ecosystem (e.g. small volcanic eruption = low vulnerability), whereas large events can completely change the environmental system (e.g. extremely violent volcanic eruption = high vulnerability). When a threshold is crossed, the system can enter a new, irreversible state (e.g. eroded coastline after a storm, landslide after an earthquake, extinction of species due to global warming). As a result, our environmental systems have different levels of vulnerability to hazard processes. Compared to the other four dimensions of vulnerability, environmental vulnerability has received much less attention in the scientific literature to date. It has been discussed in the context of biodiversity (Bellard et al. 2014; Segan et al. 2016; Silva Rocha et al. 2024), sustainability (Miyan 2015; Turner et al. 2003) and environmental tipping points (Lauerburg et al. 2019). Fundamental socio-ecological research also addresses these interactions and interdependencies (Berrouet et al. 2018; Li and Ford 2019).

5.4.5 Institutional Vulnerability

Institutional vulnerability refers not only to the vulnerability *of* institutions to hazards, but also to the way in which institutions *influence* vulnerability to hazards. For example, damage is often the result not only of poor-quality structures, but also of other factors such as the existence (or lack of) legislation to support preparedness, response and recovery measures and their implementation. The way in which disaster management actors coordinate and communicate, the level of public participation and awareness, and the risk transfer mechanisms available are also criteria embedded in the underlying socio-economic, cultural and political structures that make up a community's institutional framework (Papathoma-Köhle et al. 2021; Shi and Xie 2024). This institutional framework determines a social group's approach to preparing for, responding to and recovering from a disaster event. The importance of institutional vulnerability was clearly illustrated by Hurricane Katrina in 2005, when the southern US suffered widespread devastation,

loss of life and billions of dollars in damage (Cutter and Gall 2008). Although the storm was classified as a Category 4 hurricane, the damage cannot be explained simply by the intensity of the storm and the physical vulnerability of the affected states. The devastation must also be attributed to the inadequate response of the responsible organisations, the lack of communication and coordination at different levels and policies that increased the vulnerability of the population and created social tensions (Papathoma-Köhle and Thaler 2018).

5.4.6 Summarising Vulnerability Dimensions

To conclude this overview of the dimensions of vulnerability, it is important to emphasise the dynamic and fluid boundaries between them. The vulnerabilities mentioned cannot be strictly separated from each other, and in many cases, they even determine each other. Table 5.1 summarises the characteristics of vulnerability mentioned and provides examples of further literature.

5.5 Measuring Vulnerability

An accurate assessment and quantification of vulnerability is crucial for estimating the potential impacts of both rapid and gradual natural events. Since vulnerability curves are based on event intensity values and present the relationship between these and the damage caused by the respective event, they are a useful tool to express physical vulnerability by quantification. Indicators on the other hand are not reflected by real values. Hence, they are more so used as a foundation for the creation of vulnerability indexes, which can be used for comparison and as the backbone for the prioritisation of adaptive and risk mitigation measures to be taken. Due to its multi-faceted nature, it is challenging, if not impossible, to boil down the concept of vulnerability to a single equation or set of indicators that can be used in any context and for all hazards. At the same time, however, for the sake of comparability, it is important that global risk and vulnerability assessment methods use the same indicators without providing detailed information on specific, local circumstances, as these may require different criteria or methods (Birkmann 2013b).

For this reason, Birkmann (2013a) brings together different levels of vulnerability measurement, with different methods and different thematic foci. The results of a study by Li et al. (2010), in which a model for vulnerability quantification was developed based on the intensity of landslides and the resilience of the exposed elements, also provide an example of vulnerability assessment. The selection of a suitable approach for measuring vulnerability is strongly influenced by the spatial and temporal extent, the function of the

Table 5.1 The dimensions of vulnerability and exemplary contributions

Dimension	Definition	Selected references
Social vulnerability	Susceptibility of individuals, social groups and places to risks due to social inequalities	Aksha et al. (2019), Alves et al. (2022), Burton et al. (2018), Cutter (1996, 2006), Cutter et al. (2003), Cutter and Finch (2008), Fothergill and Peek (2015), Jozaei et al. (2022), Nguyen et al. (2017), Spielman et al. (2020), Wang et al. (2022)
Physical vulnerability	Susceptibility of elements in the physical environment to damage from hazards	Ciurean et al. (2013, 2016), Eidsvig et al. (2014), Fuchs et al. (2007; 2011; 2018), Hufschmidt and Glade (2010), Jenkins et al. (2014), Kappes et al. (2012), Li et al. (2010), Papathoma-Köhle et al. (2011; 2012; 2014; 2015)
Economic vulnerability	Susceptibility to direct or indirect economic losses	Briguglio et al. (2009), Cochrane (2004), de Silva and Kawasaki (2018), Mechler et al. (2006), Flatø et al. (2017), Mechler and Bouwer (2015), Mulder and Bussière (1999), Thaler and Jongman (2018)
Environmental vulnerability	Vulnerability of the natural environment to hazard processes and risks	Ahmed et al. (2018), Bellard et al. (2014), Botero et al. (2014), Lauerburg et al. (2019), Miyan (2015), Turner et al. (2003), Segan et al. (2016), Silva Rocha et al. (2024)
Institutional vulnerability	Vulnerability triggered by the absence or mismanagement of institutions	Alves et al. (2022), Borrego (2023), Cutter and Gall (2008), Dolfsma et al. (2011), López-Martínez et al. (2017), Papathoma-Köhle et al. (2021), Shi and Xie (2024), Spink et al. (2021), Ziga-Abortta and Kruse (2023)

approach, the thematic scope of vulnerability, the data basis, the target group, the objectives and the degree of aggregation (Birkmann 2013b). Despite this limitation and the associated challenges, it is important to develop approaches that allow comparability.

One example of the assessment of vulnerability is the WorldRiskIndex. It was developed to systemise and operationalise the main characteristics of risk and vulnerability

to natural hazards and climate change at a global level. Social, economic, health and environmental characteristics as well as governance issues were captured in this index. It describes the relationship between hazard, exposure and vulnerability and thus the risk for individual countries around the world. The four main components that make up the WorldRiskIndex are exposure, vulnerability, coping capacities and adaptation capacities. After all four components are calculated separately on the basis of assigned indicators, the vulnerability, the lack of coping capacity and the lack of adaptive capacity are added together to form a vulnerability index that characterises the circumstances and processes in societies. In the final step, the vulnerability index is multiplied by the exposure, i.e. the magnitude and frequency of a hazard, and the risk is calculated (Welle et al. 2013). The annually updated WorldRiskIndex and a global vulnerability map are provided by Bündnis Entwicklung Hilft (2025).

Another example is the INFORM risk index, the first global, objective and transparent tool for understanding the risk of humanitarian crises and the outcome of a collaborative effort between the Inter Agency Standing Committee, the European Commission and humanitarian and development organisations operating worldwide. (EC n.d.) Further information on the INFORM risk index can be found by consulting European Commission (n.d.).

Vulnerability measurements can of course also be carried out at smaller spatial scales. Examples of this include Fuchs (2016), who created a vulnerability map for Austria, and Scherer et al. (2016), who quantified vulnerability and heat risk for the city of Berlin. The validation of vulnerability assessments is crucial to ensure that the results are accurate and reliable. Possible ways of validating the WorldRiskIndex are presented in Birkmann et al. (2022). Further research into such comparable approaches must be conducted in the future, especially with regard to the various dimensions of vulnerability presented above.

5.6 Spatio-temporal Dynamics of Vulnerability

Vulnerability is a concept that is strongly linked to time and space and requires constant reassessment to ensure an appropriate response and to minimise damage. Vulnerability of any kind can change rapidly at different scales, as illustrated by the example of a residential building where the vulnerability of the occupants may be significantly higher at night when they are at home than during the day when the majority of occupants have daily commitments elsewhere. Social groups are constantly changing, and so is the vulnerability landscape - for example as a result of climate change and its impacts, or of changing social relationships and structures; in addition, personal behavioural change affects one's own vulnerability. This means that vulnerability reduction strategies need to change and adapt constantly (Fuchs et al. 2013). Spatial vulnerability can also vary widely, even within very small areas. In South American cities such as Rio de Janeiro or

São Paulo, the vulnerability of neighbouring residential areas varies considerably. Informal settlements (e.g. favelas) are significantly more vulnerable to natural hazards than neighbouring residential complexes, due to their construction or lack of access to vital infrastructure (e.g. water, electricity), but also due to prevailing power structures and marginalisation processes (Mendonca and da Silva 2020).

The dynamic nature of vulnerability highlights the need to examine the spatial and temporal context of a society and the conditions and preconditions that prevail within it, as well as the preconditions of a risk element at a given time and place, in order to reduce vulnerability, minimise risks and promote long-term adaptation to climate change.

5.7 Future Challenges

In today's risk landscape, both social and ecological systems are subject to constant and often rapid change. Factors such as climate change and associated extreme events, which are becoming increasingly difficult to predict, political instability and wars, new technologies, and affluence and over-consumption in rich countries are constantly altering the conditions specific to society, whether locally, regionally or globally. In addition, societal exposure to hazards is increasing, not least because of the combination of increased vulnerability with the self-induced introduction of risks through settlement in high-risk areas and human modification of natural systems (Cutter 2021). These dynamic changes significantly influence the vulnerability of elements at risk, both by increasing existing vulnerabilities and by creating new ones.

The increased uncertainty and complexity in the environmental-social system makes it more difficult to calculate risks, assess scenarios and respond appropriately, further weakening the resilience of the systems concerned. At the same time, technological advances, such as earthquake-resistant or flood-adapted construction methods, can help increase resilience and reduce vulnerability. In the future, it will be increasingly important not merely to acknowledge past disasters once reconstruction is complete, but to learn from them for future action. It must be considered, however, that the future might be different due to changed conditions. The knowledge of indigenous communities and impoverished populations who have developed specific adaptation strategies should be systematically incorporated into this learning process. At the same time, however, society also needs to adapt to new, previously unknown risks, or risks that have not yet occurred in this form, with the corresponding vulnerabilities. Spatio-temporal vulnerability is a continuous, dynamic process that poses a major challenge. In a world where hazards are becoming more complex and their prediction gets increasingly difficult and imprecise, vulnerability needs to be constantly reassessed in order to take timely action.

5.8 Summary

Vulnerability is a concept used in many different disciplines. For this reason, there is no universal definition of vulnerability and its various dimensions. Although vulnerability to damage or injury is addressed in one way or another in natural hazards and risk research in particular, a variety of different models have emerged in the natural and social sciences due to the wide range of applications.

For the sake of completeness, it should also be mentioned that vulnerability research has been largely complemented by resilience research in recent years (Folke et al. 2010). The strong link between the two concepts of vulnerability and resilience is highlighted by Fekete and Hufschmidt (2016) in their "Atlas of Vulnerability and Resilience" and by Fuchs and Thaler (2018a) in their textbook "Vulnerability and Resilience to Natural Hazards".

Vulnerability must be understood as a multidimensional and multidisciplinary concept that cuts across many domains and is determined by, and in turn influenced by, social, physical, economic, environmental and institutional factors. New developments refer also to systemic vulnerability, which needs to be explored further in the future. A wide range of indicators can be used to measure vulnerability at different spatial and temporal scales, which is essential for taking appropriate action to minimise risk. Only by using the same or very similar vulnerability indicaors can the comparability of the vulnerabilities analysed be ensured. This constitutes an essential basis for the assessment and decision making processes. However, the spatial and temporal dynamics of the concept, which result from the dynamics of social systems, especially in times of global change, must not be ignored, but openly addressed instead.

Key Sentences

- As the term "vulnerability" is used in many disciplines, and described within the international UNDRR terminology, there is no standardised definition. In economics, engineering and natural science based risk research, however, susceptibility to loss or damage is a common understanding.
- Vulnerability is a key factor in natural, engineering and economic-based risk analysis, together with the hazard and the elements at risk.
- There are social science and natural science concepts on vulnerability. However, to ensure a holistic perspective, an interdisciplinary approach is strongly recommended.

- Five dimensions of vulnerability can be identified: social vulnerability, physical vulnerability, economic vulnerability, environmental vulnerability, and institutional vulnerability. These cannot be strictly delimited from one another and are open to the adoption of new approaches, such as that of systemic vulnerability.
- In order to assess the impact of both fast and slow onset events, it is essential to measure vulnerability using an adapted approach.
- Vulnerability is highly dynamic across time and space dimensions and requires constant re-evaluation.

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Socio-Economic Aspects of Disaster and Climate Change Risk Management

6

Reinhard Mechler

Abstract

Disasters and climate-related risks pose significant socio-economic challenges globally and locally. As climate change intensifies extreme weather events, vulnerable communities face increasing economic and social pressures. In this chapter the socio-economic dimensions of disaster and climate change risk management, causes, consequences, interventions (cures) and choices (decision-making tools) are explored. Using insights from academic and other literature, economic vulnerabilities, risk management measures, and decision-support mechanisms that can guide resilience-building efforts are highlighted. Furthermore, risk assessment frameworks, policy interventions, and the role of financial mechanisms in reducing disaster impacts and enhancing climate resilience are discussed in this chapter. We note that socio-economic analysis often proceeds based on principles of rationality, yet biases and heuristics are increasingly acknowledged, as they often importantly determine decisions.

Keywords

Socio-economic analysis • Disaster risk management • Climate adaptation • Causes • Decision-making

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6.1 Introduction

The impacts and costs from disasters are large and rising (UNDRR 2022). Furthermore, climate-related disasters are increasing in frequency and intensity, exacerbating socio-economic vulnerabilities worldwide. According to the Intergovernmental Panel on Climate Change (IPCC 2022), the economic cost of disasters has more than doubled in the past two decades, with developing nations bearing the brunt of the financial burden. The World Bank (Hallegatte and Walsh 2021) estimates that climate-related impacts could further push over 132 million people into poverty by 2030 if effective risk management strategies are not implemented.

This chapter examines the socio-economic implications of disaster and climate risk and discusses (see Fig. 6.1):

- Causes—Drivers of disaster risk and socio-economic vulnerability.
- Consequences—Economic and social impacts of disasters.
- Cures—Economic instruments, risk financing and policy interventions.
- Choices—Decision-support tools for resilience-building.

The discussion focusses on the economic dimensions, while also going into the social realm to cover the broader socio-economic dimensions of disasters.

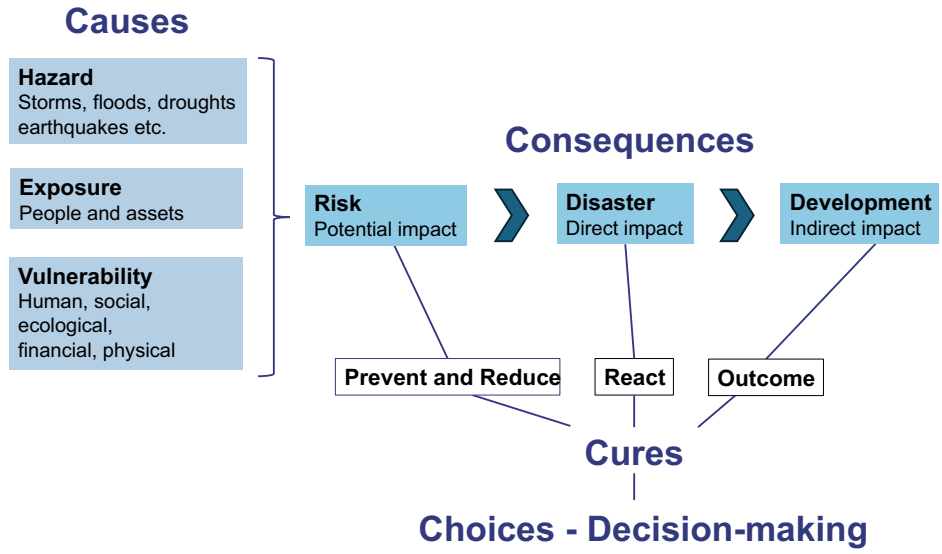


Fig. 6.1 Framework for understanding socio-economic aspects of disaster and climate change risk management. (Adapted from World Bank/UN 2010)

6.2 Causes: Drivers of Disaster and Climate Risk

Climate Change and Increasing Hazard Frequency

The IPCC Sixth Assessment Report (2022) confirms that anthropogenic climate change has significantly increased the frequency of extreme weather events, including hurricanes, wildfires, floods, and droughts. The Global Assessment Report on Disaster Risk Reduction (UNDRR 2022) states that global economic losses from climate-related disasters have exceeded $170 billion annually, with peak years surpassing $300 billion in losses. Rising global temperature has accelerated glacial melt, rising sea levels, and increased storm intensity, further exacerbating vulnerabilities in coastal and low-lying regions.

Socio-economic Vulnerabilities

Disaster risk is exacerbated by various socio-economic factors, including high exposure of assets due to urbanisation and economic development increasing property values in hazard-prone areas (UNDRR 2022); inequality and poverty issues as low-income populations lack access to insurance, credit, and social protection, making post-disaster recovery difficult, institutional weaknesses, as poor governance, inadequate infrastructure and weak regulatory frameworks increase disaster susceptibility; education and awareness gaps, where in many developing nations, limited knowledge about disaster preparedness exacerbates risks (Birkmann et al. 2022).

The Role of Development

Economic development has paradoxical effects on disaster risk. As per the Disaster Kuznets Curve hypothesis (Kellenberg and Mobarak 2007), disaster-related impacts (such as fatalities) initially rise with economic growth, triggered by unplanned urban and development processes increasing exposure, but later on decline as countries invest in resilience measures that focus on vulnerability reduction (see Fig. 6.2). While not fully conclusive, there is some more recent evidence for the hypothesis from China and Japan (Huang 2014; Lin et al. 2024).

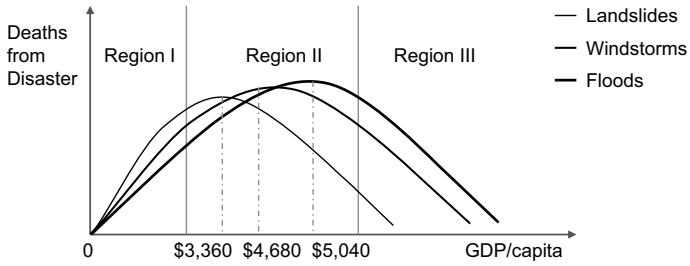


Fig. 6.2 The disaster Kuznets curve (adapted from Kellenberg and Mobarak 2007)

6.3 Consequences: Economic and Social Impacts of Disasters

As discussed elsewhere in the book, disaster risk is commonly defined as the probability of potential impacts affecting people, assets and the environment. If risk becomes manifest in an event, disasters may cause a variety of impacts which are commonly classified into social, economic, environmental and political categories as well as according to whether they are triggered directly by the event or occur over time as indirect or macroeconomic effects (UNISDR 2008).

Direct and Indirect Economic impacts

The literature is not entirely clear on definitions of economic impacts. As done here, disaster damages can be referred to as the direct monetised impacts on people, assets and nature, with losses referring to the economic consequences due to the direct impact, measured often in terms of value added, savings, taxes etc. (See Fig. 6.3).

Direct stock damages have indirect impacts on the "flow" of goods and services. Indirect economic effects occur as a consequence of physical destruction affecting households and firms. Most importantly, indirect economic impacts comprise

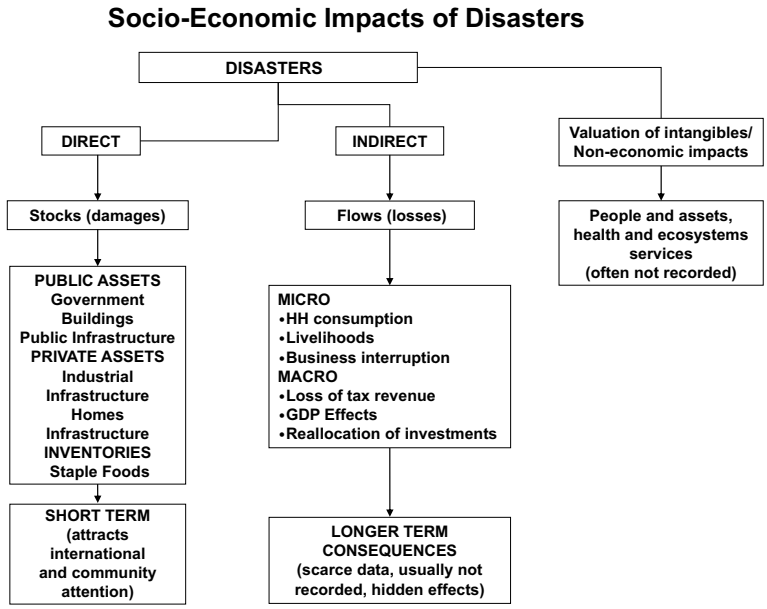


Fig. 6.3 (Socio)economic impact of disasters. (Author's visualisation)

- Diminished production/service due to interruption of economic activity.
- Increased prices due to interruption of economic activity leading to reduction of household income.
- Increased costs because of destroyed roads, e.g. due to detours for distributing goods or going to work.
- Loss or reduction of wages due to business interruption.
- Beyond financial damages and economic losses, disasters affect human well-being through:
- Health Crises: Increased disease outbreaks due to water contamination and malnutrition.
- Displacement and Migration: Climate refugees from high-risk areas.
- Loss of Cultural Heritage: Damage to historically significant sites and indigenous knowledge systems.
- Psychological and Social Strain: Increased rates of post-traumatic stress disorder (PTSD), depression, and social instability following major disasters.

Observational and Modelling Lines of Evidence

Generally, data on socio-economic impacts and risks can be generated based on observations from reported impacts in national or global databases drawing on official reports, media reports or studies. Furthermore, modelling exercises using statistical or process-based models are being used to calculate risk in terms of potential impacts (ECLAC 2014).

Reported Impacts

Reported disasters often focus on direct monetary damages and loss of life, as there are difficulties in accounting for indirect and non-monetary damages. Direct impacts are assessed and estimated post-event by local, national, or multinational institutions and insurance companies. Main standardised databases for this information are the EM-DAT database of the Centre for the Epidemiology of Disasters (CRED) in Brussels, Desinventar maintained by the United Nations Office for Disaster Risk Reduction (UNDRR) as well as the database by reinsurer Munich Re and Swiss Re. EMDAT is the only database that also routinely accounts for health effects, such as lives lost, and people affected. Swiss Re and Munich Re annually publish data on the worldwide direct economic and insured losses. EM-DAT compiles information on events, fatalities, people affected, and the losses on a worldwide basis dating back to 1900. This information is valuable and a good basis for analysis. However, it does not describe the full costs of disasters to an economy. Comparisons of those disaster loss databases have found significant variations in documented impacts with further steps undertaken to render those databases more comparable by using the same definitions and estimation methods (Guha-Sapir and Below 2002).

Modelling of Economic Consequences

With respect to *modelling* the economic effects of disasters and disaster risk management, there has been a substantial, yet heterogeneous body of modelling research, which can render the access to this body of research complex for non-modellers.

Two basic types of analyses are used to assess the economic effects of disasters: top-down, and bottom-up modelling approaches. The top-down approach is based on macroeconomic and mesoeconomic analysis focussing on the national or regional economy. Existing macroeconomic or top-down approaches utilise several types of models, including Input-Output (I-O) and Computable General Equilibrium (CGE) models, economic growth frameworks and simultaneous-equation econometric models (Botzen et al. 2019).

Most studies have assessed impacts by assessing scenario events, often based on actual observed events in the past, and gauging the different, often hidden follow-on costs of disasters, which is useful for response planning. Recently, risk-based approaches taking a probabilistic and forward—looking approach and better accounting for the fat-tailed characteristics of extremes have received increasing emphasis. These models can be used ex-ante to conduct economic planning for disaster risk (Hallegatte 2008; Hochrainer 2006; Mechler et al. 2010).

As to *macroeconomic effects,* disasters have been found to pose a problem for development:

- In developed countries, no longer-term adverse macroeconomic, but regional—and micro-level effects occur;
- Developing countries: significant adverse short—and medium-term impacts are to be expected: GDP, budget deficit, trade balance (see Fig. 6.4);
- Factors that prevent spillovers into the macroeconomy:
  - literacy rate, institutions, higher per capita income, higher degree of openness to trade, and high levels of government spending.
  - ability to mobilise resources for reconstruction.
  - foreign exchange reserves, and levels of domestic credit.
  - inflow of external aid and capital.

The bottom-up approach, grounded in microeconomics, aims at evaluating actual impacts or risks on consumers' willingness to pay (alternatively, willingness to accept) (Van der Veen 2004). Such approaches measure direct property damage as well as business interruption costs, health impacts and reductions in well-being, and sometimes impacts on ecosystem services. Approaches used include replacement value, benefits transfer, contingent evaluation, travel cost and hedonic pricing methods (Handmer et al. 2002; Ready and Navrud 2006). Lately, interest has emerged as to the effects of systemic disaster risk on income and livelihood generation or whether extreme events can trap people in poverty (Carter and Barrett, 2006). Rather than running numerical models, the focus of work on the microeconomics of disaster risk has been on empirical and statistical analysis and

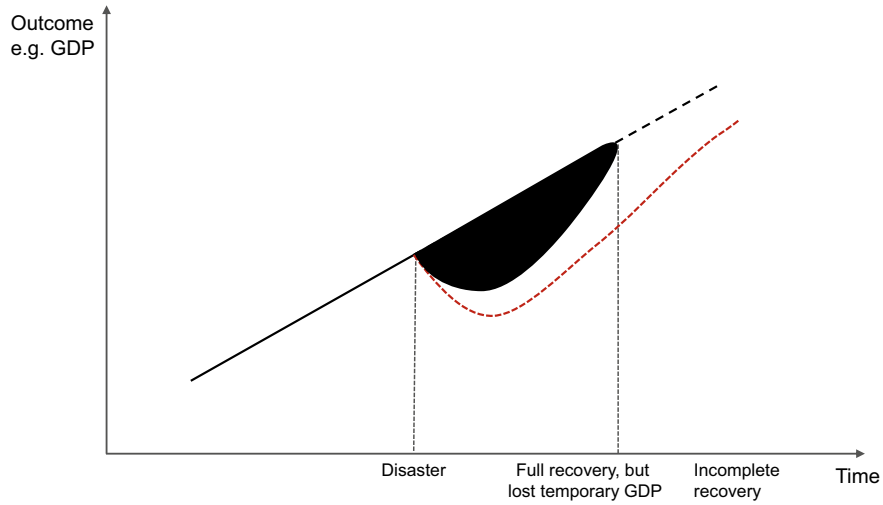


Fig. 6.4 Stylised indirect macroeconomic disaster impact. (Adapted from World Bank and United Nations (2010), based on Hochrainer (2006))

understanding households' and firms' decisions to (often not) invest in risk reduction. One focus area over the last few decades has been on insurance-related applications (French and Kousky 2023; Kunreuther 1996; Linnerooth-Bayer et al. 2011).

6.4 Cures: DRR Interventions and Economic Options

We now turn to a discussion of key risk management interventions for addressing both the causes and consequences of disasters and identify which of these follow a (socio)economic logic. For this assessment, we adopt the framework of the risk management cycle, which breaks actions down into *ex-ante* measures, risk management interventions, and *ex-post* relief, response, and recovery. Policy options aimed at reducing the various impacts of disasters and managing risk may include assessing risk, reducing risk through prevention and preparedness, preparing for impacts, transferring and spreading risk across a broader base (risk financing), and, finally, responding to events and undertaking reconstruction and rehabilitation (see Table 6.1).

While *ex-post* efforts are ever-important and today still dominate policy, there is a need for upgrading deliberate *ex-ante* efforts. We focus on the *ex-ante* options risk assessment, risk prevention, preparedness and risk financing to be taken by government and international institutions. Prevention and preparedness options *reduce* damages and losses, while insurance and other risk financing instruments lessen the *variability* of losses by spreading and pooling risks, but do not directly reduce them.

Table 6.1 Disaster management options and economic options (marked in red). (Authors own construction)

Type	Ex-ante risk management				Ex post disaster management	
	Risk assessment	Prevention	Preparedness	Risk sharing and financing	Response	Reconstruction and rehabilitating
Effect	Assessing risk	Reduces risk addressing underlying factors	Reduces risk in the onset of an event	Transfers risk (reduces variability and longterm consequences)	Responding to an event	Rebuilding and rehabilitating post event
Key options	Hazard assessment and monitoring (frequency, magnitude and location, including climate change)	Physical and structural risk reduction works (e.g. irrigation, embankments)	Early warning systems, communication systems	Risk transfer (by means of (re-) insurance) for public infra-structure and private assets, microinsurance	Humanitarian assistance	Rehabilitation/ reconstruction of damaged critical infrastructure
	Vulnerability assessment (population and assets exposed)	Land-use planning and building codes	Emergency response	Alternative risk transfer	Clean-up, temporary repairs and restoration of services	Revitalization for affected sectors (tourism, agriculture, exports etc.)
	Risk assessment as a function of hazard, exposure and vulnerability	Economic incentives for proactive risk management	Networks of emergency Responders (local/national)	National and local reserve funds	Damage and loss assessments	Macroeconomic and budget management (stabilisation, protection of social expenditures)
	Mainstreaming risk into development planning	Education, training and awareness raising about risks and prevention	Shelter facilities and evacuation plans	Calamity funds (national or local level)	Mobilisation of recovery resources (public/ multilateral/ insurance)	Incorporation of disaster mitigation components in reconstruction activities

Focus: Risk Financing and Insurance Mechanisms

To mitigate financial shocks, various such risk sharing and financing (economic) instruments are used:

- Risk Transfer Mechanisms: Catastrophe bonds, reinsurance, and microinsurance schemes.
- Sovereign Disaster Funds: National reserve funds for immediate response.
- Public–Private Partnerships: Shared financial risk among stakeholders.
- Climate Adaptation Financing: Funds allocated by global financial institutions such as the World Bank and the Green Climate Fund (GCF) to support disaster-prone nations.

By providing indemnification in exchange for a premium payment, insured victims benefit from the contributions of the many others that are not affected, and thus in the case of a disaster they receive a contribution greater than their premium payment. However, over the long run, insured persons or governments can expect to pay significantly more than their losses in terms of financial costs. When the true opportunity costs (such as those associated with business or personal bankruptcy post-disaster) are counted in, then in a lot of instances transferring risk pays off. This is due to the costs of insurance transactions and the capital reserved by insurance companies for potential losses (or reinsurance), as well as the financial return required for absorbing the risks. Response and reconstruction/rehabilitation do not focus on risk (and probability) but reacting to impacts. Despite substantial focus on such interventions, the financial adaptation gap remains significant even in the global North, with global investment in resilience measures falling short of required levels (UNEP 2022).

6.5 Choices: Decision-Support Tools for Disaster Risk Management

A number of decision-support tools can inform different stages of the decision cycle. Economics-focussed decision-makers often rely on cost-benefit analysis (CBA), multi-criteria analysis (MCA), and robust decision-making (RDM) to evaluate risk reduction measures. Yet, information based on single objective Cost-Benefit Analysis has been often used to defend, not to make decisions. Behavioural biases and short-term political cycles often limit proactive investments. Particularly in climate research, as a response to the substantial uncertainties and complexities found in socioecological systems interacting with climate-related stressors, analysts have been emphasising iterative and adaptive decision-making and learning processes for fostering transitions from ex-post to ex-ante action (Chambwera et al. 2014).

Consequently, decision-making on adaptation and climate risk management has broadened from using expert-based tools, such as cost–benefit analyses, that identify ‘best

economic adaptations' to decision tools that conduct multimetric evaluations with stronger consideration for non-monetary and non-market measures, risks, equity issues, barriers, and limits as well as co-benefits of actions (Chambwera et al. 2014).

Mechler and Hochrainer-Stigler (2019a) list relevant decision tools (see Table 6.2). They distinguish between

- more strongly expert-focussed tools for option selection (cost–benefit analyses CBA, cost–effectiveness analyses CEA, and robust decision-making approaches RDMA) and,
- more participatory methods for informing iterative risk management decisions in terms of assessment and selection, as well as monitoring and evaluation, including multi-criteria analysis (MCA), adaptation pathways, and resilience capacity assessments.

CBAs have shown that every $1 invested in disaster preparedness saves $5 in post-disaster recovery (Mechler 2016). However, political and financial constraints often delay implementation of preventive measures. Overall, this means that more comprehensive approaches are required that can make a case for DRM and help practice and policy more robustly prioritise their investment.

Behavioural Barriers: The Prevention Paradox and Normalcy Bias

The Prevention Paradox describes how preventive measures are undervalued because their benefits are less visible. Behavioural biases, such as status quo bias and myopia, lead to underinvestment in long-term resilience strategies (Kellett and Caravani 2013). Despite wide-spread recognition of the large burdens imposed by climate and disaster impacts as well as solid evidence demonstrated regarding the benefits of reducing climate and disaster risk (see Mechler 2016), it has remained difficult to motivate sustained investment into resilience-generating disaster risk reduction (DRR) and climate adaptation (CCA) policies at project level as well as aggregate scale. This underestimation of occurrence probability (*Normalcy Bias* as called in behavioural science, see Mileti 1999) as well as the benefits of risk reduction (*Prevention Paradox*, see Kunreuther and Heal 2003) denotes the underestimation of ex-ante disaster occurrence probability and ex-post underestimation of the benefits actually created by reducing and managing risk. It is importantly driven by aleatoric uncertainty associated with disaster events (natural variability). Combined with *myopia*, i.e. positive time preference for current expenditure, this means that, rather than focussing on future investments with uncertain (probabilistic) outcomes, there is systematic underinvestment into resilience-generating risk reduction and adaptation policies at project level as well as aggregate scale (IPCC 2012).

Governments and financial institutions are working to overcome these biases by promoting evidence-based policy frameworks and incentivising proactive disaster risk management.

Table 6.2 Applicability of decision-support tools for resilience option assessment (Mechler and Hochrainer-Stigler 2019a)

Tool	Opportunities	Challenges	Typical application
Expert-focussed tools for option selection			
Cost–benefit analysis (CBA)	Rigorous framework based on comparing costs with benefits	Need to monetise all benefits, difficulty in representing intangible impacts, such as value of life	Well-specified *hard-resilience* projects with economic benefits (e.g. flood risk prevention)
Cost–effectiveness analysis (CEA)	Ambition level fixed, and only costs to be compared. Intangible benefits, particularly loss of life, do not need to be monetised	Ambition level needs to be fixed and agreed upon	Well-specified interventions with important intangible impacts, which should not be exceeded (loss of life, etc.)
Robust decision-making approaches (RDMA)	Addresses uncertainty and robustness	Technical and computing skills required	Projects with large uncertainties and long timeframes (context of climate change where flood return periods may become more uncertain)
Multi-criteria analysis (MCA)	Consideration of multiple objectives and plural values	Subjective judgments required, which hinder replication	Multiple and systemic interventions involving plural values (e.g. investing in infrastructure and education)
Adaptation pathways	Scenario-based decision-making at decision points depending on future system changes	Considerable investment into scenarios and stakeholder interaction	Portfolios
Resilience and Capacity Assessments	Measure capacity and change over time, aligns with community-based decision process	Cannot be linked to individual intervention assessment, but program-level activities	Community-level resilience assessment

Biases, or heuristics, which are particularly relevant in disaster decision-making include:

- **Myopia** denotes strong focus on the present rather than making decision for the long terms,
- **Simplification**, or the tendency to simplify complex problems and make decisions based on limited and personally relevant information.
- A tendency to **overemphasise information** that is more easily remembered or made salient by a specific environment.
- **Anchoring**, or using an irrelevant number as the basis for decisions under conditions of great uncertainty.
- **Optimism and overconfidence**, or a general tendency for people to see situations as less threatening than they are and to see themselves as more capable than they are.
- **The status quo bias and loss aversion**, or the tendency to accept existing situations (even if negative) and to be concerned more about the risk of loss than the potential gain.

While it can be argued that some of the biases are irrational, myopia is entirely rational, as generally people emphasise making decisions for the present. In decision-making this is represented by the discount rate, where future income or costs (financial flows) are depreciated by a discount factor to derive value for today (net present value). The discount factor is similar to what financial firms charge as interest. Figure 6.5 shows the consequences of discounting on the present value. Generally, discount rates used in public policy amount to between 3 and 12%.

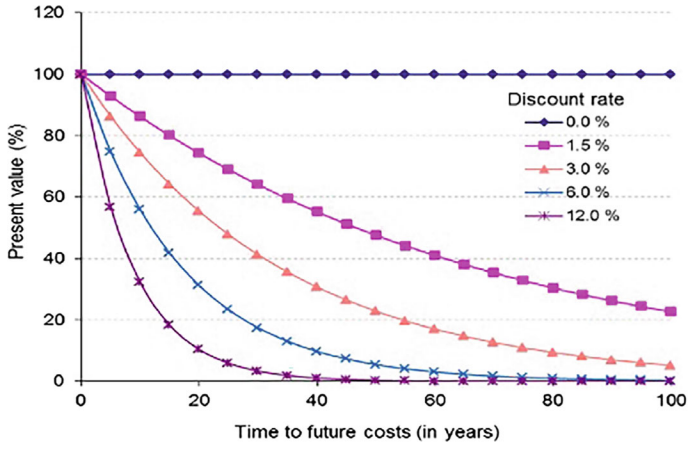


Fig. 6.5 Discounting future costs and the present value (Author's own construction)

6.6 Conclusions and Perspectives

Conclusions

(Socio)economic analysis forms an important part of efforts towards understanding the causes and consequences of disasters, as well as helping to inform choices and interventions (cures) for enhancing DRR and CCA. These dimensions are often interlinked. Causes and consequences determine choices and interventions, which again define causes and consequences. For example, the level of exposure of people and assets and associated potential impacts defines choices and interventions, i.e. what level of risk to reduce, insure and retain. Such a profile of risk and risk management then dynamically impacts exposure decisions of people and assets-where to build, work and live. Choices and interventions are strongly defined by causes such as socio-economic status and available options. A systemic understanding helps to navigate this complex interplay of drivers and effects. To note, socio-economic analysis has often proceeded premised on principles of rationality and optimality (minimising costs, maximising benefits); yet biases (such as the *Normalcy Bias* or the *Prevention Paradox*) importantly determining decisions have been increasingly acknowledged as well as the role of heuristics in decision-making, thus overall more broadly informing choices and interventions.

Perspectives

In terms of forward-looking perspectives, we suggest socio-economic analysis should better consider the following issues.

Holistic Understanding of Causes

The chapter highlights that disaster risk is not solely driven by natural hazards but also deeply rooted in socio-economic vulnerabilities such as inequality, poor urban planning, and institutional weaknesses. It emphasises the importance of integrating climate change trends with development patterns, such as those illustrated by the Disaster Kuznets Curve. A holistic understanding requires examining how these interacting factors shape exposure and vulnerability over time, rather than attributing impacts to isolated shocks.

Differentiating Between Direct and Indirect Consequences (Stocks and Flows)

The document underscores the need to distinguish between immediate physical damage (to assets or "stocks") and the ripple effects on economic activity ("flows"). Direct damages include impacts to buildings or infrastructure, while indirect impacts manifest in reduced income, disrupted services, and increased poverty. This differentiation is critical for accurately assessing long-term socio-economic impacts and for designing appropriate recovery and risk management interventions.

Broader Understanding of Cures

Cures should go beyond post-disaster relief and incorporate ex-ante measures such as risk prevention, preparedness and financial instruments, like insurance and catastrophe bonds. The chapter advocates for a systematic risk management approach, aligning with the risk management cycle that includes prevention, risk sharing, and recovery. Broader cures also involve mainstreaming disaster risk into development planning, improving institutional capacity and enabling transformative adaptation strategies.

Wider Understanding of Choices and Decision-Making

While tools like cost–benefit analysis and robust decision-making are valuable, the chapter stresses that behavioural factors—such as myopia, normalcy bias, and overconfidence—often undermine rational planning. It argues for expanding the decision-support toolkit to include participatory methods and multi-criteria analysis, which capture equity, non-monetary values, and long-term resilience. Recognising these biases is essential for developing realistic and inclusive policies that move from reactive to proactive risk governance.

Key Sentences

- When discussing socio-economic implications of disaster and climate risk, attention must be paid to the causes, consequences, cures and choices.
- Disaster impacts include direct and indirect disaster losses and tangible and non-tangible impacts.
- The socio-economic impacts of disasters and disaster risk management can be analysed using either a top-down approach—focussing on macro—and meso-economic levels—or a bottom-up approach centred on microeconomic dynamics.
- Disaster management actions include *ex*-ante interventions (taken in anticipation of events to deal with risk-potential impacts) and *ex-post measures* (taken during and after events to manage actual impacts).

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Psychosocial Support Mechanisms within Disasters

7

Barbara Juen, Alexander Kreh, and Dietmar Kratzer

Abstract

Based on current literature and guidance we outline psychosocial interventions within disasters. We structure these interventions according to the disaster cycle and discuss their effectiveness based on the current state of the art. There is a need for complex multilevel approaches that are adapted to the needs, circumstances and culture of the target groups/persons. These approaches should be based on the elements: safety, connectedness, calm, self and collective efficacy and hope. Building community resilience becomes more and more prominent in disaster management. Furthermore, a holistic approach where human health is seen as dependent of animal health and environmental health is recommended.

Keywords

Psychosocial interventions • Disaster • Debriefing • Psychological first aid • Community resilience • One health

7.1 Disasters

During the last decades, the number of disasters has continually increased mostly due to climate change (ADREM et al. 2024; IFRC 2002). A disaster has been defined as a situation or event that overwhelms local capacity, necessitating a request to a national or international level for external assistance. The most recent definition of the United

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Nations Office for Disaster Risk Reduction (UNDRR) is focussing more on the effects that disasters have on communities: they define a disaster as a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts (UNDRR 2017).

In 2023, there were 326 reported natural disasters worldwide affecting 117 countries and regions, killing 86,473 people, affecting 93.05 million people and causing economic loss of USD 202.65 billion. Compared to the average from 1993 to 2022, the frequency in 2023 was 3% lower, but the death toll was 73% higher. The affected population was 53% smaller, but the economic loss was 32% greater (ADREM et al. 2024).

Affected people may show a wide range of reactions that are seen as normal reactions to abnormal events. Some of the affected persons may develop psychological complaints as a result of the disaster: Posttraumatic Stress Syndrome is only one of many. Depression, anxiety disorders, as well as many other health complaints may follow (see for example Leiva-Bianchi et al. 2018; Norris et al. 2002, 2006).

7.2 Mental Health Complaints after Disasters

Numbers of how many people develop mental health complaints after disasters vary significantly, and the types of complaints are highly diverse (see for example: Morganstein and Ursano 2020; Norris 2005). Norris (2005) gave an overview of studies on people affected by floods and hurricanes. In 57 selected studies, she found

> … that 3 (5%) showed minimal impairment, meaning that the majority of the sample experienced only transient stress reactions, 34 (60%) showed moderate impairment, wherein prolonged but subclinical distress was the predominant result; 12 (21%) showed severe impairment, meaning that 25% to 49% of the sample suffered from clinically significant distress or criterion-level psychopathology; and 8 (14%) showed very severe impairment, meaning that 50% or more of the sample suffered from clinically significant distress or criterion level psychopathology (Norris 2005, p.1)

The mental and physical health consequences of disasters on direct survivors of the event have been documented in various studies over the years (Thormar et al. 2010). According to Thormar's review, post-traumatic stress disorder (PTSD) is the most frequently reported mental health disorder with levels ranging from 10.3% to 34.3% between 6 and 18 months post-disaster. The main predictors for civilian complaints after a disaster have been listed as: loss of a loved one, pre-disaster mental health issues, feelings of guilt, life events post-disaster, female gender, old age, physical injury, lack of social support, exposure to gruesome things, low level of government support or dissatisfaction with post

disaster aid and/or insurance, damage to property. But not only do the affected population show negative psychological consequences, but also professional workers responding to disasters. Two of the most commonly reported complaints are PTSD and subjective health complaints. The prevalence of PTSD in professionals after disasters has varied from 7% to 18% (Thormar et al. 2010). More recent studies on Covid-19 showed similar patterns of not-so-high PTSD rates but rather alarmingly high rates in anxiety and depression especially in young people, people with socio-economic problems, females and those who have been especially exposed to the virus (e.g. Hossain et al. 2020, Kumar and Nayar 2021). During the Covid-19 pandemic, a lot of data has been collected that showed the widespread impact of the pandemic on mental health. Symptom levels vary between countries, time and study design. For example, Xiong et al. (2020) found relatively high rates of symptom levels in various mental health outcomes reviewing studies that have been published internationally in the beginning of the pandemic until May 2020. PTSD rates were found in 7–53.8%, anxiety in 6.3–50.9%, depression in 14.6–48.3% and psychological distress in 34.4–38%. Among risk factors the authors identified female gender, younger age, pre-existing chronic/psychiatric illnesses, unemployment, student status, and high exposure to social media/news concerning Covid-19.

Also here, professional helpers showed negative consequences. For example, a systematic review and meta-analysis by Li et al. (2021) identified high prevalences of moderate depression (21.7%), anxiety (22.1%), and PTSD (21.5%) between December 2019 and August 2020.

More recently, a new focus has emerged in disaster psychology, based on the assumption that positive change and resilience after disasters have generally been underestimated (e.g. Bonanno et al. 2006; Fu and Zhang 2024; Kourtit et al. 2023; Mayer 2019).

7.3 Models of Mental Health Complaints after Disasters

After natural disasters, affected people show a wide range of reactions and needs that may differ from phase to phase. Models on how disaster survivors react and what they need have changed a lot over time. The first models of disaster impact on mental health primarily focussed on short-term response and direct impacts. In later models, the loss of resources has been more prominent (Hobfoll et al. 2003), and the indirect and long-term social effects came into view (Morgado 2020). Social factors, personal factors, and environmental factors may influence people's reactions to disasters. Direct factors are for example intensity of exposure, duration, risk and trauma whereas indirect influences are resource loss, infrastructure damage, life disruption and forced displacement (Heanoy and Brown 2024). In more recent years, the focus shifted from the individual to the community.

The FEMA model proposes 6 phases of community reactions (FEMA 2016, 2021, 2024). The pre-disaster phase is when warnings and threats are expressed (1). During the

disaster impact phase various connected stressors (e.g. displacement and injury) occur, and emphasis is placed on regaining control (2). The heroic response phase is about the often-observed altruism and saving of others. This phase also includes temporary relocation, restoring safety, and support from government and NGOs as well as insurance agencies (3). Following that, Heanoy and Brown (2024) describe a honeymoon phase where external assistance remains and community bonding increases through shared experience. Survivors' level of positive emotions (solidarity, thankfulness and hopefulness) are often high although fear, despair and grief may persist at the same time. The honeymoon phase may last several months after the disaster, but timing and length may vary (4). Then follows a disillusionment phase that is characterised by disappointment. Disaster survivors are disillusioned because agencies and volunteers pull out and the community's hopes for restoration may remain partially or totally unfulfilled. During this phase, community cohesion may be also weakened when individuals focus more on their unmet needs and injustice. Whereas in the beginning similarities are promoting community cohesion now differences between subgroups may become more visible. Heanoy and Brown (2024) describe the least impacted neighbourhoods returning to life as usual. This can discourage people living in more severely impacted neighbourhoods. Survivors may become exhausted due to growing multiple demands, including financial pressures, relocation or living in a damaged home, family discord, bureaucratic hassles, and a lack of free time for recreation or self-care. Mental health problems and the exacerbation of pre-existing conditions emerge as a result of ongoing stress and fatigue (5). Lastly, the reconstruction phase, including short-, intermediate-, and long-term recovery, may begin a few days after the disaster but can last up to several years depending upon the level of damage. Survivors attempt to restore their lives by rebuilding homes, returning to old jobs, finding new employment, and resuming or forming new social support systems. Some can accept new circumstances, including losses and changes, whereas others may instead focus on resentment and anger, identifying themselves as victims (6) (Heanoy and Brown 2024).

It is recommended to look at the transitional impact of disasters together with the impact on mental health in two phases: during and after the disaster. During the disaster, exposure and resource loss are major influencing factors, whereas after the disaster, post disaster life stressors gain importance.

Climate change-related disasters have led to an accumulation of risks and impacts. According to Gousse-Lessard et al. (2023) the new reality brought about by climate change forces researchers and practitioners to question previous models of risk and stress reactions of survivors. The phase model of communities' and individuals' reactions to disasters (e.g. Math et al. 2015; Young et al. 1998) is now questioned because disillusionment and restoration phases may be interrupted by the occurrence of another disaster or shock in the context of climate change. In this situation of cascading events, biopsychological responses to disaster would be impaired by the second shock or disaster. Frequent repetition of disasters such as floods as well as long duration disasters could affect initial

optimism (hero and honeymoon phases; see Raphael 1986) and lead to discouragement and exhaustion, which may impair recovery (Gousse-Lessard et al. 2023).

7.4 Community Resilience and Disaster Preparedness

In trauma and disaster research, a progressive shift has taken place from a focus on defining disaster impact primarily as deficit or loss to one that emphasises the capacity of individuals and communities to adapt, and possibly grow in the face of adverse circumstances (Antonovsky 1993; Kourtit et al. 2023; Paton 2009, 2000).

Resilience has become a more and more important element of research since (Mayer 2019; Morgado 2020). Resilience is generally defined as the capacity of an individual or group to come back to normality after adverse events (e.g. Bonanno et al. 2006). The following factors promoting resilience (Bonanno et al. 2006) have been scientifically verified: Being able to make connections, sense of control, realistic plans and goals, positive view, projection into future, communication skills, problem solving skills, taking care of self and community (Hobfoll et al. 2007). Resilience of an individual person always consists of two components: personal factors and situational factors. Personal factors are for example personal beliefs, assumptions, biases, previous relevant experiences and others. Situational factors are for example information and knowledge about the specific crisis, involvement into the given situation, and type of event. These factors are always of relevance for humans in a crisis situation—be they part of official crisis management or single individuals. The salutogenetic concept (focussing on determinants of health instead of disease) of a sense of coherence (Antonovsky 1993) is a key concept for mental and physical health. People with a high sense of coherence remain capable of acting even in situations of extreme stress and they show less symptoms after living through potentially traumatising events. The sense of coherence consists of three components: comprehensibility, manageability and meaningfulness. Influencing these factors is crucial for enhancing resilience. Also, recent approaches are based on this classical concept.

A main aspect in conceptualisations of community resilience is based on the ability of communities to use internal personal and social resources and competencies to manage the demands and challenges that arise during and after disasters (Paton 2000). According to this definition, community resilience consists of two aspects. The first aspect is the existence of resources required to facilitate coping with the disruption and loss associated with the disaster. Preparation in this sense is the process by which resource availability is encouraged (Paton 2003). The second aspect is about the competencies required by people and communities to coordinate and utilise these resources to confront challenging circumstances and to adapt or adjust to the consequences of disasters (Paton et al. 2001).

Paton et al. (2001) differentiated between skills needed in the impact, response and recovery phases of the disaster experience. During the immediate impact phase people

may be isolated from external assistance and may have limited or no access to normal community and societal resources and functions. Under these circumstances, resilience will depend on prevailing levels of individual/household preparedness and their capacity for self-reliance (Paton 2003). Later on in the impact phase, people will have more opportunities to work with neighbours and other community members on local demands. At this later stage, resilience reflects the capacity of community members to work with others and to plan and execute tasks.

In the response phase formal interventions will be more present. Now resilience is dependent, so Paton (2000), on the quality of interaction between people, communities and institutions. Similar processes will be required to facilitate effective resolution of issues during recovery and rebuilding. Ways of involving citizens in all phases of the disaster must be developed in advance.

Research shows that preparedness often remains low, even in areas where risk is high (Ballantyne et al. 2000; Paton 2000). A main reason for this has been the misconception that providing the public with information will automatically translate into preparedness. This assumption is wrong (Paton 2003). The reasons for this are numerous and may include, for example, that the dissemination of general information is a passive form of communication that does not address needs and expectations within a community (Ballantyne et al. 2000; Fu and Zhang 2024; Morgado 2020).

Strengthening community resilience in the face of disaster is a process that must be managed through the active involvement of community members. Enhancing resilience is not only about giving information but about a two-way process of communication by interacting with the community, getting to know their needs and help them to actively engage in preparedness decisions (Fu and Zhang 2024; Paton et al. 2005).

Devaney's "Understanding Resilience" report provided a discussion of the varied definitions of resilience as well as recommendations for building resilience at multiple levels in disaster programming (Devaney 2016). Recommendations encouraged a focus on building psychological capability (e.g. hope, optimism, self-efficacy), increasing human capital through practical programmes increasing knowledge, including psychological and emotional preparedness, increasing physical resources such as first aid kits and emergency grab bags, and promoting interconnectedness through bonds, social capital, and a sense of community. The International Federation of Red Cross and Red Crescent Societies' (IFRC) Community-Based Disaster Risk Reduction Study of the characteristics of community resilience affirmed many of these recommendations (IFRC 2012). Characteristics of resilient communities identified included knowledge of risks and ability to build on past experiences, organisation, connectedness, in-place infrastructure and services, economic opportunities, and natural assets. Many disaster risk reduction programmes or materials are particularly focussed on building community level resilience (Chandra et al. 2011; Fu and Zhang 2024; Mayer 2019).

7.5 Effective Psychosocial Interventions after Large-Scale Events and Disasters

After disasters, Mental Health and Psychosocial Support (MHPSS) is highly recommended (e.g. Bisson et al. 2007; IASC 2007; Juen et al./OPSIC 2016; NATO 2008; NICE 2025; TENTS 2008; Williams et al. n.d.). Dückers (2022) identified four guidelines as most useful and valid: the IASC guidelines from 2007, the OPSIC guidelines from 2016 (Juen et al.), the ICRC guideline (2018) and the EUTOPA guideline from 2007 and 2013 (EUTOPA 2007; Te Brake et al. 2013). A further comprehensive overview of recent guidelines and policy papers can be found at the MHPSS International Movement Hub of the IFRC (2025).

The term "psychosocial support" refers to actions that address both the psychological and social needs of individuals, families and communities (see APA 2018; MHPSS International Movement Hub 2025). Psychosocial support aims to enhance the resilience of affected individuals, groups and communities.

This is done by promoting resources of individuals, families or groups as well as the community as a whole. Mental health and psychosocial support programmes (MHPSS) can prevent distress and suffering from developing into something more severe and shall help overcome adversities, coming back to normality and recover after crisis. Silove and Zwi (2005) very early stated that

> there is a growing consensus that psychosocial programmes should operate at multiple levels […] and should: (1) provide early, accurate, and well-targeted information about trauma and grief responses and their natural histories; (2) promote and resource the work of indigenous recovery systems (religious, spiritual and cultural), as well as local nongovernmental organisations and public-sector services; (3) attend to context-relevant training, mentoring support, and supervision of front-line personnel across the sectors of health, education, police, and social services; (4) assist in developing community mental-health services to extend skills and ensure geographical coverage; and (5) advice on the coordination and planning of services, and in so doing, maintain a medium-term to long-term horizon aimed at sustaining developments. (Silove and Zwi 2005, p. 269–270)

Psychological first aid (PFA) is a term that refers to a separate and unique form of psychosocial support that is complementary to disaster mental health and aims at the immediate support during the disaster (Jacobs and Meyers 2005). Psychological first aid contains the following 8 principles of action: (1) Contact and engagement, (2) safety and comfort, (3) stabilisation, (4) information gathering: needs and current concerns, (5) practical assistance, (6) connection with social support, (7) information on coping, (8) linkage with collaborative services (Brymer et al. 2025). In more recent times these 8 factors have been reduced by the WHO into the three main factors: Look (for reactions); Listen (and assess needs); and Link (to further supports) (WHO 2011). There is a big amount of literature and guidelines on the principles and effectiveness of PFA and psychosocial

support (Bisson and Lewis 2009; Brewin et al. 2008; Mtiraoui et al. 2025; Schreiber et al. 2005; Silove and Zwi 2005; van Ommeren et al. 2005; Wang et al. 2024).

Hobfoll et al. (2007) reviewed the literature on psychosocial support and psychological first aid and came to a strong consensus that psychological support should be provided for those involved in disasters and that responses should promote the following five aspects. Additionally, considering more recent studies these five elements remain the most effective after disasters (e.g. Park et al. 2021):

- a sense of safety;
- self and community efficacy;
- connectedness;
- calm;
- hope.

The provision of a sense of safety is effective in reducing stress and works against dysfunctional cognitions (Hobfoll et al. 2007). This includes the provision of a safe place as well as giving honest and precise information. Connectedness aims at family reunions as well as the promotion of social support structures. Calm means the re-establishment of the protective shield and the re-establishment of normalcy and everyday routines. Self and collective efficacy is established by giving chances for action and decision. Instilling hope means to give some information about the immediate next steps as well as giving chances for positive emotions (Hobfoll et al. 2007, 2003). According to Hobfoll et al. (2003) psychosocial interventions in this field should be services to people that help them get their lives back in place in terms of housing, employment etc. Employment status is the best predictor of hope, as well as interventions that help to regain trust in one's own capacity to move forward.

7.6 Framework of Psychosocial Support in Disasters

Numerous guidelines on mental health and psychosocial support in disasters recommend needs-oriented, community-based approaches based on the five Hobfoll principles (Hobfoll et al. 2007).

The pyramid of mental health and psychosocial support (IASC 2007, p. 12) describes supports in four levels (basic safety and protection, community and family support, focussed supports and specialised supports). Multi-layered response and stepped approaches encompass basic, non-formalised Psychological First Aid and psychosocial support for all affected groups, community supports that shall enhance community resilience, more structured and specific interventions for specific vulnerable groups and finally specialised professional interventions for the few that need them even at the beginning. These recommendations are still valid and have been integrated into many national

and regional MHPSS guidelines since (Bisson et al. 2007; Hobfoll et al. 2007; IASC 2007; Mollica et al. 2004).

Psychosocial interventions after disasters may complement the formalised mental health system but never substitute it. Needs assessment is the basis of all interventions (Bisson et al. 2003, 2007; IASC 2007; Mollica et al. 2004; NICE 2025). At first, one has to assess what people need before making further decisions such as what interventions to use. Interventions must meet different needs. Furthermore an (intersectional) vulnerability and capacity assessment may give information on where to prioritise support especially during the first phases when resources are few. According to the stage of the disaster, interventions may have to answer different needs.

Constant coordination of mental health services and activities are necessary in order to avoid overlap of programmes (IASC 2007; Mollica et al. 2004; TENTS 2008). Population-based mental health assessment (IASC 2007; Mollica et al. 2004; TENTS 2008), a triage for serious mental health problems and the identification of high-risk individuals via screening (Mollica et al. 2004; NICE 2025) should be made. De facto the mental health system should be built up and used by integrating local healers, local primary health-care practitioners and disaster relief personnel (IASC 2007; Mollica et al. 2004). A link to community services facilitates the access to formalised services (Bisson et al. 2003, 2007; NICE 2025) and making mental health services available within primary health care (WHO 2001). Outcome assessment and research should be done by using simple and standardised methods (IASC 2007; Mollica et al. 2004).

All this requires multi-level, multi-organisational networking before disasters that may be then used in the disaster situation in order to provide adequate services. In most European countries, multi-level MHPSS systems are active in the aftermath of disasters although capacity building is still ongoing. In 2017, Dückers (2017) has presented a review on multi-layered MHPSS programmes where he integrated the community resilience approach. In 2022, an overview over the most prominent MHPSS guidelines and models and their validity was provided (Dückers et al. 2022; Te Brake et al. 2022). Dückers et al. (2022) stated that

> … the MHPSS knowledge base embedded in the guidelines is comprehensive, coherent, and sufficiently universal to serve as the 'overarching framework' considered missing yet vital for the integration of MHPSS approaches in DRR. Although application contexts differ geographically, this common ground should allow policymakers and practitioners globally to plan, implement, and evaluate MHPSS actions contributing to DRR, ideally together with target groups. (Dückers et al. 2022 p.1)

7.7 Conclusion and Future Perspectives

Disasters pose complex challenges for mental health and psychosocial well-being, affecting individuals, professionals, and entire communities. Direct and indirect social, personal and environmental factors influence people's reactions on an individual level. Regarding community reactions, different phases should be considered from the pre—to post-disaster phase. As accumulated risks and impacts in climate change-related disasters are critical, established models of these phases are questioned. Evidence shows that sustainable recovery requires multi-level, community-based support systems that are needs-oriented and strengthen safety, connectedness, calm, efficacy and hope. Building resilience—both individually and collectively—is central for reducing vulnerability and promoting adaptive coping. Psychosocial interventions must be integrated across all phases of disaster management. Constant coordination including multi-level multi-organisational networking before disasters is key.

Current challenges are addressed in many EU and national projects. The main topics are the building of community resilience in the population as well as in healthcare workers in the face of more and more complex and interlinked disasters (e.g. PsyResK 2025), the inclusion of marginalised and vulnerable groups—e.g. EUNAD-IP (Federal Office of Civil Protection and Disaster Assistance Germany 2017; Vymetal 2017), the inclusion of spontaneous volunteers in the response phase—e.g. PFA-CE (Juen et al. 2019) as well as the development of specific recommendations for MHPSS in armed conflicts and ongoing disasters like pandemics—e.g. IPP and WhoCares (WhoCares n.d.).

Future perspectives in disaster management must include mental health aspects in all phases of the disaster circle and have to be built upon a community resilience framework. Furthermore, future disaster management has to include animal welfare and environmental health based on a One-Health approach where health is seen as interconnected between human health, animal health and environmental health as presented in the United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA) Humanitarian Network and partnership Weeks (HNPW 2025) in Geneva 2025 (DCNA 2025).

Key Sentences

- A multi-layered system has been proven to be an effective framework for adequate psychosocial support.
- Psychosocial interventions in disasters are most effective when guided by the five essential Hobfoll elements: safety, connectedness, calm, self—and collective efficacy and hope (Hobfoll et al. 2007).

- Resilience is not only an individual trait but a community capacity that must be actively developed through participation, preparedness and constant multi-level and multi-organisational coordination.
- Future disaster management has to include animal welfare and environmental health based on a One Health approach where health is seen as interconnected between human health, animal health and environmental health..

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Impact Chains: Conceptual Models for Risk Assessment

8

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Abstract

Impact Chains are conceptual models designed to better understand, systematise and prioritise the various factors that drive risks (hazards, exposure, vulnerability and other underlying risk drivers). By identifying and prioritising these factors, Impact Chains play a crucial role in understanding the complexity of risks and in guiding effective risk management and adaptation planning. The methodology was born in the climate change adaptation community and is based on the terminology and concepts of the IPCC Sixth Assessment Report (AR6). It has been applied in a wide variety of contexts, from European research projects to the European Climate Risk Assessment. Their development and application in comprehensive risk management includes several stages which are illustrated in this chapter. In its latest applications, the aim is

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to develop more structured and consistent Impact Chains that systematically incorporate all relevant knowledge and metadata, ensuring consistency and reusability across different sectors and assessments.

Keywords

Impact chains • Risk assessment • Vulnerability • Climate change adaptation • Forensic analysis

8.1 Introduction

Climate-related hazards can pose significant challenges to a wide range of natural and human systems. For instance, the extreme precipitation and consequent large-scale floods that occurred in Germany and Belgium in 2021, as well as in Slovenia and Greece in 2023, had severe, direct impacts on settlements, infrastructure, agriculture, and human health. Extreme temperatures during the summer of 2022 have led to between 60,000 and 70,000 premature deaths in Europe (EEA 2024a). In the same year, record droughts as well as wildfires directly affected ecosystems, forestry, agriculture, water supply and human health, but also caused indirect impacts to energy production, transport services and tourism (EEA 2024a). Overall, between 1980 and 2023, weather and climate-related extremes resulted in economic losses of assets in the European Union, estimated at 738 billion EUR (EEA 2024b). Climate-related hazards are increasing in frequency, duration, and magnitude worldwide due to climate change (Seneviratne et al. 2021), potentially leading to increasing damages to different sectors. Most regions around the world are also likely to experience multiple hazards; these may occur simultaneously, be cascading, or occur in the same area over time, thereby generating potential compounding effects. Compound events are more challenging to be assessed and managed compared to risks which are linked to only one hazard (Zscheischler et al. 2018).

Along with climate-related hazards, it is important to acknowledge that other types of hazards such as geological (e.g. earthquakes, volcanic eruptions), biological (e.g. pandemics), technological hazards (e.g. industrial accidents) can also pose significant threats to human and natural systems (UNDRR and ISC 2020). Such hazards can interact with climate-related ones or trigger cascading impacts. Therefore, understanding the systemic nature of risk increasingly requires a multi-hazard perspective, integrating both the disaster risk reduction and climate change adaptation perspectives (Hochrainer-Stigler et al. 2023). Furthermore, disasters and potential impacts of climate change also occur due to non-climatic risk drivers, which aggravate vulnerability and exposure (Bednar-Friedl et al. 2022). Risks are indeed not driven exclusively by hazards but also depend on society's preparedness (EEA 2024a). For example, deforestation and wetland loss can reduce natural buffers against floods and droughts. Weak governance, inadequate early warning systems, and poorly-enforced building codes can also make communities more vulnerable

to extreme events. Non-climatic risk drivers are not only numerous but also variable from region to region (Bednar-Friedl et al. 2022).

In addition, impacts can cascade from one system or region to another, causing complex and interconnected adverse consequences as well as systemic failures. For example, a heatwave and drought can cascade across multiple sectors, leading to widespread disruptions. Low water levels in major rivers can reduce cargo transport capacity, resulting in delayed shipments and increased costs for manufacturers. At the same time, drought can reduce hydropower production, exacerbating energy supply constraints. This can lead to rising electricity prices, which can strain households and businesses, potentially triggering social tensions and increasing pressure on governments to implement emergency measures. Being aware of potential cascades is therefore crucial for reducing climate risks (EEA 2024a).

Given the complex and systemic nature of risks, comprehensive risk assessments are essential to identify key risk drivers and support more integrated approaches to climate change adaptation and risk management. Risk assessments are typically supported by relevant information from past observations and future scenarios of climate change, as well as non-climatic risk drivers, which can lead to potential impacts on different sectors (EEA 2024a). Assessments vary widely depending on their aim, geographic scope, and sectoral focus, resulting in a diverse range of methods and tools being applied. Consequently, there is no standardised approach or common scheme to conduct a risk assessment (Menk et al. 2022; Zebisch et al. 2022). Different guidelines exist to provide guidance: for example, the ISONorm: ISO/DIS 14091: Adaptation to climate change- Guidelines on vulnerability, impacts and risk assessment (ISO 2021) and the Adaptation Support Tool (Climate-ADAPT 2016). Both guidelines propose the concept of Impact Chains to conduct a comprehensive risk assessment.

Impact Chains are conceptual models designed to better understand, systematise, and prioritise the various factors that drive risks. By identifying and prioritising these factors, Impact Chains play a crucial role in understanding the complexity of climate and disaster risks and in guiding effective risk management and adaptation planning (Zebisch et al. 2022). The latest guidance on Impact Chains can be found in the Climate Risk Sourcebook (Zebisch et al. 2023) and in the technical guidance on application of climate information for comprehensive risk management (UNDRR 2022).

8.2 The Concept of Impact Chains

Impact Chains facilitate the structuring of cause-and-effect relationships between drivers affecting a system. They are an analytical tool which enables the visualisation of interrelations, assisting in identifying key impacts and which hazards may lead to them (Zebisch et al. 2023).

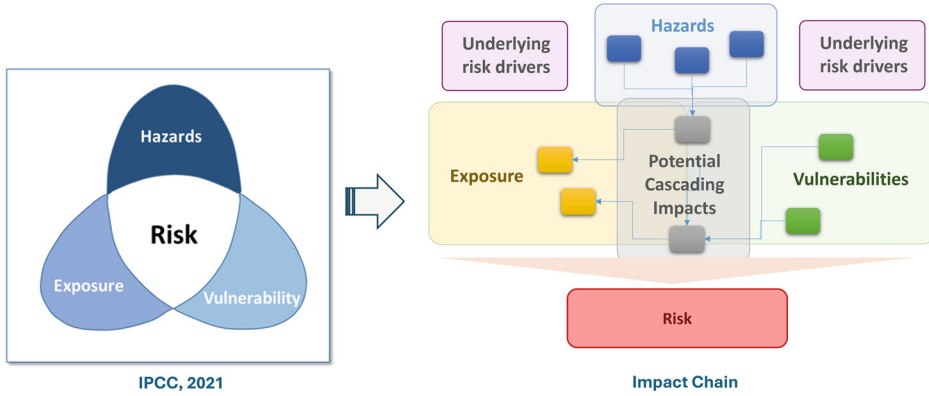


Fig. 8.1 The IPCC risk propeller and its translation into Impact Chain factors (Adapted from Zebisch et al. (2023))

The methodology is based on the terminology and on concepts of the IPCC Sixth Assessment Report (AR6), which states that risks arise from dynamic interactions between climate-related hazards and the exposure and vulnerability of the affected human and/or ecological systems to these hazards (Bednar-Friedl et al. 2022; IPCC 2021; Zebisch et al. 2023) (see Fig. 8.1). The approach aligns with broader disaster risk reduction frameworks, such as those promoted by the UN Office for Disaster Risk Reduction (UNDRR). Both perspectives emphasise the importance of addressing underlying risk drivers and recognise the need for integrated, systemic approaches to managing complex, interacting and cascading risks across sectors and scales.

Impact Chains are, therefore, not simply tools for representing the potential cascading impacts that may occur; but also for capturing the complex interplay of climatic and non-climatic risk drivers (hazards, exposure, vulnerability and other underlying risk drivers) that lead to adverse consequences.

To understand and construct Impact Chains, it is essential to recognise the definitions of risk, along with those of its components (hazards, exposure, vulnerability and other underlying risk drivers); below are the main definitions.

Definitions

Risk refers to the potential for adverse consequences for human or ecological systems such as loss of life, injury, destroyed or damaged assets (IPCC 2021; UNDRR 2017). IPCC AR6 emphasises risk as a function of hazard, exposure, and vulnerability (IPCC 2021). UNDRR includes coping capacity and notes that risk can be intensified by underlying drivers such as poverty, governance and environmental degradation (UNDRR 2017).

Impact refers to the effect or consequence resulting from a hazard or from another preceding impact. For both UNDRR and IPCC, impacts encompass both adverse outcomes (such as economic losses, damage to infrastructure or loss of life) and, in some cases, positive outcomes (such as increased demand for certain services or economic gains in specific sectors) (IPCC 2021; UNDRR 2017). In the context of Impact Chains, impacts are understood primarily as adverse (negative) consequences that represent potential materializations of risk. These consequences can be direct or indirect, and may be observed or anticipated (Zebisch et al. 2023). Direct impacts are the immediate consequences of a hazard event. Examples include an increase in heat-related illnesses during and shortly after heatwaves, damage to crops caused by drought or hail events, or traffic accidents and road damage following heavy precipitation and flooding events. Indirect impacts develop through subsequent or cascading effects within social, economic or environmental systems. These may include interruptions to supply chains after transport infrastructure is damaged, or higher food prices that emerge when agricultural production is reduced. Indirect consequences often unfold over longer periods and can amplify the overall effects of an event.

Hazards: Any type of extreme events that can become more frequent and more intense due to climate change, as well as slow-onset processes or trends that are generating adverse consequences for human or ecological systems. Climate-related hazards can trigger other hazards (e.g. intense precipitation can trigger landslides) or appear in combination in a compound event (e.g. a heatwave during a pandemic or a flood after an earthquake) (Zebisch et al. 2023). Non-climate-related hazards, which can be classified into geological, environmental, hydrometeorological, technological, biological, chemical and societal hazards (UNDRR 2017), can also be included in the Impact Chains.

Exposure refers to the presence of people, livelihoods, ecosystems, infrastructure, or other tangible human assets located in places that could be adversely affected by hazards (IPCC 2021; UNDRR 2017).

Vulnerability refers to the propensity or predisposition of individuals, communities, assets, or systems to be adversely affected by hazards (IPCC 2021; UNDRR 2017). It is determined by a combination of physical, social, economic and environmental factors or processes and it encompasses a variety of elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2021). While the previous chapter adopts a physical vulnerability perspective, expressed as the expected degree of physical damage to elements at risk, the present chapter follows the broader UNDRR and IPCC understanding. This broader perspective considers not only physical characteristics but also social and institutional conditions that influence how severely an element, group or system can be affected by a hazard. **Sensitivity and susceptibility** refer to those physical attributes (e.g. building material of houses, type of soil on agriculture fields) or social, economic and cultural attributes (e.g. age structure, income structure) which make a system more vulnerable**. Lack of capacity** refers to the absence or limitation

of knowledge, technology, financial resources, institutional arrangements or legal frameworks that reduces the ability of individuals, communities or systems to anticipate, cope with and recover from the impacts of hazard events (IPCC 2021; UNDRR 2017). For a more detailed discussion on vulnerability, please refer to Chap. 5.

Underlying Risk Drivers: The (non-climatic) risk drivers that may significantly alter the socio-economic or environmental situations and possibly amplify the negative consequences of impacts but cannot be mitigated or controlled within the scope of the Impact Chain (Zebisch et al. 2023). These include those processes or conditions such as poverty, inequality or demographic changes which increase levels of exposure and vulnerability or reduce the capacity to respond (UNDRR 2017).

Building on these foundational definitions, it is important to recognise that the concept of risk is influenced by both knowledge and values. Individual stakeholders often have partial or biased perspectives, and combining knowledge from multiple sources can provide a more complete overview of potential consequences. At the same time, objectives and values shape what is considered a potential adverse consequence. For example, a decrease in tourism due to lack of snow in winter may be perceived positively by the local population, but as a potential adverse consequence by the tourism sector, such as hotel owners. In this context we only consider adverse and severe consequences for relevant human and ecological systems that should be avoided or mitigated. When applying the Impact Chains, we consider both the risks that are already present as well as those that might arise in the future due to climate change (Zebisch et al. 2023).

Moreover, although vulnerability is internationally recognised as a key driver of risk, its operational assessment remains a challenge. The *MOVE Framework* (Birkmann et al. 2013) identifies five dimensions of vulnerability: economic, physical, environmental, socio-cultural, and institutional. A comprehensive risk analysis should ideally encompass all dimensions. For each vulnerability factor, the associated risk drivers should be examined. A vulnerability factor may be connected to multiple risk drivers, and vice versa. By emphasising vulnerability as a critical yet often overlooked risk factor, Impact Chains provide a framework for identifying adaptation and risk mitigation measures.

As illustrated in Fig. 8.2, an Impact Chain generally consists of the above-mentioned main elements: hazards, exposed elements, impacts, vulnerabilities and underlying risk drivers. Key risks and potential adaptation or risk mitigation actions can also be included.

Over the past 10 years, Impact Chains have gained significant recognition in the climate community as a valuable tool for Climate Change Adaptation (Menk et al. 2022). More recently, their application has expanded into the field of disaster risk reduction, including the assessment of risks related to geophysical hazards such as earthquakes, volcanic eruptions and storms (Cocuccioni et al. 2023, 2024). They offer a shared risk perspective grounded in both IPCC and UNDRR definitions, highlighting how social, economic, and environmental conditions shape risk. By visualising cascading and systemic impacts across sectors, Impact Chains support integrated planning and prioritisation of actions that address both present and future risks, fostering more coherent and effective

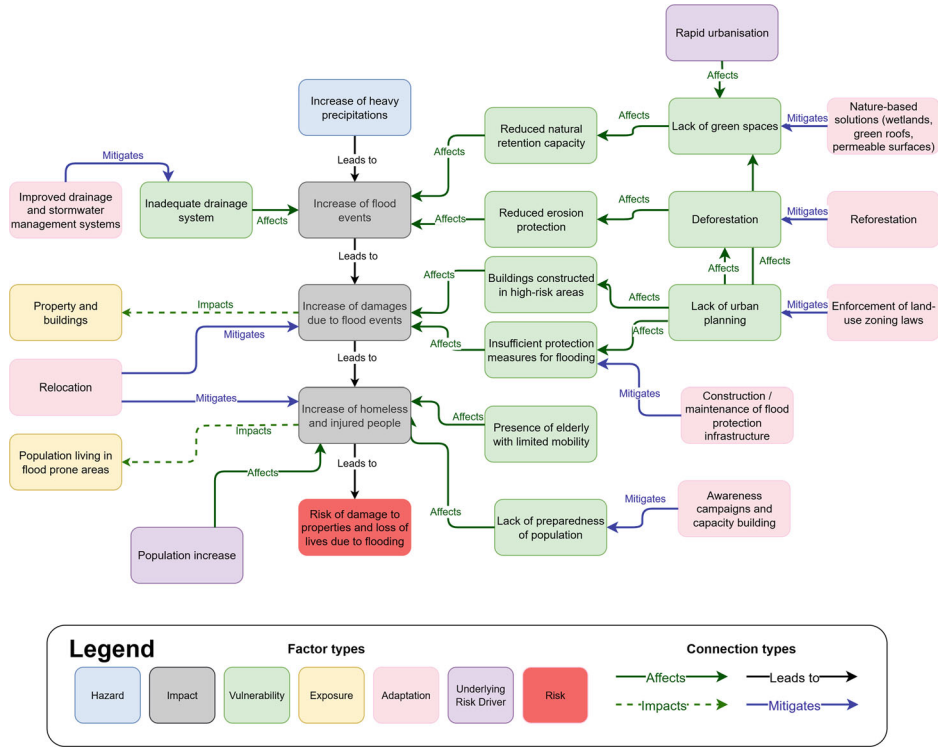


Fig. 8.2 A simple Impact Chain example where the main elements leading to the risk of damages to properties and loss of lives due to flooding are illustrated (Pittore et al. 2026)

strategies across the climate change adaptation (CCA) and disaster risk reduction (DRR) communities. Their integration into comprehensive risk management supports a holistic approach to reducing both climate and disaster risks (UNDRR 2022).

Across their various applications, Impact Chains facilitate a shared understanding among experts and stakeholders. Their structured approach helps to analyse both current and future risks using diverse knowledge sources, from quantitative data to qualitative narratives. Impact Chains can indeed be developed through a participatory approach (e.g. working with subject-matter experts), by desktop-analysis of empirical evidence and scientific literature, or combining the two approaches.

8.3 The Process of Developing Impact Chains for Climate and Disaster Risk Assessment

The development of Impact Chains and their application in comprehensive risk management includes several stages which can be summarised as follows (Pittore et al. 2026; Zebisch et al. 2023).

Scoping: In this phase, the risk assessment is linked to the context and the set-up is defined. The scope of the Impact Chain should be described clearly indicating the objective, the method of constructing the Impact Chain itself (participatory workshops, desk-based data analysis, etc.), the administrative scale, the geographical scope and the time horizon.

Mapping the Exposed Systems and Functions: To analyse exposure, it is helpful to use a systemic approach, which considers both individual elements and the connections between them. This helps to identify how impacts can propagate through a system. For example, the energy system can be divided into three main subsystems: energy supply; energy consumption and transport infrastructure. The energy supply subsystem includes different generation sources such as hydropower, photovoltaic, wind, thermal and nuclear power plants. The consumption subsystem comprises households, industries and other end users that rely on energy. The transport infrastructure subsystem includes transmission lines and pipelines. Mapping these subsystems and their elements helps to identify which parts of the energy system are exposed and how impacts may propagate through the network. The overall exposed systems and functions relevant for the scope of the Impact Chain need to be listed, including the relevant sub-systems which compose them. These will represent the possible yellow-exposure elements of the Impact Chain.

Brainstorming and Mapping Possible Impact Chain Elements: Starting from the identified systems and sub-systems, the connected risk components can be identified. A table can be created listing the possible hazards (including both climate-related and possible compound non-climate-related ones), which can affect the identified systems as well as potential current or future, direct and indirect impacts. Finally, the vulnerabilities of the exposed systems can also be added to the overview table, ensuring the coverage of different vulnerability dimensions (economic, physical, environmental, socio-cultural and institutional).

Building the Impact Chain: The visual representation can be developed linking all the previously identified elements and integrating any missing aspect. Different tools exist to develop Impact Chains, for example, proprietary, commercial or free online software such as Kumu (2025), or Draw.io.

Identifying Key Risks: Risks relevant to the region or sector under consideration can be identified by selecting a subset of impacts present in the Impact Chain or by adding new ones. Possible criteria for analysing the relevance of impacts include the magnitude or

likelihood of adverse consequence, the preparedness or ability to respond, the unavoidable losses and damage, their irreversibility, the importance of the impacted system, etc. It is also helpful to consider which impacts might lead to missing or overshooting targets and objectives relevant for the region or sector examined.

Integrating the Impact Chain Through Mixed Methods Approaches: Quantitative, semi-quantitative, qualitative and narrative approaches can be adopted to support the Impact Chain and to conduct a more in-depth analysis. For instance, expert interviews can be conducted to identify additional vulnerability factors (Stephan et al. 2023), storylines can be adopted to describe the graphic representation or specific pathways within the overall Impact Chain (Zaccaria et al. 2024). Learning from the past, applying a Forensic Analysis approach and studying historical disaster events can also support the integration of missing aspects. Moreover, Impact Chains can serve as a backbone for more quantitative risk assessment (Stephan et al. 2023; Zebisch et al. 2017).

Identifying Adaptation or Risk Mitigation Options: The Impact Chains can be used to identify entry points for adaptation or risk mitigation. Adaptation options and risk mitigation measures decrease the negative consequences of an impact by addressing one or more vulnerabilities or impacting mechanisms. Options can be prioritised based on their potential effectiveness, feasibility, co-benefits and implantation time. In the climate change adaptation context, adaptation pathways can be developed, exploring different combinations of option implementation over time and under different climate change scenarios (Haasnoot et al. 2013).

Implementing Adaptation: The work conducted can serve as a basis for the development of a climate change adaptation strategy. This means to translate into action and put into practice the adaptation measures foreseen in adaptation policy documents. An important means of implementation are adaptation action plans, which includes specific actions, timelines, resources, and responsibilities (Climate-ADAPT 2016).

8.4 Examples for Impact Chain Applications

Since 2014, when the approach was initially developed (Fritzsche et al. 2014), Impact Chains have been applied in a wide variety of contexts: from national risk assessments (e.g. in Germany, Burundi, Bangladesh, Thailand, Vietnam, Madagascar), to provinces (e.g. the Autonomous Province of Bolzano, Italy) and regions (e.g. Marche and Liguria Regions, in Italy), including also the European Scale in the European Climate Risk Assessment (EEA 2024a). Additionally, several European research projects have applied the Impact Chain concept, such as JPI Climate project UNCHAIN (JPI Climate 2025), Horizon 2020 IMPETUS (2025), Horizon Europe PARATUS (2025) and the ESA project EO4MULTIHAZARDS (ESA 2025). Different examples of Impacts Chains are presented below.

One illustrative example comes from the *Climate Risk Sourcebook* (Zebisch et al. 2023), which presents Impact Chains as a core tool to guide climate risk assessments in support of adaptation planning. Figure 8.3 illustrates the cascades which can occur through interconnected systems. Climate-related hazards can initially have direct impacts on the environment (e.g. on water availability) and over time can indirectly affect human systems such as the agricultural sector.

Another recent application example results from the PARATUS project (Cocuccioni et al. 2024). In this context, a Forensic Analysis framework was developed for investigating past events and improving the understanding of current risks. The Forensic Analysis provides Impact Chains with evidence, based on past disaster events and supports the identification of missing elements and connections. In particular, the framework provides a structure for documenting and analysing historical disaster events, which involves four key components that can be allocated into the event's timeline (see Fig. 8.4): (1) Pre-disaster conditions; Why could the event happen?; (2) Hazard and impact analysis—What happened during the event?; (3) Recovery—What actions were taken to restore service and address impacts during the recovery phase?; and (4) Building back better—What

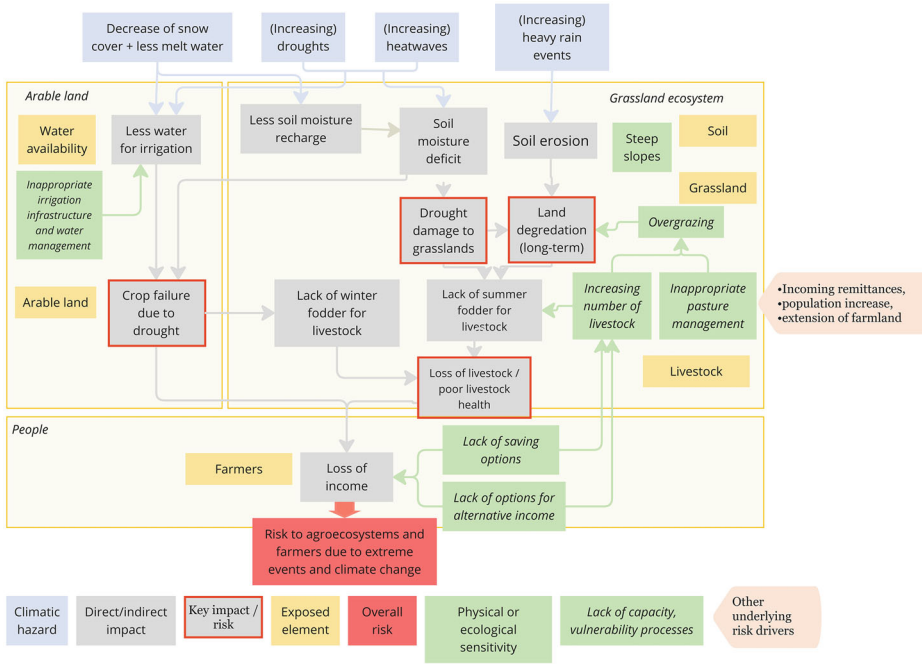


Fig. 8.3 An example of an Impact Chain illustrating cascading impacts of prolonged drought and heatwaves on different interconnected systems: arable land, grassland ecosystems and people Zebisch et al. (2023)

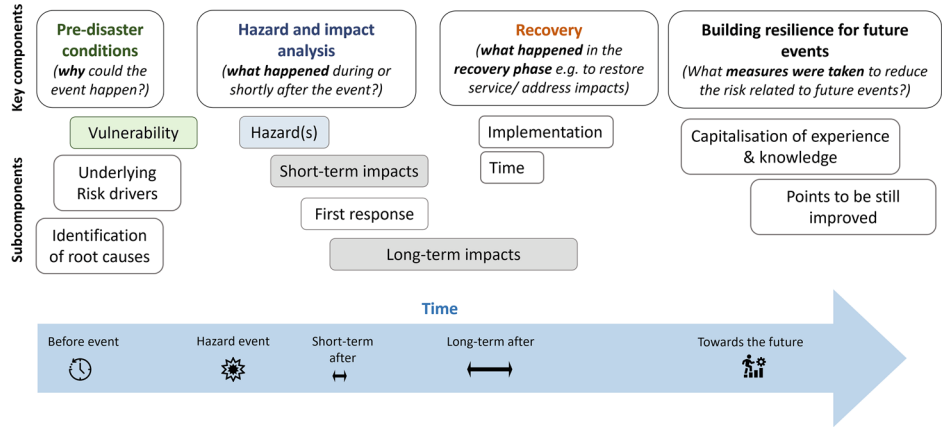


Fig. 8.4 The PARATUS forensic analysis framework to improve the development of Impact Chains. The different components of the framework are ordered chronologically in time with respect to the occurrence of the hazard event. On the top, the four main components are displayed; these are divided into sub-components, listed below. The coloured sub-components are those which feed directly into the Impact Chains (Cocuccioni et al. 2024)

measures were taken to reduce future event risks and increase resilience? Each component of the framework has specific characteristics and subdivisions that address key points necessary to understand the disaster event.

An example of an Impact Chain resulting from the forensic analysis is presented in Fig. 8.5. It refers to Storm Vaia, which struck Northern Italy in 2018, bringing exceptionally strong winds and intense rainfall. The event caused landslides, flooding and widespread forest destruction, as well as significant damage to infrastructure and power lines. In the aftermath, the large volume of fallen spruce trees created ideal conditions for a bark beetle (*Ips typographus*) outbreak, leading to further degradation of forest ecosystems in the following years. This example illustrates how compound and cascading risks can emerge across sectors and timeframes. The forensic analysis also identified key vulnerability factors that can inform improved risk management practices and enhance preparedness for future events.

8.5 Conclusions and Perspectives of Impact Chains

Impact Chains offer a structured approach to identify, conceptualise, visualise, and communicate knowledge about climate and disaster risks. Their application varies across projects and contexts. Each time a new risk assessment is conducted, the process often starts from scratch, following all the steps outlined in Sect. 8.3. This has led to a growing need for a more structured and systematic approach to using Impact Chains (Pittore et al.

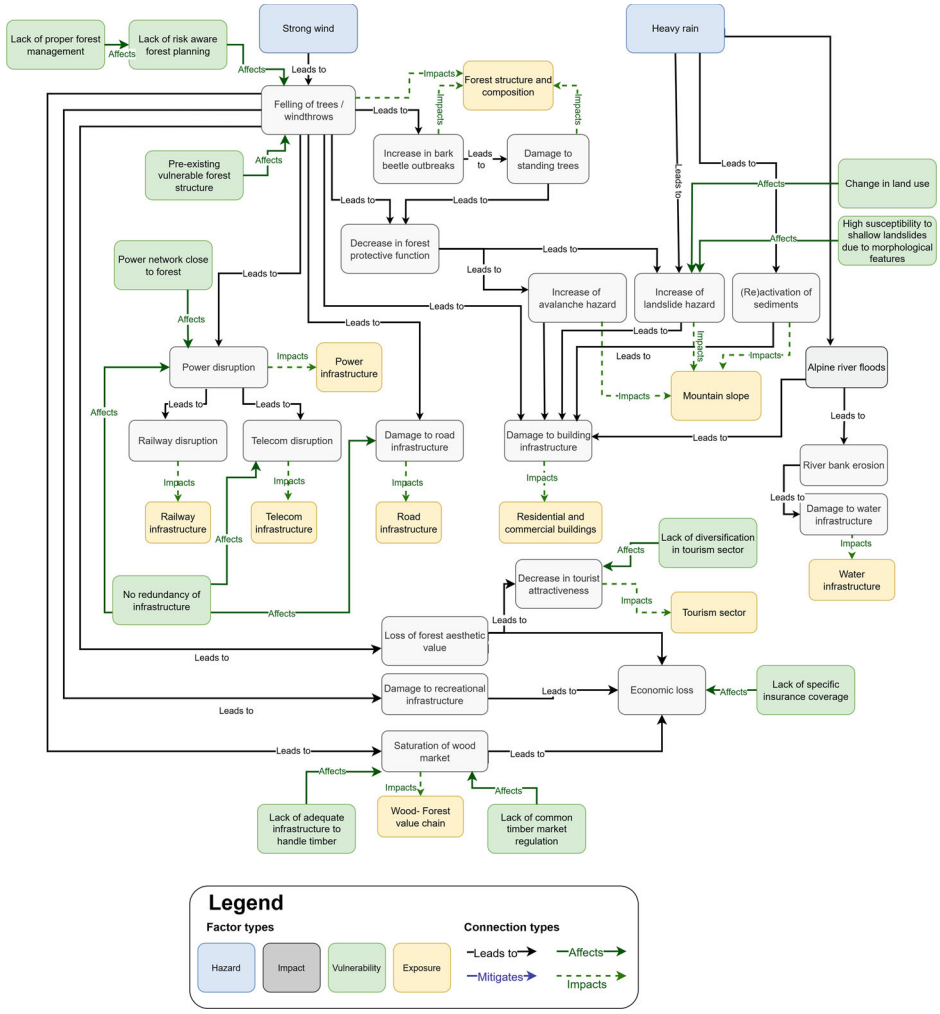


Fig. 8.5 Impact Chain developed through the forensic analysis of the 2018 Vaia storm, which severely affected parts of Northern Italy. Storm Vaia caused exceptionally strong winds and intense rainfall, triggering widespread forest destruction, landslides, flooding, infrastructure damage and a subsequent bark beetle outbreak (Developed by the author based on Cocuccioni et al. (2024))

2026). Traditionally, they have been viewed primarily as graphical conceptual models, offering clear and meaningful representations tailored to different stakeholders. However, recent applications are expanding beyond visualisation. A key prerequisite for building an Impact Chain should be maintaining a standardised format that systematically incorporates all relevant knowledge and metadata describing the different elements and connection. This ensures consistency and reusability across different assessments. Therefore, the aim

is to develop more structured and consistent Impact Chains as an actionable knowledge tool to be leveraged in the framework of comprehensive risk management.

Currently, Kumu (2025) is considered the most advanced tool for creating Impact Chains in a structured environment. It enables users to assign predefined types to each element and connection, ensuring a more systematic approach. Beyond graphical visualisation, Kumu also stores metadata for each component, including fields such as Label, Type, Description, and Confidence, offering a more detailed representation. Additionally, the visual model is dynamically linked to an underlying table repository, which can be exported as an Excel (.xlsx) file for further analysis. More details to build standardised Impact Chains can be found in Pittore et al. (2026).

The final aim is to establish a library of Impact Chains that serves as a structured knowledge base, enabling users to query and filter information across and within complex Impact Chains. These reference Impact Chains can provide a valuable starting point for future assessments, supporting the development of new climate change adaptation strategies and contributing to more comprehensive and integrated risk management. An example of such a library of standardised Impact Chains is available on the Disaster Risk Stakeholder Hub (CMINE n.d.), in the Impact Chain Wiki.

To summarise, Impact Chains offer a valuable framework for understanding, visualising, and communicating the complex interplay of hazards, exposure, and vulnerability, including cascading and compound effects across sectors. By integrating perspectives from both climate change adaptation and disaster risk reduction, they help bridge disciplinary and institutional gaps, supporting more comprehensive and forward-looking risk management. Whether developed through participatory processes, expert analysis, or a combination of both, Impact Chains enable practitioners and decision-makers to identify key risk drivers and prioritise effective measures.

Key Sentences

- Impact Chains offer a structured and visual approach to risk analysis, illustrating how hazards interact with exposure and vulnerability to generate direct, indirect, and cascading impacts across sectors and systems.
- The methodology builds on the IPCC AR6 risk framing and aligns with UNDRR concepts, supporting a shared understanding of risk that bridges climate change adaptation and disaster risk reduction communities.
- Impact Chains support integrated and systemic risk management, enabling the identification of critical risk drivers and potential intervention points to guide adaptation and risk mitigation strategies.

- They can be developed through participatory processes and/or desk-based analysis, drawing on diverse knowledge sources to capture context-specific dynamics and promote comprehensive, evidence-based decision-making.

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Synthesis and Perspectives for Natural Hazards in Disaster Risk Management

9

Thomas Glade, Sophia Sternath, Annika Fröwis, and Philipp Marr

Abstract

Natural hazards are a global phenomenon, occurring in all regions of the world. A multitude of processes are implicated in this phenomenon; some of these processes act in an autonomous manner, while others exhibit interconnectivity. Furthermore, the consequences of natural hazards are manifold. These range from a brief traffic disruption caused by a road blockage to long-term disturbance of the economy due to business or critical infrastructure interruption. The various examples presented in this book introduced a variety of consequences. In addition to the advancement of the respective disciplines, some general conclusions can be drawn, and future perspectives can be delineated. Firstly, it is necessary to explore the notion that natural hazards and associated phenomena are not static, but rather dynamic by nature. Secondly, it is imperative to acknowledge that the factors that drive natural hazards and risks are subject to change. It is evident that the occurrence of a natural hazard does not invariably manifest in a linear sequence; rather, it is exhibited in diverse spatio-temporal dimensions. Thirdly, this includes, in particular, any aspects of climate change and foresight. Fourthly, there is a necessity to continue the efforts to develop and implement adapted methods and concepts to analyse natural hazards and risks, and especially to revise Disaster Risk Management (DRM) principles on a constant basis. Finally, it is essential to demonstrate the capacity to respond to conditions that have not yet been encountered. These conditions may materialise in the form of extreme events, increased frequency of events, or the emergence of novel natural hazards that have

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not been previously experienced in a specific location. Recent European policy documents increasingly frame preparedness and prevention in disaster risk management as long-term investments with net socio-economic benefits.

Keywords

Deepening detailed knowledge • Dynamic natural hazards and risks • Drivers of change • Climate change and foresight • Adapted methods and concepts

9.1 Synthesis of the Presented Aspects

A series of syntheses and perspectives can be drawn on the content of this book volume. Firstly, there is a necessity to enhance our knowledge about past and recent dynamics of natural hazards. This encompasses the utilisation of all available resources, including but not limited to written historical archives, traditional community knowledge, paintings, drawings and photography, records stored in book archives, bibliographies, churches, and sedimentary archives, such as deposits of past events (e.g. boulders transported by tsunamis, volcanic ash, or debris flow materials).

In addition to the provision of more detailed information on past events, there is an urgent need to obtain further insights into the mechanisms of individual hazards, as explored in Chap. 2. It is imperative that these natural processes are subject to continuous monitoring in order to facilitate a more profound comprehension of their behaviour and respective interactions. In the light of recent advancements in the field, particularly those stemming from novel methodologies, there is a requirement to enhance our comprehension of the interplay between pre-conditioning, triggering, and controlling factors that govern the spatio-temporal dynamics of natural hazards.

The management of disasters has evolved from a reactionary approach, which was limited to the response to natural hazards, to a more comprehensive evaluation of specific natural hazards (e.g. disaster management of floods). This progression has led to the development of general concepts within multi-hazard and risk frameworks, which now incorporate considerations of interconnections. In future studies, particular attention should be paid to the roles of extreme events, social media, social simulation, big data and artificial intelligence, and newly emerging risks. An overview of the past and current situation in DRM and expected future trends was given in Chap. 3.

It is evident that any compromise in disaster risk management and risk governance has the potential to impact a variety of dimensions and experience demonstrates that institutional environments, discussed in Chap. 4, constitute the foundation for any action. In addition to human and financial resources, institutional settings are instrumental in determining the range of available responses, which exhibit notable variations across different environments. Therefore, efforts should focus on providing a range of actionable options

that can be adapted to the given conditions as effectively as possible. In addition, potential development paths should be offered for potentially changing institutional environments.

In the context of any risk assessment, it is imperative to undertake a thorough evaluation of the vulnerabilities involved. As discussed in greater depth in Chap. 5, this encompasses various forms of structural vulnerabilities, including bridges and houses; social vulnerabilities of affected populations, such as economically disadvantaged individuals; economic vulnerabilities of impacted parties, such as insurance coverage; institutional vulnerabilities of involved organisations, such as effective disaster risk governance; and environmental vulnerabilities of landscapes, such as susceptibility to landslides, to name some examples only. Further exploration must be conducted into these various dimensions of vulnerabilities, with due consideration given to their respective interactions and dynamics.

Chapter 6 shows that numerous cases have demonstrated the paramount importance of socio-economic dimensions of disaster and climate change risk management. While socio-economic responses to natural hazards have varied significantly between decades, numerous concepts have been developed to unify not only the assessment of socio-economic aspects, but also the incorporation of this knowledge into disaster risk management. In this instance, the consequences of climate change are virtually without real outcomes. The development of a shared socio-economic analysis is also a key priority for the future. Such analysis must be sufficiently flexible to accommodate any anticipated alterations.

It is apparent that research in the field of natural hazards and risk management, and in particular disaster risk management, frequently concentrates on conventional management strategies, encompassing plans and constructions. Chapter 7 addresses psycho-social support, which is frequently not considered to a great extent. Common mechanisms within disasters are frequently absent, and as such, further exploration is required in the future to ascertain their existence. In this regard, any future development must be predicated on a profound reflection of the specific social and cultural nuances that are characteristic of this context.

Furthermore, there is a necessity to develop a more profound comprehension of the consequences that naturally occurring hazards have on human populations. As discussed in Chap. 8, the notion of "Impact Chains" has been identified as a significant development in the field of future consequence research and the interconnectedness of impacts within an event, particularly in the context of natural hazard occurrence. Consequently, a comprehensive assessment of the consequences is imperative, necessitating quantification to inform the establishment of priorities in disaster risk management.

The examples provided highlight the necessity of considering natural hazard processes, their potential consequences, and possible disasters (UNISDR 2013). Furthermore, these issues must be explored in future inter- and transdisciplinary research approaches. As most recent figures (CRED 2025) for human impacts (e.g. death tolls or total affected people) or for economic loss by different disaster types show (refer to Fig. 9.1), this necessity is

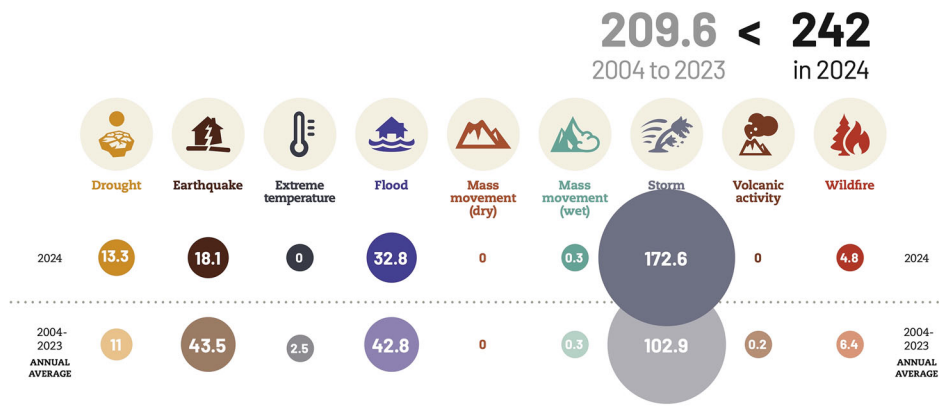


Fig. 9.1 Economic losses (US$ billion) by disaster type: 2024 compared to the 2004–2023 annual average (CRED 2025)

evident. In this context, it is important to recognise the mid- to long-term efforts required to adequately address these domains.

9.2 Some Future Perspectives

In addition to synthesising the diverse subjects encompassed by the chapters in this book volume, it is possible to delineate a number of more general perspectives. The following list comprises a selection of topics only; a multitude of other subjects are equally relevant.

Dynamic Natural Hazards and Risks: It is imperative to further explore the dynamic nature of natural hazards and risks. In certain domains, this subject has already been the focus of extensive research (e.g. flood hazard and risk (Kaushik et al. 2024; Nandam and Patel 2024)), while in others, only limited studies are available (e.g. subsidence hazard and risk (Li et al. 2025)). Our society must progress towards the implementation of dynamic assessments of natural hazards, including their interconnections and the consequences of occurrences.

Drivers of Change: In view of the fact that all involved factors are subject to constant change, it is essential to direct attention towards the specific drivers in question. It has been observed on numerous occasions that the conditions which give rise to natural hazards appear to be in a state of flux. Extremes are becoming increasingly pronounced, as outlined in the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC) (Seneviratne et al. 2021). For instance, there has been an increase in the amount of snowfall in a single night, elevated temperatures during extended periods of drought, and increased wind speeds during hurricanes. Additionally, there has been an increase in

the duration and intensity of rainfall. These are merely a few examples of the observed conditions. Concurrently, heightened exposures and vulnerabilities give rise to escalating socio-economic ramifications on a global scale (UNDRR 2025). It is evident that, in the future, strategies for the management of disaster risk must be adapted accordingly.

Climate Change and Foresight: Furthermore, a plethora of changes can be observed in almost all climate-change associated domains. Consequently, a future research focus should be on climate change-related aspects. This encompasses novel pre-conditioning factors (e.g. drier or wetter periods prior to the occurrence of natural hazards), shifting triggering factors (e.g. stationary rainfall over small regions causing flash floods) and modified controlling factors (e.g. drier soils lead to less infiltration during a rainfall event with consequent increased surface runoff) of natural hazards. Attribution studies, for instance, investigate the influence of anthropogenically induced climate change on the intensity and frequency of natural hazards (Barbosa et al. 2025; Trapp et al. 2025), and it remains crucial to conduct such studies to better understand future climate-hazard relationships and the inherent uncertainties. Simultaneously, climate change has the potential to modify or consolidate societal conditions, consequently resulting in a variety of consequences, including rising inequality and shifting power structures (Shamsuddoha et al. 2024; Zahnow et al. 2025). To illustrate this point, one may consider the potential consequences of extreme heat, which has been shown to result in the degradation of infrastructure (e.g. bridges), or prolonged periods of drought, which have been linked to migration driven by climate change. A more in-depth investigation is required to fully understand the consequences of these changes and their potential impacts.

Adapted Methods and Concepts: The investigation of diverse natural hazards, the analysis of respective consequences, and the development of appropriate and sustainable disaster risk management strategies have given rise to the development of numerous methods and concepts. Considering the aforementioned future challenges, a thorough evaluation of the present processes and strategies is imperative to ascertain their capacity to address these novel developments. One of the primary foci should be to determine whether the available concepts can be adopted or whether novel approaches must be developed and implemented in certain domains in order to accommodate the anticipated changes. One example are the necessary efforts to reach the citizen dimension to enhance a so-called "culture of risk" and improve societal resilience (Quevauviller et al. 2026). Recent EU strategies explicitly highlight that the long-term benefits of preparedness outweigh its upfront costs in terms of resilience and reduced disruption (European Commission n.d.).

Indeed, these considerations are selected perspectives only. Many others are equally important. Some of these are further detailed in the other volumes of this series on *Civil Protection, Disaster Management, and Resilience* including:

- *From Single Hazards to Multi-Hazards and Systemic Risks: Scientific, Operational and Communication Perspectives* by Schrott L., Bell R., Billing P., Chiimba E.

- *Geospatial Innovations in Disaster Management: An Overview of Recent Developments* by van Westen C. J., van den Homberg M., Kerle N., Nabukulu C.
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Key Sentences

- Natural hazards and risks, as well as disaster risk management concepts and applications, must be revised according to expected changes.
- Specific identified foci of future changes include dynamic natural hazards and risks, drivers of change, climate change and foresight, and adapted methods and concepts.
- Preparedness and prevention are increasingly recognised as cost-effective components of future disaster risk management.
- Natural hazards in DRM are not static, but very dynamic in nature.

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