Scoping Study On Compound, Cascading And Systemic Risks In The Asia Pacific

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EXECUTIVE SUMMARY

The 'Scoping study on compound, cascading and systemic risks in the Asia-Pacific', undertaken by the United Nations Office for Disaster Risk Reduction (UNDRR) and Asia Pacific Scientific and Technical Advisory Group (AP-STAG), presents an important opportunity to explore the challenges and potential associated with better understanding and managing of compound, cascading and systemic risks in the global context, focusing, in particular, on the application of these concepts in the Asia Pacific region. As a scoping study, the report attempts to map and study the extent and nature of available studies and work on compound, cascading and systemic risks. Thereby, it brings forth prevalent terminologies, concepts and pertinent features of these risks.

The scoping study was conducted through a methodology comprising: (1) a thorough review ofexisting literature; and (2) a review of the invited case studies to capture examples, good practices, and evidence of compound, cascading and systemic risks, and their management in the region. The study analyses compound, cascading and systemic risks by understanding the triggering and triggered hazards, type of underlying vulnerabilities, the scale of the associated effects and impacts – global, regional, national or local, other driving factors and interactions therein, that exacerbate the risk to exposed and vulnerable communities, infrastructures and systems.

The study proposes six basic principles for the management of such risks. These are:

1. Identify interconnectedness between root causes, drivers and effects of all dimensions of risk A holistic assessment of all dimensions of risk, namely: hazard, exposure, vulnerability along with identifying the interconnectedness among their root causes, drivers and effects across systems and at varied scales, is crucial for formulating future actions to better understand and manage compound, cascading and systemic risks.

2. Focus on strengthening the resilience of interconnected systems through a 'systems approach' In order to manage compound, cascading and systemic risks effectively, focus should include strengthening the resilience of a given system and interconnected networks, via a systems approach. This helps in identifying vulnerable linkages and potential tipping points prevailing in the system and networks, and supports building in redundancies and strengthening their resilience and sustainability.

3. Strengthen transboundary risk governance through coordinated policy and planning For effective management of compound, cascading and systemic risks, active engagement and coordination of transboundary governing bodies and inter-governmental organizations is a necessity, with time-bound roles and responsibilities fixed for all stakeholders.

4. Invest in social systems for reducing vulnerability and advancing overall well-being Safety-net systems and social services such as health, public health, nutrition, and education should be promoted for protecting vulnerable groups and advancing their overall well-being.

5. Promote ecosystem-based approaches for building resilience to complex risks Ecosystems should be sustainably managed, conserved, and restored, to reduce environmental drivers of disaster risk. This is because ecosystem-based approaches and nature-based solutions help to prevent and mitigate or buffer disaster impacts, and thereby, build resilience. Ecosystem-based adaptation and nature-based solutions improve the health of ecosystems and restore or protect ecosystem services, reducing vulnerabilities and exposure, and thus, reducing risks.

6. Invest in innovative risk-informed multi-sectoral planning and interventions at multi-scalar levels Risk-informed decision-making approaches should be adopted for multi-sectoral planning and interventions at multi-scalar levels including national, regional and local. These should be backed by adequate and robust disaster risk reduction financing mechanisms and sustainable financial resources.

The study identifies pertinent gaps in the current understanding and management of compound, cascading and systemic risks. These are:

- Definition and scope of compound, cascading and systemic risks are under-studied.
- Lack of established scientific approaches for assessment and management of compound, cascading and systemic risks.
- Limited record of compound, cascading and systemic events and impacts in disaster databases.
- Inadequacy of institutional and financial mechanisms to address compound, cascading and systemic risks.
- Limited stakeholder awareness on compound, cascading and systemic risks.
- Inadequate resilience standards and their compliance in critical infrastructures.
- Insufficient integration of climate change action and DRR measures.

The study brings forth the following key lessons learnt:

- Consideration of all dimensions of risk for its assessment and management.
- Developing disaggregated vulnerability and exposure databases for better anticipation and management of compound, cascading and systemic risks.
- Adaptive and integrative risk governance to manage compound, cascading and systemic risks.
- Innovative risk reduction financing mechanisms for compound, cascading and systemic risks.
- Evidence-based mapping at spatio-temporal scales via scenario-building.
- Understanding and addressing the risks involved in critical infrastructure systems.
- Dynamic multi-hazard disaster risk management plans.
- Adopting ecosystem-based approaches to mitigate and manage risk.
- Investing in systems that protect and advance the overall well-being.

The study concludes with the development of a framework to strengthen governance of compound, cascading and systemic risks in the Asia Pacific region and offers thematic recommendations at local, national and regional scales. By outlining the key gaps, lessons learnt and thematic recommendations, the study provides a way forward for the development of a roadmap for designing short-term research agenda, undertaking collaborative research and actions in the Asia-Pacific for better understanding and management of compound, cascading and systemic risks.

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1. INTRODUCTION

In the increasingly interconnected and globalized world, multiple hazard scenarios have been drastic reminders of the evolving nature of risk, manifested as compound, cascading and systemic risks. Conventional risks, coupled with the context of climate change and rapid urbanization, and increasingly interdependent supply chain and systems, have taken on unprecedented, often irreversible characteristics by becoming more intense, frequent, and complex. Over the past two years, the world has witnessed how the COVID-19 pandemic, along with various natural, and human-made hazards, has led to devastating direct and indirect impacts on the communities and infrastructures across sectors and countries. Further, it is observed that risk management is often too compartmentalized to delegate responsibilities at local, regional, and global scales (UNDRR, 2019). However, this compartmentalized risk assessment and management approach not only overlooks the linkage between the different elements of a system or inter-dependencies, but also the intersectionality of multiple dimensions of vulnerabilities and the fact that the failure in one element may lead to compound, cascading or systemic failures in other interconnected systems.

Therefore, it has become the need of the hour that the complex nature of risk and the interplay of its different dimensions (hazards, exposure, vulnerability) are analysed for deciphering impending risk patterns. This analysis can be comprehensively undertaken by bringing together the all-hazards and the whole-of-society approach to disaster risk governance. Such a comprehensive analysis can play an instrumental role in laying down risk-informed and effective policies and strategies for the management of complex risks.

1.1 ASIA PACIFIC REGION AND ITS RISK PROFILE: AN OVERVIEW

Due to its geographical and geological location, the Asia Pacific region is exposed to an intimidating array of natural and human-made hazards and is severely affected by disasters (UNESCAP, 2019). Since 1970, the region has accounted for 57 per cent of the global fatalities and 87 per cent of the global affected population from disasters induced by natural hazards (Figure 1). Between 1970 and 2020, such natural hazards in the region have affected 6.9 billion people and killed more than two million people, i.e., one life lost every 13 minutes. weather could do to them.

In 2018, when 315 disasters induced by natural hazards were recorded globally, the Asia Pacific region suffered the highest impact and accounted for 45 per cent of the disasters, 80 per cent of deaths, and 76 per cent of people affected. Of all the countries in the region, Indonesia recorded nearly half the total deaths, and India recorded the highest number of people affected (EMDAT, 2019).

The effects of potential hazards and their interactions with underlying socio-economic andecological conditions are reshaping an Asia Pacific risk-scape that is expanding and becoming ever more complex. The need for a holistic understanding of risks is more profoundly felt in the case of management or occurrence of multiple disasters simultaneously or sequentially in an area, underscoring the need for adopting the all-hazards and the whole- of-society approaches. For example, the Great East Japan Earthquake and Tsunami of 2011, coupled with underlying vulnerabilities and exposure, triggered the Fukushima nuclear disaster – a level 7 nuclear meltdown at the facility. As a result of this, the population and ecosystems were exposed to harmful radiation. In November 2020, during the ongoing COVID-19 pandemic, typhoon Goni made landfall in the Philippines, which resulted in crowding in the health centres, and triggered a far greater risk of transmission of the virus.The typhoon isolated several towns and damaged the main COVID-19 laboratory, resulting in the suspension of COVID-19 testing (UNESCAP, 2021a). Similarly, many states in India witnessed the surge in COVID-19-positive cases during recent floods (Assam) and cyclones (Odisha and West Bengal). This begs the question of enhancing the overall resilience and ensuring the continuity of services of critical infrastructures such as electric power stations which, if they fail, will inevitably affect the critical operational performance of the health infrastructure for treating infected patients (e.g., oxygen concentrators, Intensive Care Units, etc. in a hospital). Thus, while the COVID-19 pandemic raged on, the Asia Pacific region continued to battle other hazards. This brings forth the complexities in the management ofmulti-hazard risks, cascading and compound disasters in the context of increasingly interconnected systems, and calls for a better understanding of all its dimensions and their complex interactions. The same is also underscored under the priorities of action of the Sendai Framework for Disaster Risk Reduction (SFDRR) and in the Global Assessment Report (GAR) of 2019. Against this backdrop, the need for understanding the emerging disaster-climate-health-urbanization nexus through an informed systems approach to Disaster Risk Management (DRM) cannot be overemphasized (CRED, 2021; UNESCAP, 2021a).

On one hand, poverty, rapid urbanization, weak risk governance, the decline of ecosystems, and climate change exacerbate the complex nature of risk. On the other hand, complex risks and their manifestations not only push back the years and decades of development gains but also act as an impediment to sustainable development (IRP, 2020). This raises the need for embedding risk management into sustainable development for creating the resilient and sustainable future enshrined in the 2030 Agenda for Sustainable Development.

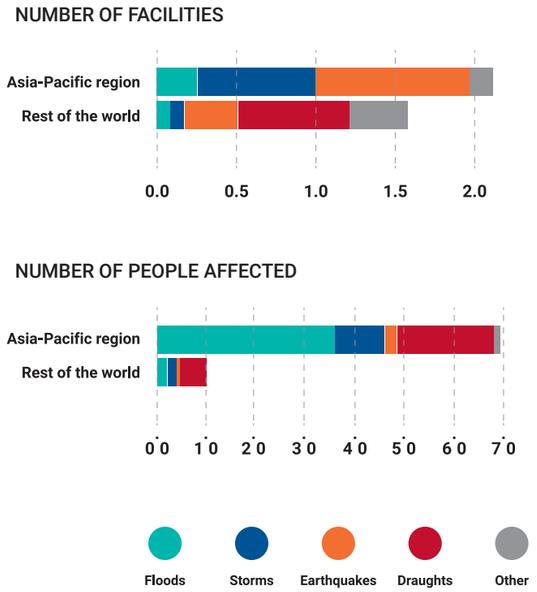

Figure 1: No. of fatalities and people affected in the Asia Pacific region and the rest of the world (1970 to 2020)

(Source: UNESCAP, 2021a)

1.2 SCOPE AND OBJECTIVES

With increased recognition and discourse on the pluralistic nature of risk, it is imperative that the compound, cascading and systemic nature of risk is adequately understood and analysed for comprehending inherent and impending risk patterns. This comprehensive understanding of risk is a precursor for laying down effective frameworks, policies, and strategies for its assessment, reduction, and management. This puts forth the need for not only studying the existing terminologies, explanations and literature on such risks, but also mapping their past and predicted manifestations in the Asia Pacific region.

The scoping study aims to understand and address this complex nature of risk, to accelerate solutions for building resilience. It envisages fulfilling the following key objectives:

- To analyse and learn from good practices.
- To understand gaps and key challenges.
- To develop a framework for strengthening the governance of compound, cascading and systemic risks.

Figure 2: Map showing locations of case studies

1.3 METHODOLOGY

The scoping study takes a case-study-based approach, augmented by an intensive literature review, to understand the complex nature of risk and its management in the region. Forty case studies of past disasters portraying compound, cascading and systemic risks were received from authors and organizations in sixteen countries of the region, namely: Australia, China, Fiji, India, Indonesia, Japan, Malaysia, Nepal, New Zealand, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vanuatu and Vietnam, as shown in Figure 2. The case studies are aimed at capturing the lessons from past disasters in different countries of the region, in the relationship between the triggering and triggered hazards; multi-dimensional vulnerabilities and complex interactions therein; characteristics of the relationship between trigger and impacts; multi-dimensional impacts and interactions amongst the systems affected. Besides, case studies provide the diverse measures undertaken for managing the associated risks before, during, and after the hazard event. The template used for the case study submissions placed in Annexure A. Annexure B and C provide an overview of the case studies used in the study and their respective summaries.

The overall methodology of the study involves the following steps (Figure 3):

- Review of existing literature.
- Development of a framework for case study analysis, guided by the literature review.
- Review of the invited case studies.
- Data analysis resulting in the identification of gaps, lessons learnt, and recommendations.

- Consultation with regional experts (details placed in Annexure D).
- Formulating principles and a framework for strengthening the governance of compound, cascading and systemic risks.

1.4 CURRENT KNOWLEDGE BASE

A thorough literature review through keyword search on ScienceDirect was undertaken to analyse the temporal trend change in the publications concerning compound, cascading and systemic risks.

The keywords used for the search are as follows:

- "compound risk" OR "compound disaster"
- "cascading risk" OR "cascading disaster"
- "systemic risk"

Based on the keyword searched for, ScienceDirect categorized the available publications across the subject areas of Medicine and Dentistry, Biochemistry, Genetics and Molecular Biology, Immunology and Microbiology, Pharmacology, Toxicology and Pharmaceutical Science, Neuroscience, Nursing and Health Professions, Environmental Science, Agricultural and Biological Sciences, Veterinary Science and Veterinary Medicine and Social Sciences. Out of the total publications, the relevant publications, mostly belonging to the subject areas of Environmental Science and Social Sciences, were mapped. The temporal trend from 2000 to 2021 (as of 1 st November 2021) of relevant literature on the compound, cascading and systemic risks and the types of these publications, is shown below in Figures 4 to 6.

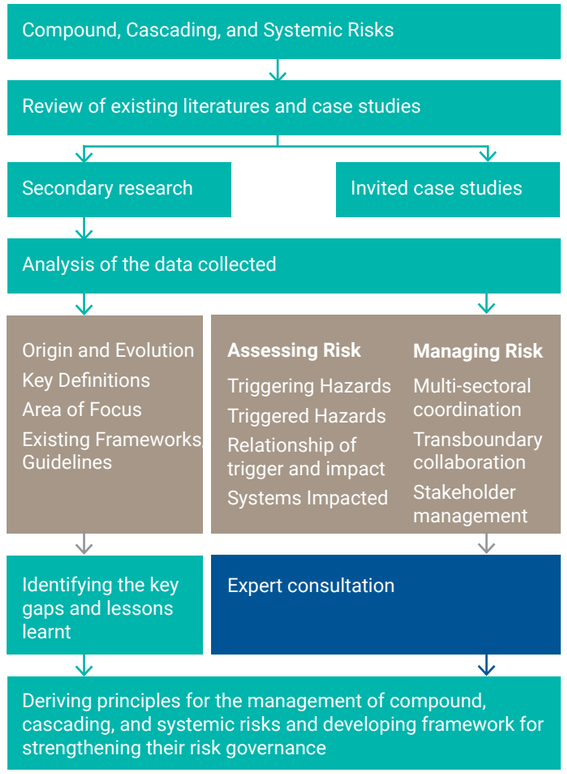

Figure 3: Methodology for the scoping study

In the existing knowledge base, research articles form the major share of publications, followed by review articles for all three categories of risk. Conference proceedings, book chapters, etc. were found to be the other types of publications.

The findings emerging from the literature review suggest that there has been a key positive shift in the academic interest concerning compound, cascading and systemic risks. It has thus been noted that from 2000 to 2021 relevant publications on compound risk increased from 89 to 936; those on cascading risk increased from only 5 to 130, and those on systemic riskincreased from only 8 in number to 145 (Figures 4 to 6).

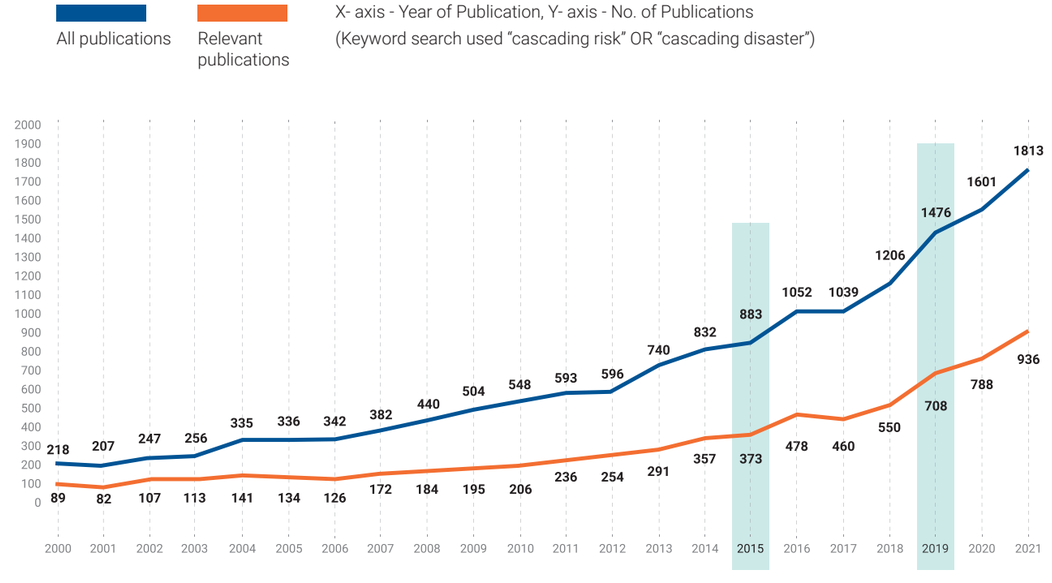

Figure 4 (a): Temporal trend of relevant publications on compound risk/ disaster

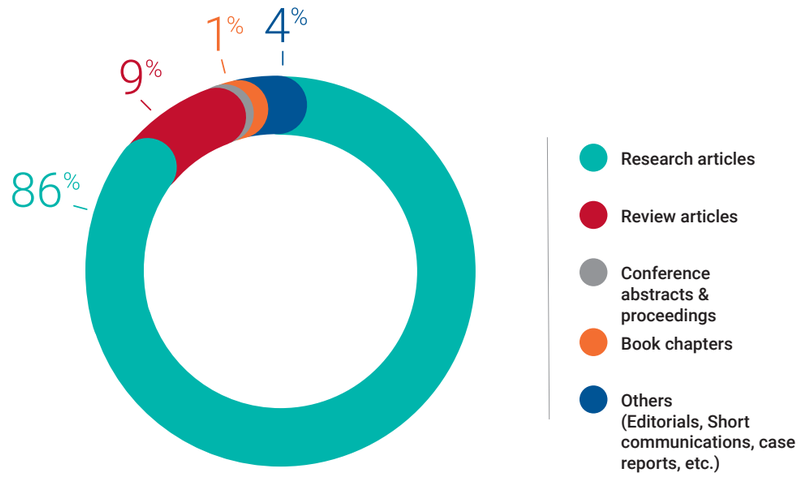

Figure 4 (b): Types of relevant publications on compound risk/ disaster

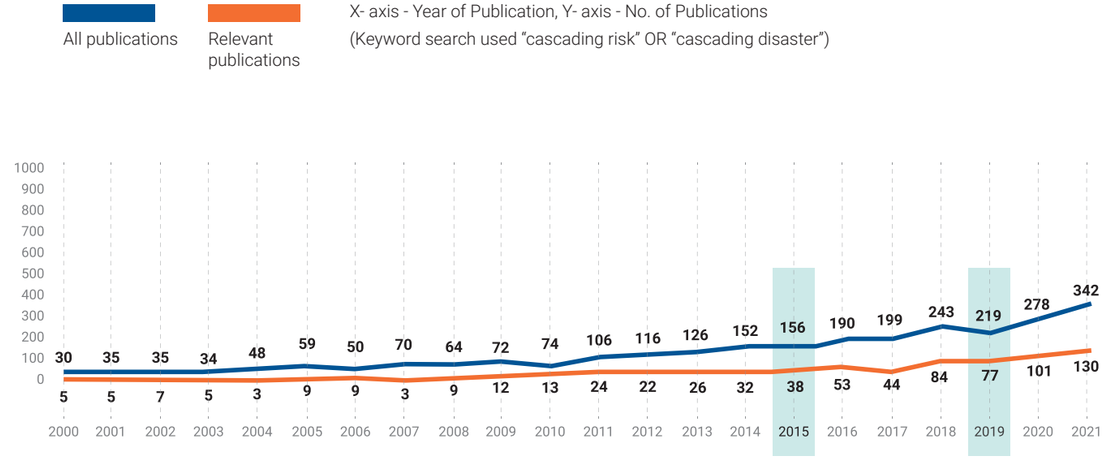

Figure 5 (a): Temporal trend of relevant publications on cascading risk/ disaster

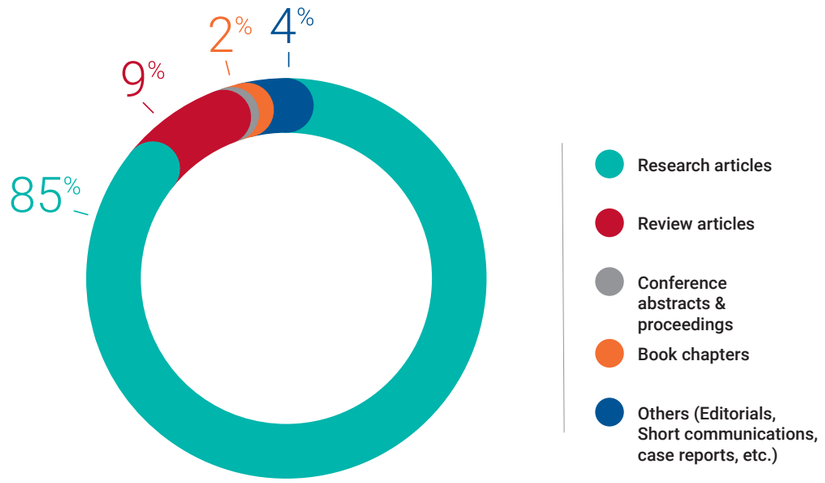

Figure 5 (b): Types of relevant publications on cascading risk/ disaster

In the existing knowledge base, research articles form the major share of publications, followed by review articles for all three categories of risk. Conference proceedings, book chapters, etc. were found to be the other types of publications.

The findings emerging from the literature review suggest that there has been a key positive shift in the academic interest concerning compound, cascading and systemic risks. It has thus been noted that from 2000 to 2021 relevant publications on compound risk increased from 89 to 936; those on cascading risk increased from only 5 to 130, and those on systemic risk increased from only 8 in number to 145 (Figures 4 to 6).

This shift, especially since 2011, could be associated with the discourses concerning cascading and systemic risks after disasters such as the Great East Japan Earthquake and Tsunami of 2011, and the introduction of novel outlooks and frameworks such as the Sendai Framework 2015-30 and the GAR 2019, which have invigorated research into these areas.

Therefore, the years 2015 and 2019mark the increasing trend of publication for each of the three categories of risk discussed in this study. Moreover, in the case of compound risk, the availability of publications has beenon the higher side, since 2000, in comparison to those on cascading and systemic risks.

While the concepts of compound, cascading and systemic risks are not new to the disaster risk management field, there has been a resurgence in their interest due to three factors:

7. the potential of such risks to spur on widespread disruptions to global societies and economies because of the interconnectedness between the systems.

8. frequent recurring of these types of interconnected disasters every year.

9. each system or stakeholder group with their knowledge or approaches, engage differently or individually with these hazards (Cutter, 2018).

Some of the key available literature on the three categories of risk were studied and the findings thereof are discussed in detail, in Sections 2 and 3.

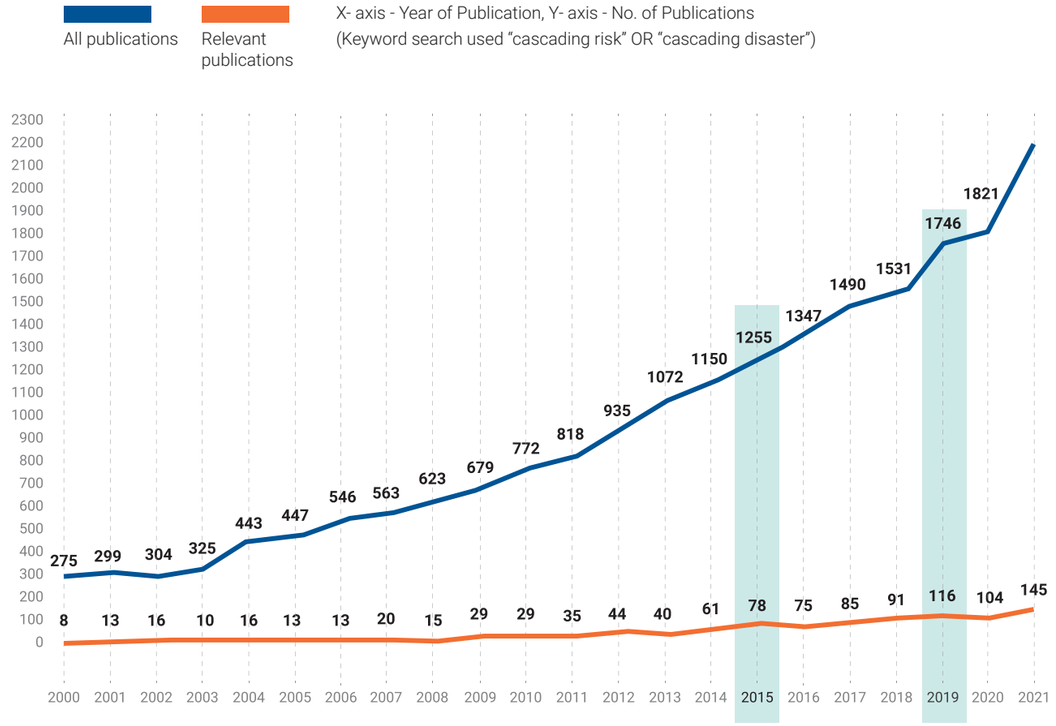

Figure 6 (a): Temporal trend of relevant publications on systemic risk

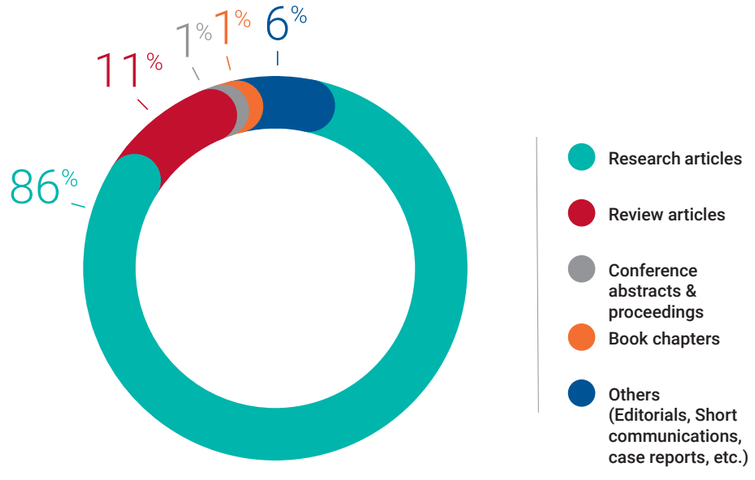

Figure 6 (b): Types of relevant publications on systemic risk

2

UNDERSTANDING COMPOUND AND CASCADING RISKS

2. UNDERSTANDING COMPOUND AND CASCADING RISKS

Compound risk is associated with the interaction of socially constructed vulnerable conditions with potential compound effects that may arise from the simultaneous occurrence of two or more events. These events are independent of each other and one is not the causal factor for the other (Zaidi, 2018). Cascading risk can be understood as the risk posed by sequential occurrences of two or more events, where the first event triggers one or more events.

2.1 ORIGIN AND EVOLUTION

The concept of compound risk mainly involves the risk of hazard events that occur simultaneously, and are combined with conditions that amplify the overall impact. The reported examples of compound risks include high sea-level rise coincident with tropical cyclones, or the impact of heatwaves on wildfires (Pescaroli & Alexander, 2018). A very clear example is the ongoing COVID-19 pandemic, coupled with floods, cyclones or locust attacks, in different parts of the world.

In cascading disasters, one or more events can be identified and distinguished from the source of disaster. One of the earliest usages of the term 'cascading disasters' stemmed from the consequences of the 2011 Great East Japan Earthquake and Tsunami which, coupled with underlying vulnerabilities, led to the radioactive contamination of the Fukushima nuclear reactors. Since then, the concept has been widely used among researchers and practitioners. To explain a sequence of interconnected failures, the word 'cascading' is often associated with the metaphor of toppling dominoes, which may have an impact on the 'cause and effect' relationship that is a feature of most catastrophic events.

Cascading risk has been referred to as 'uncontrolled chain losses' in disaster risk management studies (Pescaroli and Alexander, 2018). Amidst the high level of interdependency in different socio-economic and ecological systems of the society, when vulnerabilities overlap and interact, escalation points are created that can trigger secondary effects that are greater than or equal to the impact of the primary event. This allows the impact of disasters to penetrate across different sectors of the economy and sections of society. Rinaldi (2004) discussed the cascading failures associated with critical infrastructures and suggested key recommendations for modelling frameworks for analysing the interdependencies, regulating the risk patterns in critical infrastructures, and promoting effective policies. Conrad et al., (2006) discussed cascading effects on the power sector, telecommunication services, and emergency services, and noted that there are huge financial implications of power outages, due to cascading effects that follow. Similarly, studies such as those conducted by Peters et al. (2008) and Rose (2009) studied the cascading effects of infrastructural failures on subsequent systems through models. It should also be noted that cascading risk patterns may contribute to systemic risk if they are poly-synchronous in nature (UNDRR, 2019). Poly-synchronous events refer to simultaneous disruptions (events) in a system or systems. Thus, compound and cascading risks may lead to systemic failure but not all systemic failures are a result of compound and cascading risks.

"Compound risk is the interaction of simultaneous or successive multiple hazards or events that combine to produce extreme disasters capable of generating widespread losses."

- IPCC, 2012

2.2 KEY DEFINITIONS AND EXPLANATIONS OF COMPOUND AND CASCADING RISKS

As per Pescaroli & Alexander (2018), compound events are:

1. extremes that occur simultaneously or successively

2. extremes combined with background conditions that amplify their overall impact, or

3. extremes that result from combinations of 'average' events.

In other words, compound risk has been referred to as the risk associated with multiple hazard events that: can occur simultaneously or successively; can be combined with background conditions that amplify the overall impact or can be as a result of the combination of average events. The heatwaves of 2020 in Northern India highlight the compounding impact of heatwaves and locust attacks in a pandemic stricken, over-stressed system, and underscore the need for effective resource mobilization across sectors such as healthcare, robust administrative mechanism, and so on.

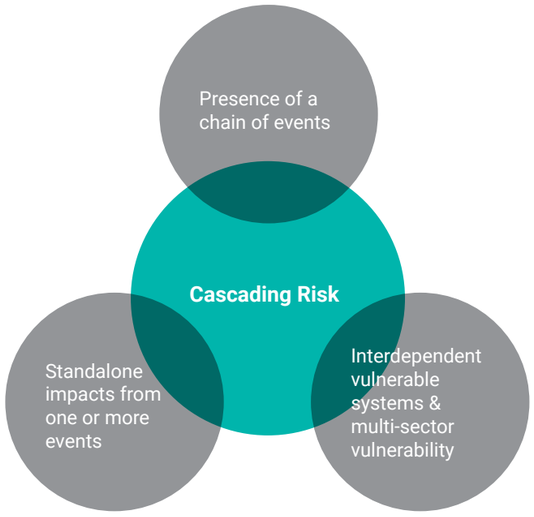

Figure 7: Key characteristics of cascading risk

"Cascading risk remained a fragmented subject that lacked both official definition and an inter-governmental dimension."

- Pescaroli & Alexander (2018)

In the aftermath of a hazard event, subsequent crises can be exacerbated by the failure of physical structures and the socio-economic functions that depend on them, or by the inadequacy of disaster risk governance strategies. May (2007) notes that to understand the path of a cascade, three contributing factors must be taken into account, namely, the interactions in the system, the context of the event, and the triggering event. The key characteristics of cascading risk are illustrated in Figure 7. Cascading disasters are often found to be correlated with the involvement of interdependent vulnerable systems such as supply chains, infrastructural systems, and critical infrastructures that cascade the effect and the spread of impacts when there are pre-existing vulnerabilities that aggravate consequent failures. It is to be noted that cascading failures in critical

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infrastructures can happen rapidly and over large areas due to their interdependent functioning at multiple scales, and do not occur alone in silos (Ouyang, 2014). Disruption or destruction of critical infrastructure can have a significant impact on the health, safety, security, economy, and social well-being of a community (Zio, 2016).

Key definitions of compound and cascading disaster/risk are listed in Table 1.

2.3 FRAMEWORKS, APPROACHES, AND GUIDELINES ON THE MANAGEMENT OF COMPOUND AND CASCADING RISKS

Much literature is available on compound and cascading risk analysis. While the Sendai Framework does not explicitly mention the terms compound and cascading risk, it is instrumental in the promotion of the multi-hazards approach for risk assessment, planning, and management. The risks associated with a chain of events, as discussed, have complexities that make them difficult to comprehend. Thus, the framework emphasizes understanding the risk in all its dimensions. It underscores the multi-hazard approach[1] of assessing and managing disaster risk, addressing underlying drivers such as societal aspects to keep a check on compounding risks, and so on, in its priorities. Another similar approach is an all-hazards approach[2]; which also challenges the conventional single hazard[3] approach. Additionally, some researchers have also proposed a top-hazards approach that specifies that hazards should be prioritized according to their scale of risk and then dealt with so that the top-ranking hazards are given priority in planning activities (Bodas et al., 2020).

The Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (IPCC, 2012) offers a detailed discussion on compound risk and underscores the interaction between impacts that may become extreme due to the combination of two or more events which are occurring simultaneously or successively. Multi-hazard risk management approaches provide opportunities to reduce compound and cascading hazards, both in rural and urban contexts. For example, drought, coupled with extreme heat and low humidity, can increase the risk of wildfire (IPCC, 2012) and such risk can only be captured and addressed through a multi-hazard approach.

The GAR 2019 (UNDRR, 2019) provides a detailed discussion on cascading risks. It underscores the urgency of mitigating and repairing impacts from realized cascading consequences so that systems are less susceptible to collapse. The report puts forth the fact that cascading effects can be devastating, chaotic, and occur over potentially prolonged periods. This is because of the presence of a chain of events, with each of the events having the potential to cause stand-alone effects on the system that can influence social, economic, physical, environmental, or institutional or governance vulnerabilities, leading to an escalation. Vulnerabilities and exposure of the system are key in determining their susceptibility to potential effects, impacts and escalations. Therefore, there is a need to understand and assess the compound and cascading nature of risk for better management of risks and their dimensions.

1 Multi-hazard approach – Considering more than one hazard at any time

2 All-hazards approach – Considering all possible hazards
According to the World Health Organization (WHO), "All-hazard approach is the approach that covers risk reduction, emergency preparedness, response actions and community recovery activities regarding the related natural, technological, societal issues regardless of the cause when a health system is challenged."

3 Single hazard – Considering one hazard at a time

3

UNDERSTANDING SYSTEMIC RISK

3. UNDERSTANDING SYSTEMIC RISK

Systemic risk is the culmination of various risk patterns, including cascading and compound risk. It generally remains unidentified and hence unaddressed, as it is not considered a risk in itself. However, when some of the characteristics of the system change, systemic risk has the potential to adversely impact the functioning of the overall system. Systemic risk is a significant challenge that demands more sustained and rigorous approaches due to the overlapping of hazards and the interconnectedness of various systems and economies at different scales. It is better understood through a systems approach[4] (UNDRR, 2019).

3.1 ORIGIN AND EVOLUTION

One of the earliest pieces of literature on systemic risk is in the financial sector. The earlier discussions on systemic risk can be traced back to the 1990s when the banking systems were flourishing and large markets were opening up. Systemic risk has remained a pivotal aspect of Economics for over decades. (Dijkman, 2010) suggests 'contagion' as a core characteristic of systemic risk patterns that can trigger losses in the economies. Experts cite the financial crisis of 2008, which was triggered by the collapse of Lehman Brothers, USA, as an aftermath of unregulated systemic risk.

> *"Systemic risk is defined as the likelihood that cumulative losses will occur from an event that triggers a series of successive losses along a chain of institutions or markets."*
>
> **– Kaufman (1996)**

While these discourses existed around financial aspects, researchers such as de Bandt and Hartmann (2000) have, in the early 21st century, suggested that systemic risk is also prevalent in other fields such as health. The emerging complex risk patterns have opened up debates on systemic risk in fields outside economics and finance, mainly in disaster risk management and climate change action. OECD (2003) was one of the earliest reports on systemic risk patterns associated with disasters. The report suggested various driving factors of systemic risk, such as demography, environmental challenges (such as climate change), advancement in technology, and socio-economic structures. In recent times, various reports such as those by IRGC (2018) and UNDRR (2019) continue to discuss the issue under the purview of disaster risk management and climate change action.

3.2 KEY DEFINITIONS AND EXPLANATIONS OF SYSTEMIC RISK

> *"Systemic risk is characterized by linkages and interdependencies in a system, where the failure of a single entity or cluster of entities can cause cascading impacts on other interlinked entities."*
>
> **– IPCC (2012)**

The IPCC (2012) report suggests that systemic risk could have global and transboundary impacts where the actions in one country tend to impact another.

4 Systems approach calls for understanding the connections within components of a system and between different systems, prioritizing the components and system whose resilience is most critical, mapping the threshold of each component/system through stress testing steps. This captures the dynamics of systems within systems, and informs robust risk governance mechanisms.

> *"Systemic risks are threats that individual failures, accidents or disruptions present to a system through contagion."*
>
> **– IRGC (2018)**

The IRGC (2019) report suggests that systemic risk is characterized by complexities and fat-tailed events that can trigger large-scale changes to the existing systems.

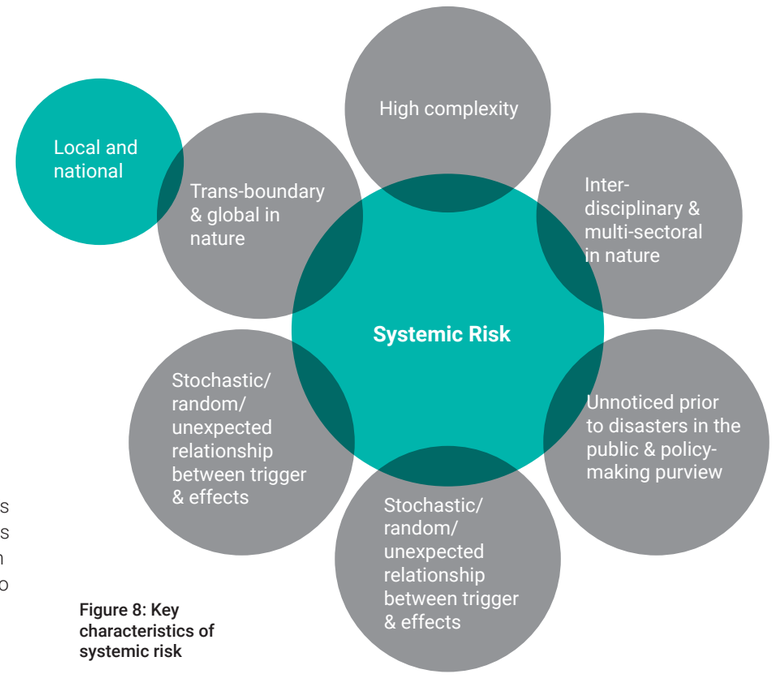

Figure 8: Key characteristics of systemic risk

> *"Systemic risk is endogenous to, or embedded in, a system that is not itself considered to be a risk and is therefore not generally tracked or managed, but which is understood through systems analysis to have a latent or cumulative risk potential to negatively impact overall system performance when some characteristics of the system change."*
>
> **– UNDRR (2019)**

Schweizer (2019) puts forward the fact that risks become systemic based on five characteristics. Additionally, multiple pieces of literature state that systemic risk is interdisciplinary and multi-sectoral in nature and demands a systems approach for its management (Renn, 2016; Renn et. al., 2019 & 2021).

Accordingly, these are some of the characteristics of (global) systemic risk (Figure 8):

- High level of complexity, characterized by interconnections.
- Transboundary and global in nature.
- Stochastic relationships between trigger and effects.
- Systemic developments are non-linear, with tipping or trigger points.
- Often unnoticed in the public policy-making purview because of uncertainties of point of occurrence and the extent of damage.
- Inter-disciplinary and multi-sectoral in nature.

In reference to the characteristics of systemic risk being transboundary and global in nature, the recent work done by UNDP (2021) brings forth some alternative insights. It highlights that systemic risk, like any other risk, is socially constructed and exists even at the local scale. It further raises the concern that systemic risk is often associated with the global risk in financial systems, global supply chains and economic infrastructures, while the quotidian systemic risks prevailing at local and national level, particularly in low- and middle-income countries often go unnoticed and unaddressed (UNDP, 2021). These include failure or disruptions in the local supply chain, infrastructural systems or ecosystem services, etc. In fact, systemic risk has always been there at local and national scales. Now, with increased and complex interconnections, its manifestation and impact tend to get magnified and are often visible as global systemic risk (ibid). This alludes that such local and national manifestations of systemic risk, and even localized hazard events with the potential to trigger systemic risk, can be best mitigated and managed at local and national scales.

Denyer & Sutliff (2021) talk about the threats and systemic risks involved with the growing interdependence between different elements in a system. The authors recommend the following key aspects to strengthen the resilience of such a system:

- Discussing failures to avoid dissatisfaction in the future.
- Considering the connections and potential effects among different sectors.
- Prioritizing factors whose resilience is most important to the society.
- Setting the maximum tolerable limits of an impact that a sector can face, through stress testing of the sectors.
- Balancing efficiency and innovation for strengthening systemic resilience.

The strongly connected global networks with highly interdependent systems are not understood well and hence cannot be controlled in a timely manner, making them vulnerable to failure at all scales, and posing serious threats to society (Helbing, 2013). The GAR 2019 notes the prevailing unplanned and unsustainable patterns and practices of growth in varied sectors. This results in the creation of systemic risks that often go unnoticed until they become strong enough to disrupt and adversely affect an entire system and its functioning. This, therefore, makes systemic risk a strong impediment to sustainable development (UNDRR, 2019).

Literature suggests that systemic risk patterns show certain characteristics that help in comprehending the issue. One of them is the complex interconnection within and across systems such as social, financial, physical, institutional, and environmental. The risk patterns are characterized by building stressors, such as urbanization, environmental degradation, vulnerabilities of lifeline infrastructure and health systems (Chan, et al., 2021) that can adversely influence the normal functioning of the system. The accumulation of these stressors and their adverse effects beyond a point (often called a tipping point) may eventually cause the system's breakdown. A tipping point can be understood as a point where the system can no longer cope with the building stressors, and any further changes to the dynamics of the system have the potential to trigger significant disruption or even complete collapse of the system. As noted earlier, a good example of such interconnected systems is the 2008 financial crisis, which crippled the world economy (Smaga, 2014). In the aftermath of Hurricane Katrina in 2005, oil prices rose not only in the United States, but also as far as Canada and the United Kingdom, illustrating the systemic nature of financial and economic impacts from the disaster. Additionally, the case of successive droughts in the Anantapur district, Andhra Pradesh, India, highlights a key linkage of social and gender instability associated with drought in an agrarian community. The study suggested that the drought eventually led to an agricultural crisis, stress migration, and farmer suicides, that eventually led to female drop-outs from educational institutions, exploitation, and trafficking at national and international scales under the pretext of domestic-worker recruitment, thus highlighting the disruption and failure in multiple systems. GAR 2019 highlights that climate change is now being increasingly recognized as a systemic risk with the potential to trigger catastrophic effects across systems such as financial, ecological, and social (UNDRR, 2019).

In conclusion, the term focuses on inherent risk patterns, characterized by multi-spatio-temporal, complex, and unidentifiable risk patterns that can eventually lead to a systemic breakdown and reformation. To make these systems manageable, a fundamental paradigm shift in collective thinking and knowledge is required, since, as mentioned by Hewitt (1997), 'risk resides in the fabric of everyday life'. Thus, the concept of systemic risk is interdisciplinary and multi-sectoral, and its management calls for a deeper understanding of the functioning of interconnected and interdependent systems.

3.3 FRAMEWORKS, APPROACHES AND GUIDELINES ON THE MANAGEMENT OF SYSTEMIC RISK

The Sendai Framework does not explicitly mention the term systemic risk. However, the framework does lay emphasis on multi-sectoral aspects of managing risks and disasters, understanding risk in all its dimensions, and so on, in its priorities for action. The Sendai Framework promotes a holistic understanding and governing of the dynamic nature of risks, yet many countries lack the means to assess and manage risks in an integrated manner, mainly due to obstacles faced in the coordination and collaboration between individuals and the authorities (Mofazali and Jahangiri, 2018). This can be overcome by imbibing the whole-of-society approach for not only risk management but also for better understanding of exposure, vulnerability, and capacities of different sections of society and stakeholders belonging to multiple sectors. Such an all-inclusive approach underpinning the leave-no-one-behind principle is crucial for the management of systemic risk (which can have far-reaching detrimental impacts across society).

The GAR 2019 (UNDRR, 2019) provides a detailed discussion on systemic risk. It underscores the need for a decentralized, transdisciplinary, integrated, and multi-sectoral mechanism of disaster risk governance for addressing systemic risk. It puts forth a systems approach to address the systemic changes different systems (such as land, industries, ecosystem, urban areas) are undergoing. This approach can help in mapping, assessing, prioritizing, and managing risk prevailing across the interactions and inter-linkages of the existing systems. Such risk, due to its dynamic, multi-dimensional, and complex nature, also calls for a multi-hazards approach to risk assessment and management. Besides, due to its inherent potential to

HAZARD	EXPOSURE	VULNERABILITY	SCALE	SYSTEMS
Earthquake	Structural	Economic	Global	Human
Volcano	Agriculture	Social	Regional	Ecological
Tsunami	Basic service	Environmental	National	Economic
Flooding	Housing	Governance	Sub-national	Political
Draught	Critical Systems	Legal	Metropolitan	Cultural
Fire	Subsystems	Security	Local	Financial
Biological	Natural capatical			
Chemical				
Industrial				
NATECH				
Nuclear				
Radiaolgical				

Figure 9: Global Risk Assessment Framework (GRAF 2020 – 2030)
(Source: UNDRR, 2019)

have an impact across geographical boundaries, there is a need to understand and address the systemic nature of risk at various scales – local, national, regional, and global.

This complex interaction between different risk factors has been taken into consideration in the Global Risk Assessment Framework (GRAF) (Figure 9) underscored in the GAR 2019 (UNDRR, 2019). This paradigm shift in the risk assessment – from the Hyogo Framework of 2005 to the Sendai Framework of 2015 to the GRAF 2020+ – is much needed to manage systemic risk rather than the mere management of conventional hazards and associated risks. Therefore, GRAF has been designed to focus on the risk management actions at different scales of exposure and vulnerabilities associated with the multiple hazards and their effects on the different systems, to improve the understanding of systemic risk and guide the decision-makers and policymakers to lay down risk-informed policies and strategies.

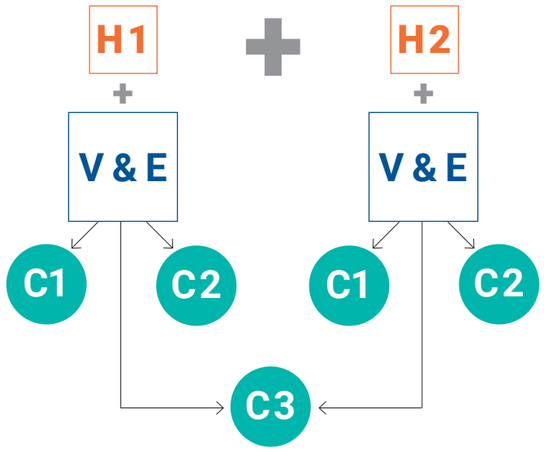

Figure 10 (a): Understanding compound risk

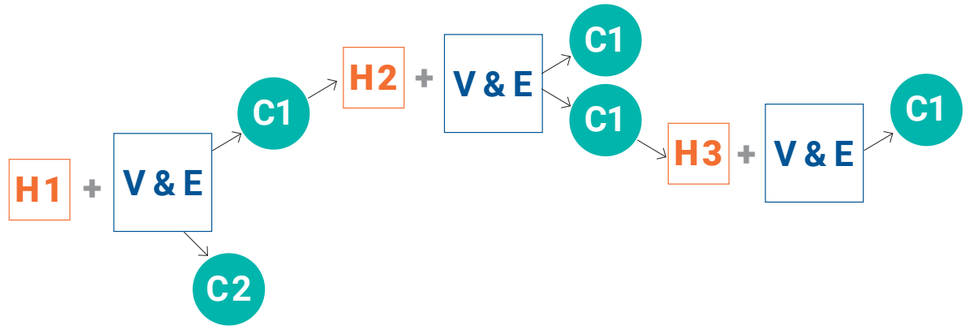

Figure 10 (b): Understanding cascading risk

3.4 COMPOUND, CASCADING AND SYSTEMIC RISKS: AN OVERVIEW

The three types of risks explained in Sections 2 and 3 above can be conceptualized through the following Figure 10 (a-c), where H, H1, H2, H3 = hazard events; V & E = vulnerability and exposure; CI, C2, C3 = consequences or effects; S1, …, S5= systems; and St1, …, St4= stressors. In the case of compound risk, simultaneous hazard events take place followed by their respective or combined consequences. Cascading risk is characterized by a chain of hazard events that may take place and the consequences thereof. In case of systemic risk, hazard events may act as stressors or further exacerbate the stressors acting on the different interdependent systems or may even act as a tipping or trigger point resulting in disruption or collapse of the entire system. Table 1 below gives an overview of the key characteristics of these risks.

The findings from the literature review suggest that compound, cascading and systemic risks can be associated with the cross-scale accumulation of vulnerability paths constituted by events waiting to happen (Pescaroli et al., 2018). This makes it important to assess these risks at the local, national, regional and global scales through a systems approach where all the components of a system are considered and dealt with holistically to strengthen its resilience (UNDRR, 2019). This will help improve the assessment of related exposure and vulnerabilities across multi-spatio-temporal scales (Zaidi, 2018). However, this cannot be achieved effectively without the multi-hazards and whole-of-society approach. Besides, disaster risk management strategies should be able to address both short-term and long-term risks and should be duly integrated with climate change adaptation policies and ecosystem-based DRR[5] (UNESCAP, 2021a).

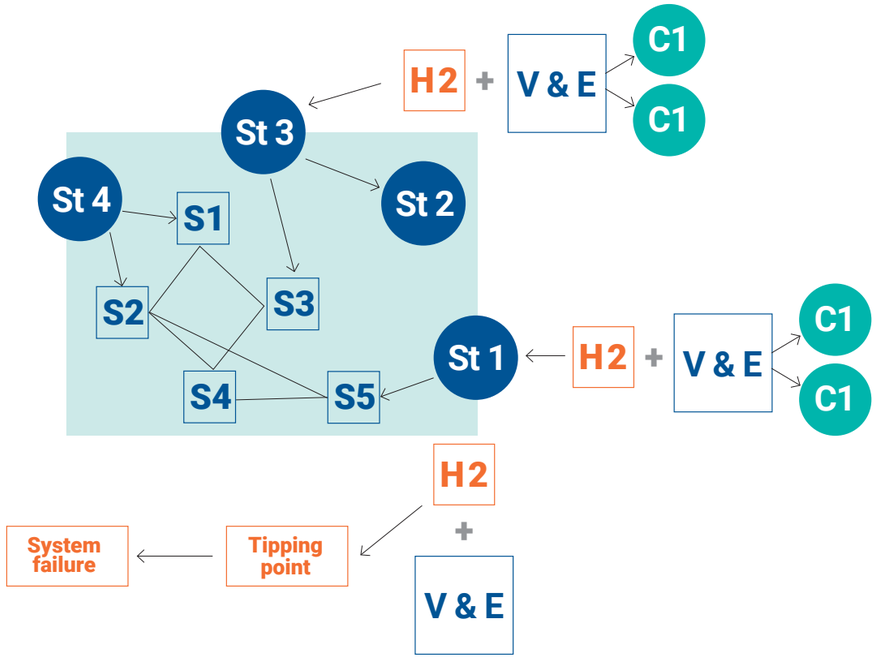

Figure 10 (c): Understanding systemic risk

5 Ecosystem-based DRR is the sustainable management, conservation, and restoration of ecosystems to provide services that reduce disaster risk by mitigating hazards and by increasing livelihood resilience (IUCN, 2021)

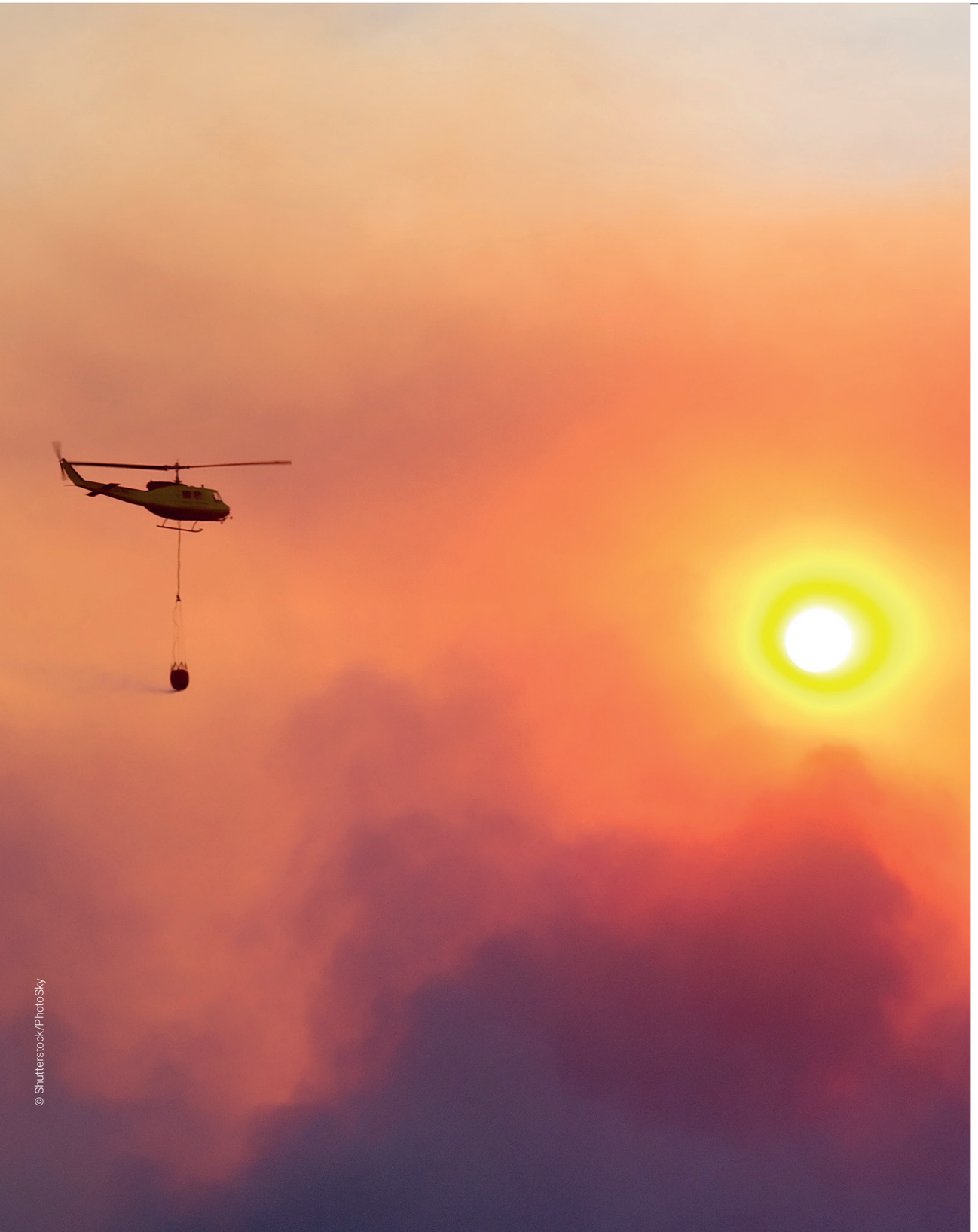

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Table 1: Key definitions and characteristics of compound, cascading and systemic risks

Key definitions	Key characteristics
Compound risk is defined as "Two or more extreme events occurring simultaneously or successively, combinations of extreme events with underlying conditions that amplify the impact of the events, or combinations of events that are not themselves extremes but lead to an extreme event or impact when combined." – **IPCC in SREX 2012 report**	• Simultaneous or successive • Combination of multiple events leading to severe impacts • Events are independent of each other
"**Cascading disasters** are extreme events in which cascading effects increase in progression over time and generate unexpected secondary events of strong impact. These tend to be as serious as the original event, and contribute significantly to the overall duration of the disaster's effects. These subsequent and unanticipated crises can be exacerbated by the failure of physical structures and social functions that depend on them. In cascading disasters one or more secondary events can be identified and distinguished from the original source of disaster." – **Pescaroli and Alexander, 2015** "**Cascading effects** are the impact of a physical event or the development of an initial technological or human failure that generates a sequence of events in human sub-systems that result in physical, social, or economic disruption. Thus, an initial impact can trigger other phenomenon that lead to consequences with significant magnitudes. Cascading effects are complex and multi-dimensional and evolve constantly over time. They are associated more with the magnitude of vulnerability than with that of hazards. Low-level hazards can generate broad chain effects if vulnerabilities are widespread in the system or not addressed properly in sub-systems." – **Pescaroli and Alexander, 2015**	• Chain of events • Stand-alone impacts of each event • Multisector vulnerability
Systemic risk is defined as "Endogenous to, or embedded in, a system that is not itself considered to be a risk and is therefore not generally tracked or managed, but which is understood through systems analysis to have a latent or cumulative risk potential to negatively impact overall system performance when some characteristics of the system change." **– UNDRR in GAR 2019**	• Complex • Can prevail at all scales • Random and unexpected • Non-linear with tipping points • Unnoticed prior to disasters • Failure of a system

4

CONCEPTUAL FRAMEWORK AND ANALYSIS

4. CONCEPTUAL FRAMEWORK AND ANALYSIS

The framework used for the analysis of the case studies is guided by a thorough review of literature on compound, cascading and systemic risks and their management. The framework consists of two steps. The first step helps in analysing the case studies for understanding the compound, cascading and systemic risks (Figure 11) while the second step is aimed at analysing the aspect of management of compound, cascading and systemic risks in the case studies (Figure 12).

- In the first step (Figure 11), 40 case studies received were analysed to understand compound, cascading and systemic risks. This was done by undertaking (a) Trigger analysis (b) Studying the relationship between trigger and impacts and (c) Impact analysis. Under trigger analysis, the cases were studied for the types and speed of onset of the triggering hazards along with understanding the underlying vulnerabilities, their dimensions and complex interactions, therein. Further, the triggered hazards, their key types and interplay were studied through different cases received.

Thereafter, the key characteristics of the relationship between trigger and impacts as identified through literature review on compound, cascading and systemic risks were studied through the cases. Further, under the impact analysis, the triggered hazards were studied to understand their scale, duration, types, and systems affected and their inter-dependencies.

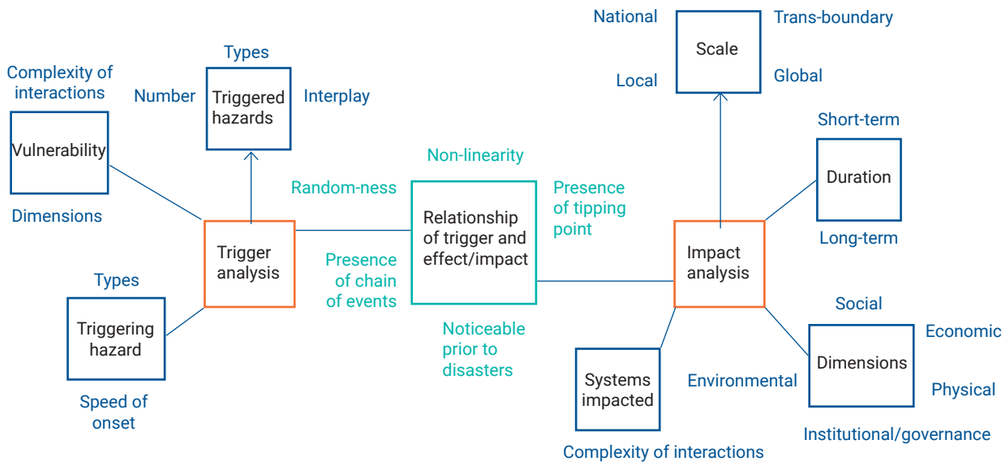


Figure 11: Conceptual framework for analysis of compound, cascading, and systemic risks

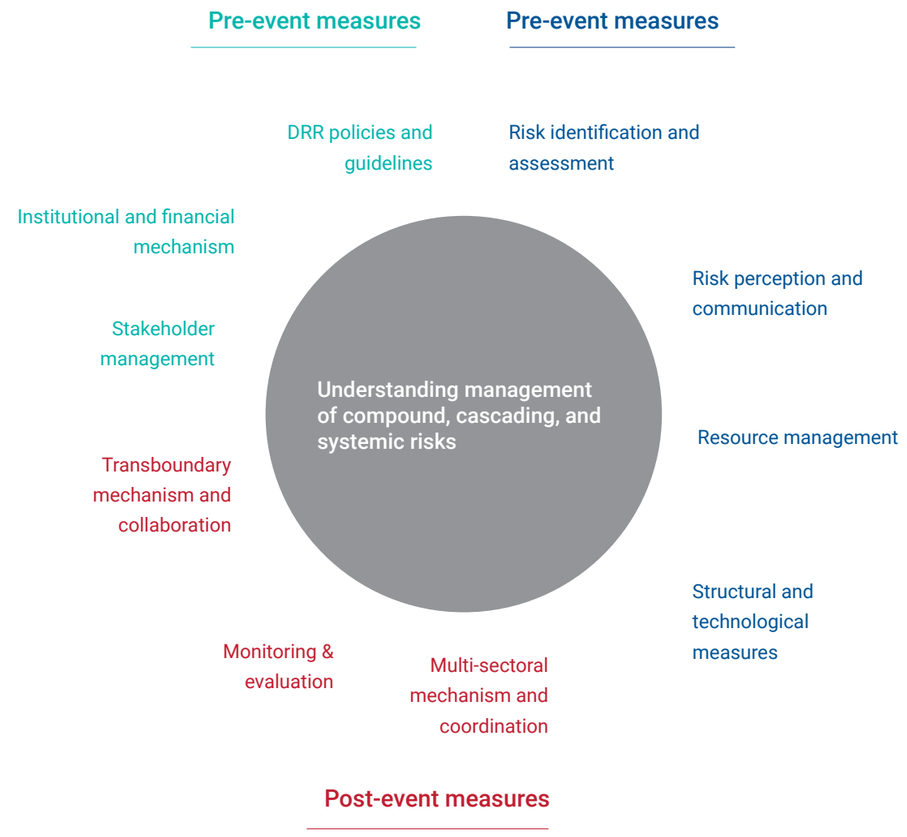


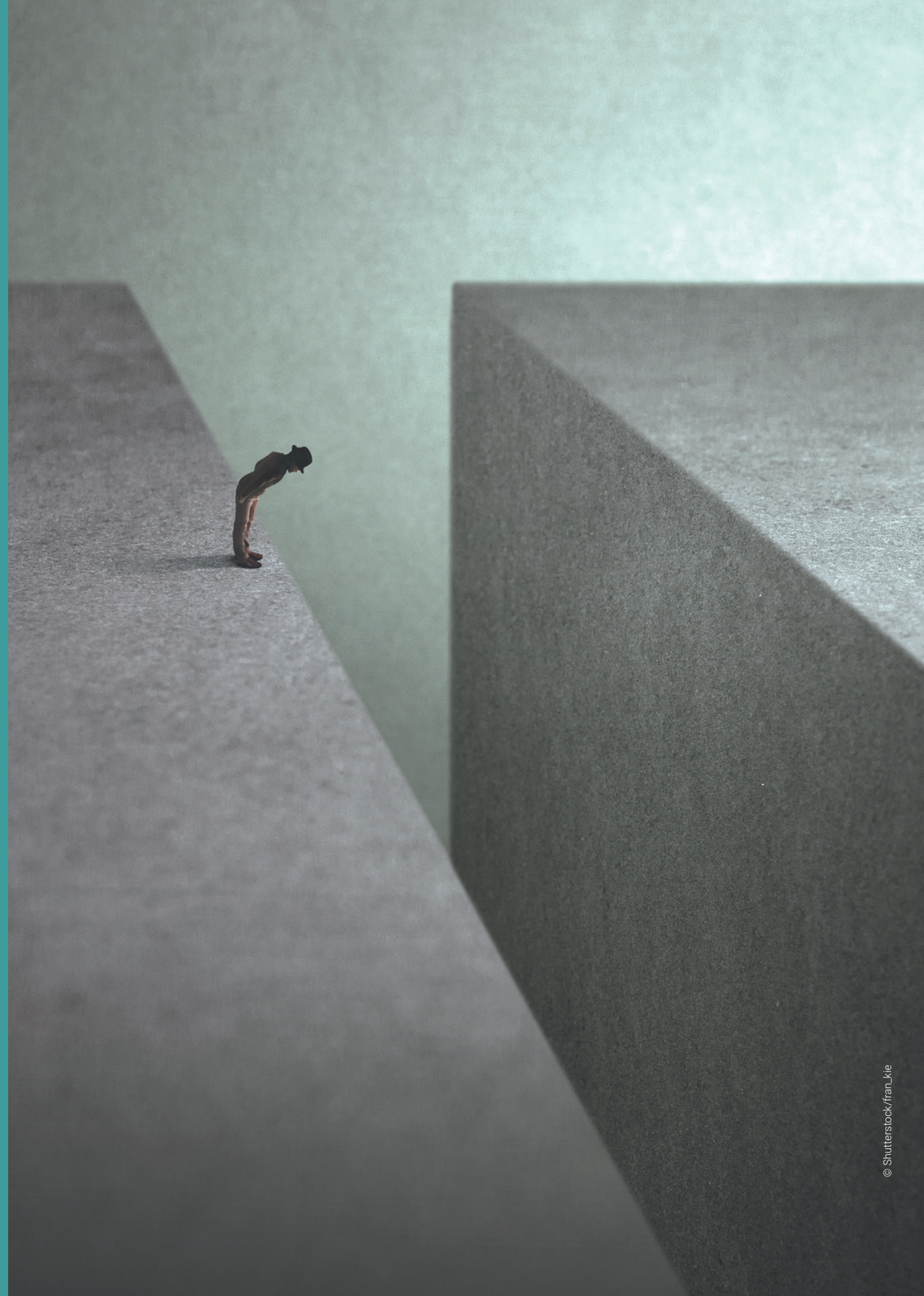
Figure 12: Conceptual framework for assessing risk management measures

- In the second step (Figure 12), the case studies were analysed for understanding the Risk Management of compound, cascading and systemic risks. This is done by studying the ten elements of risk governance – institutional and financial mechanism, stakeholder management, transboundary mechanism and collaboration, multi-sectoral mechanism and coordination, resource management, risk perception and communication, risk identification and assessment, and DRR policies and guidelines – across pre-event, during-event, and post-event measures undertaken.

The analysis of case studies and discussion on findings are detailed in Annexure E.

5

KEY GAP AREAS AND LESSONS LEARNT



5. KEY GAP AREAS AND LESSONS LEARNT

5.1 KEY GAP AREAS

Based on the case studies' analysis (Annexure E) and a thorough review of literature, the following key gap areas in understanding and managing compound, cascading and systemic risks have been identified (Figure 13).

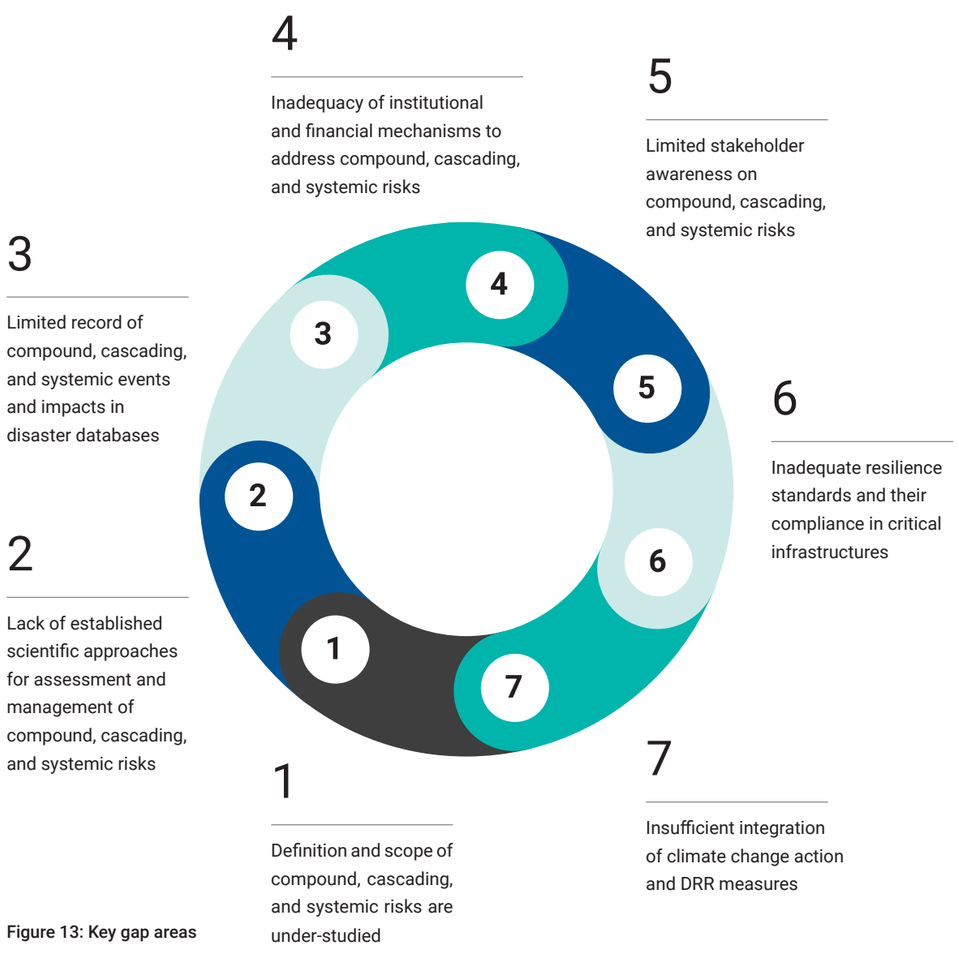


Figure 13: Key gap areas

1. Definition and scope of compound, cascading and systemic risks are under-studied

Owing to challenges that the definition and scope of compound, cascading and systemic risks are still under-studied (in disciplines such as Disaster Risk Management, Environment Sciences, Social Sciences, and Climate Change Action), there is a lack of adequate scientific basis for supporting long-term planning and effective decision support systems to govern such risks. Often these terms are used loosely or even interchangeably. There is a serious knowledge gap in comprehending the exposure and vulnerabilities at various scales associated with compound, cascading and systemic risks. The crucial need is therefore to have a holistic understanding of the state-of-the-art concept of the three types of risks (Pescaroli and Alexander, 2018).

2. Lack of established scientific approaches for assessment and management of compound, cascading and systemic risks

There is a key gap in the availability of scientific evidence-based approaches that are effective in assessing and managing the compound, cascading and systemic risks. A narrow, single-hazard approach is seen to be prevalent for assessing and managing risk. Besides, there is a gap in mapping and understanding the interdependencies and existence (or lack) of redundancies in the different interconnected systems and networks. On the contrary, the emerging landscape of the pluralistic nature of risk, calls for a multi-hazard/all-hazard/top hazards approach of risk assessment and management, coupled with a systems approach that can capture the degree of the emergence of risk within an interrelated or interdependent network of systems, thereby bringing coherence in policymaking (UNDRR, 2021). However, it is not yet established which of these approaches is most effective and actionable on the ground for assessing and managing the three types of risk, namely, compound, cascading and systemic. For example, there is now an increased focus on the all-hazards approach, which supports analysis of interlinked hazards and is broadly based upon parameters such as 'most likely' and 'most popular' hazards as per their occurrence.

The case of the COVID-19 pandemic, the like of which has not occurred in more than a century and has caught almost the entire globe under-prepared, reflects that such new and emerging risks may fail to be accounted for in parameters associated with past occurrences of hazards. Thus, there is a need for clarity augmented by scientific evidence on the appropriateness and effectiveness of approaches of risk assessment and management for compound, cascading and systemic risks. Further, these approaches need to be supported with improved state-of-the-art tools and methodologies developed by the research and science communities which are easy to understand and implement by the policymakers and practitioners. This requires that the approaches and tools with a focus on hazard-by-hazard risk identification and management are replaced or complemented by approaches that study risk holistically through all its dimensions, root causes and their complex interplay. Also, by studying precursor signals and correlations, modelling or simulating risk scenarios, research and scientific communities can support enhancing the current approaches to anticipate, assess, prepare, adapt and better manage these risks.

3. Limited record of compound, cascading and systemic events and impacts in disaster databases

The availability of information (such as data, maps) on past disasters involving compound, cascading and systemic risks (with explicit categorization) is very limited. There is an absence of a systematic recording of the trend of occurrences of such disasters, along with the combined impacts such as loss of human lives and damage to the infrastructures caused due to such events. Often, the disaster loss databases fail to categorically record the compound, cascading and even more, systemic events and their effects and impacts. Due to this inadequate availability of data and maps, a large degree of arbitrariness exists in understanding the complexity of the risk (Pescaroli and Alexander, 2018), as also while performing scientific assessments, and during the drafting of policies. Such unavailability of a concrete database affects the predictive analysis of risks as well. The use of big data (very large datasets), which can come from a wide variety of sources such

as satellite imagery, crowdsourcing, and social media, has opened up promising approaches in this direction (UNESCAP, 2019).

While having in place such databases is crucial for better understanding of the realized risks and learning from their management (or mismanagement), the cases of COVID-19 pandemic and climate crisis suggest that the past cannot be reliably used to predict future trends. Thus, the historical databases and patterns need to be duly complemented by strong risk-modelling and scenario-building for simulating future risk trends and patterns. The traditional and indigenous knowledge, along with the use of bioindicators, can also be used to get important insights into future trends.

4. Inadequacy of institutional and financial mechanisms to address compound, cascading and systemic risks

The limited knowledge in the domain of compound, cascading and systemic risks has resulted in inadequate institutional mechanisms for their management. This can be judged from the administrative lapses while planning for the holistic management of such complex risks, which usually occur as a chain of events or simultaneously, and may also have the potential to cause a system failure. Moreover, specific policies for compound, cascading and systemic risks are found to be minimal in the developmental plans of the regions. This poses difficulties to governing bodies while planning for land-use zonation and urban development, which need to be informed of the potential hazards, vulnerabilities, exposure, and associated type of risk (Govindarajulu, 2020). Evidence-based studies, with the engagement of communities and with the support from stakeholders, help in better management of risks. This, reinforced with local, national, and regional DRR policies, supported by a strong risk-information system (capturing all dimensions of risk) along with a database on past disasters and impacts, can improve the science and evidence base of strengthening institutional mechanisms for disaster risk management (Jillson et al., 2019).

Additionally, the unavailability of adequate disaster risk reduction financing mechanisms for strengthening multi-hazard risk governance poses a major challenge. The changing landscape of insurance companies, coupled with the compound, cascading and systemic nature of risk, has been proving uneconomical to existing users, indicating possible limitations in the existing insurance mechanisms to deal with only conventional (and single) hazard events. In this regard, to strengthen risk reduction financial mechanisms, governmental bodies should collaborate with private sectors for accessing financial resources and co-creating innovative financial mechanisms to strengthen disaster risk governance. Many new and emerging sources of funding, such as the Green Climate Fund, may also be considered for investments in DRR (UNESCAP, 2019).

5. Limited stakeholder awareness on compound, cascading and systemic risks

Since the understanding of compound, cascading and systemic nature of risks is quite recent and still evolving, key stakeholders may not be well aware of, or have prior experience in dealing with such risks. Additionally, the capacity of the stakeholders in understanding, differentiating, and recognizing the direct and indirect drivers and impacts of compound, cascading and systemic events, and associated vulnerabilities, may also be limited. Due to this lack of awareness and experience, poor understanding of associated roles and responsibilities among stakeholders may exacerbate the impacts of compound, cascading and systemic risks, since such risks require multi-sectoral, transboundary and global collaboration to be managed timely (UNESCAP, 2019).

However, it may be noted that risk awareness alone may not translate into decisions and actions, and should be duly supported by action-oriented capacity building and stakeholder engagement measures. There is a lack of awareness and participation amongst the communities, who are amongst the key stakeholders in disaster risk management. Therefore, it is important to ensure the strengthening of their capacities. In this regard, it may be useful to acknowledge individual and collective value systems, such as dominant organizational ethics and cultures that can influence behaviour in decision-making and implementing action for risk governance of compound, cascading hazards and systemic risks. Considering such social dimensions is important, especially for conflict-inflicted areas with underlying conditions of social fragility (GFDRR, 2015). Such considerations are especially critical in the case of transboundary disasters.

Along with the top-down approach of governmental bodies, the bottom-up risk perception of communities will help shape the required approaches for the management of the compound, cascading and systemic nature of risk. To reach the wider community, governing bodies can extend school-based and community-based DRR for sensitization of communities on these aspects, in service of strengthening their resilience. Additionally, support for mental health and psychological recovery is very crucial in the aftermath of any disaster (Mitra and Vivekananda, 2015). Hence, psycho-social care and considerations should be made an integral part of compound, cascading and systemic risks' management, to strengthen the capacities of communities.

6. Inadequate resilience standards and their compliance in critical infrastructures

There is a lack of adequate standards on resilience and safety. Besides, there is also a gap in using the existing risk information effectively for construction and maintenance policies and practices, and updating them regularly. In addition to this, the design, construction, and maintenance of critical infrastructures are seen to be in non-compliance to the existing building design and other safety codes, thereby triggering cascading failures during disasters (Vamvakeridou-Lyroudia et al., 2020).

As an example, due to any sort of disruption in the power sector, cascading and ripple effects may be seen in other interconnected and interdependent infrastructure, such as the accessibility to health, water, transport, etc., which may significantly obstruct the services. In this regard, Hurricane Katrina (2005) has lessons to offer because it caused the most widespread critical infrastructure collapse, where virtually all the infrastructures were disrupted at the same time due to cascading impacts (Miller, 2006). Similarly, the countries of Bangladesh and Nepal, which are prone to multiple hazards, have witnessed the failure or collapse of important buildings, killing and injuring many people. This has made it mandatory for governments to update and enforce strict regulations (Ahmed et al., 2018). Additionally, it is important to integrate the existing building design codes with the DRR plans of the region, as this will provide a strong institutional basis for building the resilience of the infrastructure, and especially that of critical infrastructures (Chmutina and Boher, 2015).

7. Insufficient integration of climate change action and DRR measures

The literature and case studies' findings suggest that there exists a pressing concern in integrating climate change actions and DRR measures. This need is more profound now, with increasing recognition of climate change as a systemic risk (UNDRR, 2019). A study by Forino et al. (2017) in Australia suggested that local governments should play a major role in integrating climate change adaptation and mitigation measures with DRR measures, for promoting sustainable development. This is because climate change exacerbates the frequency and intensity of hazards. In this way, the region's policymakers, planners, and climate change action negotiators would be able to formulate long-term approaches to building resilience while planning for uncertainty in the long run.

5.2 KEY LESSONS LEARNT

Based on the case studies' analysis (Annexure E) and a thorough literature review, the following are the key lessons learnt that may support better understanding and management of compound, cascading and systemic risks (Figure 14).

Figure 14: Key lessons learnt

1. Consideration of all dimensions of risk for its assessment and management

The emerging nature of risk and its complex manifestation highlights the ever-increasing interconnectedness and interdependence of all its dimensions (hazard, exposure vulnerability) across varied systems, and at all scales, as underscored in GRAF 2020-2030 (UNDRR, 2019). This puts forth the need to take a multi-dimensional approach for understanding and assessing all dimensions of risk prevailing within interconnected and interdependent systems along with due considerations of the dynamic interactions of their interlinkages therein.

The multi-dimensional and multi-scalar understanding of risk within and across a network of systems can be undertaken through a systems approach in due considerations of all/multi/top-hazards approach and active engagement of multi-sectoral stakeholders, as advocated under the whole-of-society approach. Such an approach tends to overcome the limitations of the siloed approach to risk assessment and management, where the focus is on a single dimension of risk, say, hazards, without mapping how they interact with other dimensions of risks such as exposure and vulnerability across systems at different scales. This multidimensional understanding of risk (underscored in global and local DRR policies and strategies) can strengthen risk communication strategies to further bridge the varying awareness and perceptions gaps associated with compound, cascading and systemic risks.

2. Developing disaggregated vulnerability and exposure databases for better anticipation and management of compound, cascading and systemic risks

To strengthen the existing disaster databases, which tend to focus on hazard-related aspects, it is pertinent to have in place updated and reliable vulnerability and exposure disaggregated databases and maps that can aid decision-makers in better visualization, anticipation and management of the potential or realized compound, cascading and systemic risks and failures in an area. Further, using appropriate technologies, the existing socio-economic and ecological databases and baselines at various scales should be made compatible or easy to be integrated within existing disaster databases, baselines and maps such as source maps, hazard zonation and exposure maps. This will help in capturing the complex interactions of different dimensions of risk at varying scales, and thus, will aid in strengthening the multi-dimensional understanding and management of compound, cascading and systemic risks, as highlighted earlier.

Furthermore, the availability of these databases at various scales (local, national, regional) is of paramount importance for laying down risk-informed planning at respective scales. For maintaining these inventories, adequate and sustainable investments are required. The use of emerging technologies and platforms such as satellite imagery, drone mapping, crowdsourcing or social media, can further help in strengthening such databases, especially for documenting the temporal evolution of different dimensions of risk.

3. Adaptive and integrative risk governance to manage compound, cascading and systemic risks

Learning from past experiences and upgrading the legal and institutional policies and plans from time to time for adaptive risk governance of the evolving risk-scape, has become pertinent. Adaptive and integrative risk governance can help address the key gaps and challenges associated with the understanding and management of compound, cascading and systemic risks, namely, inadequate knowledge base, underlying complexities and associated ambiguities (Klinke and Renn, 2011). The adaptive and integrative risk governance is aligned with the whole-of-society approach as it provides a conducive environment and mechanism for bringing together multiple stakeholders for collaborating to systematically co-create and co-implement appropriate risk-management solutions. These stakeholders include government organizations, non-governmental organizations, private-sector players, academics, community and community-based organizations.

4. Innovative risk reduction financing mechanisms for compound, cascading and systemic risks

The policy landscape of the insurance should be updated to include innovative risk reduction financing mechanisms covering compound, cascading and systemic risks. There is a need for new policies and mechanisms that go beyond the conventional single-hazard risk to include new and emerging risks, including those involving multiple hazards as well.

Disaster risk insurance (DRI) is being widely recognized as a tool to deal with the increasing disaster losses, strengthen resilience to the new and emerging risks, and reduce future expenditure in case of a hazard event. Many innovative insurance mechanisms are emerging to deal with the new and emerging nature of risks, such as Catastrophic Bonds, Resilience Bonds, and InsuResilience. In the era of compound, cascading and systemic risks such as that posed by COVID-19 compounded with other hazard events, it is critical that DRI includes compound, cascading and systemic nature of risk, while designing and factoring in insurance pricing to cover a gamut of risks. Disaster insurance policies should aim to lower the financial impacts from such risks and allow more effective risk management through the quick and timely disbursal of funds.

5. Evidence-based mapping at spatio-temporal scales via scenario-building

There is a need to broaden the focus of scenario building beyond the mere mapping of direct effects from the potential hazards (UNDRR, 2021). Rather, it is recommended to use evidence-based methods to map both the direct and indirect nature of cascading effects that can be caused both at a temporal scale (immediate, short term, medium, and long term) and also at a geo-political scale (local, national, transboundary and global), to accordingly strengthen risk-governance mechanisms at appropriate scales. Additionally, through spatio-temporal mapping, informal trust networks, social and political hierarchies that influence decision-making, and resource mobilization, allocation and implementation can also be mapped. Thus, understanding and managing compound, cascading and systemic risks and their potential effects upon social, economic and environmental systems can be improved via evidence-based scenario building at a spatio-temporal level. Therefore, to build a scenario informed of all types of risks, corresponding effects on the communities and the systems, as well as the corresponding probabilities of effects need to be modelled using a large variety of heterogeneous data and scientific evidence gathered from various sources. The new and emerging technologies can play an instrumental role in doing so. In addition, these scenarios can be modelled for projecting future effects through a time-based analysis.

6. Understanding and addressing the risks involved in critical infrastructure systems

The normal functioning of society is highly dependent on the interconnected network of critical infrastructures. Due to these interconnections, any failure in one can easily cascade to others in the network. The findings suggest that there is an increased need for better assessing the potential risks associated with critical infrastructure systems for strengthening their resilience and ensuring their effective functioning before, during, and after a disaster. The same can be done by defining the role of critical infrastructures and their interdependencies in a multi-risk scenario impacting various systems, and accordingly, the infrastructures requiring immediate attention can be prioritized.

Besides, a number of critical infrastructures are more susceptible to collapse during a disaster because of lack of compliance to building design codes during their design and construction, thus causing cascading failures to the interdependent infrastructures as well. This requires improvement in effective implementation and compliance with building regulations. Moreover, land use planning and zonation are to be regularized along with stricter compliance, to ensure risk-informed development and resilience of critical infrastructures.

7. Dynamic multi-hazards disaster risk management plans

Disaster risk management has become complex because of the novel paradigms of disaster risk, which may include both compound and cascading hazard events, with the potential to eventually affect a wide array of systems. The new normal for drafting disaster risk management plans should be based on these paradigms of a multi-hazard scenario, and not on the conventional siloed single hazard impact-based planning. Such a chain of events requires effective disaster mitigation, preparedness, response and resilience-building measures for diverse stakeholders, especially the population at risk. These measures should be drafted based on the comprehension of the potential triggering factors, the triggered events, and all dimensions of risk. It is also pertinent to ensure that such dynamic multi-hazards disaster risk management plans and emergency SOPs are developed for, and by, the industrial and other hazardous units (nuclear power plants, chemical industries, etc.) to be prepared and equipped for mitigating and addressing the potential compound, cascading and systemic risks.

8. Adopting ecosystem-based approaches to mitigate and manage risk

The dependence of communities on varied ecosystems is well-known. The well-being of a community depends on the health of ecosystems that provide multiple ecosystem services such as foods and nutrition, livelihood benefits, recreational and cultural benefits. Besides, ecosystems such as wetlands, forests, and coastal systems provide cost-effective natural buffers against hazards and the effects of climate change. Further, healthy and diverse ecosystems are more resilient to new and emerging risks. Thus, understanding risk at an ecosystem level is pertinent for mapping the potential interaction of various conditions that may exacerbate the new and emerging risks, and hence, mitigating and managing the imminent compound, cascading and systemic risks. Guided by this understanding, appropriate ecosystem-based approaches can be adopted for mitigating, managing and adapting to complex risk patterns and ensuring a sustainable and green post-disaster recovery.

9. Investing in systems that protect and advance the overall well-being

Compound, cascading and systemic risks are bound to disproportionately affect the already exposed and vulnerable group more severely. These may include populations residing in areas of progressive fragility, those affected by disaster and climate change-induced displacements, those without adequate coping capacities, etc. Against this backdrop, there is an increased need for robust safety nets, social infrastructure and services, such as those targeted at health, public health, nutrition, education, etc., as these can be instrumental in protecting and advancing the overall well-being of exposed and vulnerable groups (Shaw et. al., 2020).

ADB (2003) discusses the availability of some social-protection risk covers for addressing the needs of the highly vulnerable groups in the Asia Pacific region. Labour markets, social insurance, social assistance and safety nets, micro or area-based approaches, and child protection are five components of social protection. Besides, various informal support networks in many societies also provide for social protection to marginalised groups in society. Efforts may also be taken to identify and strengthen such networks (Shaw et. al., 2020). Such steps can help build the resilience of the vulnerable groups towards multi-risk scenarios and enhance their growth and development.

6

BASIC PRINCIPLES FOR THE MANAGEMENT OF COMPOUND, CASCADING AND SYSTEMIC RISKS

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6. BASIC PRINCIPLES FOR THE MANAGEMENT OF COMPOUND, CASCADING AND SYSTEMIC RISKS

Based on the case studies' analysis (Annexure E) and a thorough review of literature, six basic principles for strengthening the management of compound, cascading and systemic risks are proposed below (Figure 15).

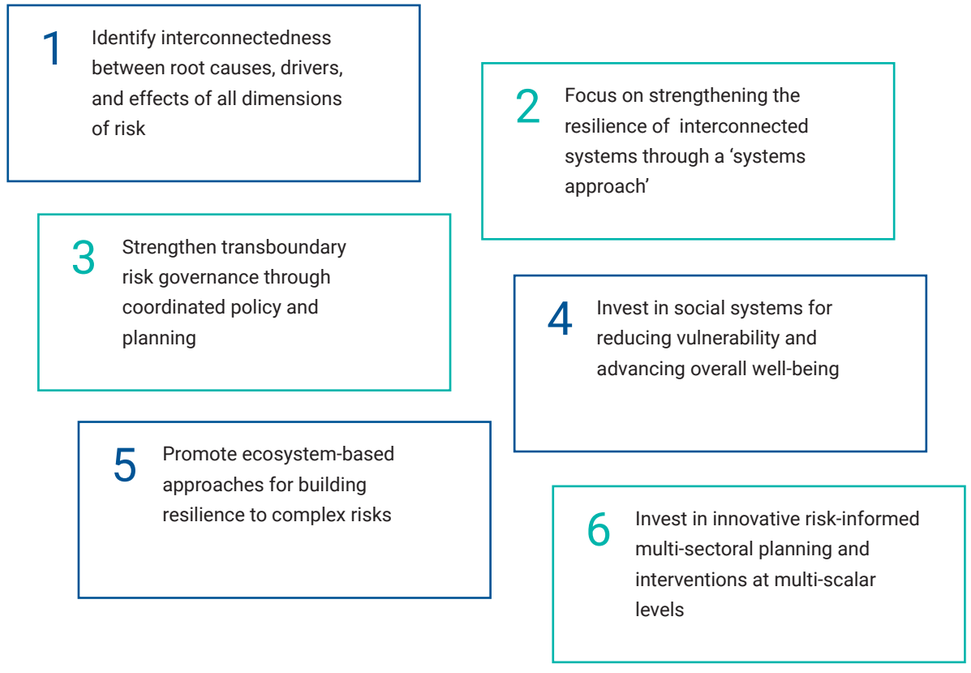

Figure 15: Basic principles for the management of compound, cascading, and systemic risks

1. Identify interconnectedness between root causes, drivers and effects of all dimensions of risk

There is an urgent need to investigate the interconnectedness between the root causes, drivers and effects of compound, cascading and systemic risks in a holistic way. This systematic investigation must consider all dimensions of risk (hazard, exposure vulnerability) across systems and at varied scales and map their complex interactions. Studying such interconnectedness and creating solutions that acknowledge and address interconnectivity between all dimensions can help reduce the severity of adverse effects and avoid a cascade of events. Given the understanding that risk is a social construct and not merely driven by natural phenomena, such a multi-dimensional understanding of risk that is not limited to just studying the hazard dimension becomes crucial. This will assist in understanding and addressing the shortcomings of the fragmented approaches of management of risk, thereby holistically addressing the underlying root causes, risk drivers and effects, and not just managing the tip of the iceberg.

2. Focus on strengthening the resilience of interconnected systems through a 'systems approach'

With the new and emerging landscape of risk, all dimensions of risk may offer uncertainty. Against this backdrop, the interconnected systems in a network can be considered only as resilient to these uncertainties as the weakest interlinkages or weakest system in this network is. Thus, interconnectedness within a network of systems should be closely studied, scientifically assessed and monitored for potential risk and resilience building of the network. This can be done by undertaking risk identification, assessment of risk-tolerance level, risk prioritization of each of the constituent systems and their interlinkages through a systems approach. This helps in identifying vulnerable linkages and potential tipping points prevailing in the system and networks, and supports building in redundancies and strengthening their resilience and sustainability. The findings should inform appropriate and effective measures for strengthening the resilience of the entire network to both known and unknown risks.

3. Strengthen transboundary risk governance through coordinated policy and planning

Compound, cascading and systemic disasters may take place across more than one geo-political boundary owing to their ability to trigger or exacerbate large-scale impacts. This calls for having in place an effective and robust transboundary and inter-governmental risk governance mechanism and cooperation in laying down bilateral and regional policies and interventions towards the management of risk. Such integrated risk governance of hazards requires a whole-of-society approach for enhancing collaboration and coordination across multi-sectoral and multidisciplinary stakeholders playing a key role in disaster risk management across geo-political boundaries. Transboundary and regional policies and plans can be co-designed for strengthening the current knowledge base, developing and updating multi-dimensional and multi-hazards disaster databases, resource management, capacity building, resilience building and coordinated response to compound, cascading and systemic risks.

4. Invest in social systems for reducing vulnerability and advancing overall well-being

There is a need to invest in strengthening the capacities and building resilience of social systems and safety nets. In this regard, both informal and formal networks, systems and mechanisms existing at different scales targeting health, public health, nutrition, and education, should be mapped and strengthened. Strengthening of such systems should be informed by two-way dialogue and approaches which promote engagement with and empowerment of the local communities and citizens. Such a bottom-up approach underpinning the 'leaving no one behind' can help capture complex vulnerabilities and needs of different sections of the society or even different members of a single household. These complex vulnerabilities and differential needs cannot be effectively addressed through a straight-jacketed solution of the 'one size fits all' approach. The social systems developed to address such diverse and complex vulnerabilities can lead to long-term positive changes in not only reducing the vulnerabilities but also empowering the communities, building their resilience and advancing their overall well-being.

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5. Promote ecosystem-based approaches for building resilience to complex risks

Scientific understanding of the interconnectedness between nature and people enables a thorough visualization of the complex interaction between various conditions that may exacerbate the risk. Ecosystem-based approaches such as Eco-DRR and EbA provide green and cost-effective measures which are inspired, supported, or borrowed from nature. These nature-based solutions can provide sustainable answers for not only mitigating the adverse impacts of disasters and climate risks, but also for directly addressing the underlying stressors (such as poverty, environmental degradation, hunger) and vulnerabilities that tend to accumulate and trigger compound, cascading and systemic risks. Eco-DRR, EbA, and other nature-based solutions tend to improve the health of ecosystems and restore or protect ecosystem services reducing vulnerabilities and exposure, therefore reducing risks. Thus, ecosystem-based approaches should be adopted for strengthening the resilience of vulnerable communities and fragile ecosystems to complex risk, while simultaneously supporting the sustainable development of the region.

6. Invest in innovative risk-informed multi-sectoral planning and interventions at multi-scalar levels

The resilience of different sectors to complex risk is of paramount significance to avoid or mitigate catastrophic disruptions and systemic failures. The compound, cascading and systemic nature of risk calls for innovative risk-informed planning and interventions for strengthening multi-sectoral resilience at multi-scalar levels including global, regional, national and local. This includes engaging with multiple sectors for risk reduction and management to strengthen the two-way integration of DRR planning and measures in the routine functioning of various sectors. The approach goes beyond just making the sectors resilient to multiple hazard risks but also making them and their stakeholders partners in disaster risk governance. To support this two-way sectoral integration of DRR, the underpinning principle is enhancing the investment for nurturing innovations in this regard. This requires adequate policy support and collaborations among global or regional financial institutions, national or sub-national government and private sector members for co-creating robust financial mechanisms and opportunities[6] for innovative risk-informed multi-sectoral planning and interventions.

6 An example of a similar fund is the Urban Climate Change Resilience Trust Fund (UCCRTF) (2013–2021) which is administered by the Asian Development Bank (ADB). It provides support to medium-sized, rapidly growing cities in the Asia-Pacific region to invest in innovative risk-informed approaches (from strategy development to implementation). This fund also provides investment to build multi-sectoral resilience capacity, and provides support in monitoring and evaluation of funds (ADB, 2020).

7

FRAMEWORK FOR STRENGTHENING THE GOVERNANCE OF COMPOUND, CASCADING AND SYSTEMIC RISKS

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7. FRAMEWORK FOR STRENGTHENING THE GOVERNANCE OF COMPOUND, CASCADING AND SYSTEMIC RISKS

Manifestations of compound, cascading and systemic risks depict that the increasing and complex nature of risk is difficult to manage unless it is addressed from a systems approach. This understanding of a system and various patterns of risk it is exposed to calls for a holistic assessment of all dimensions of risk. Such a multi-hazards, multi-dimensional and multi-scalar assessment of risk is the precursor for strengthening the governance of compound, cascading and systemic risks.

The proposed framework (Figure 16) for strengthening risk governance extends the GRAF 2020-2030 (UNDRR, 2019) to highlight specific considerations required for assessing and managing compound, cascading and systemic risks. These considerations are laid down across hazard, exposure, vulnerability, scale and systems.

The proposed framework encompasses the following:

- The first step is to map and assess all possible triggering and triggered hazards, their relationship and potential effects thereof. This supports undertaking a multi-hazards risk assessment which also captures the potential scenarios of a simultaneous or sequential chain of hazard events that may cause a potential system failure. Guided by this multi-hazard risk assessment, the key to breaking the chain of cascading events or mitigating the adverse effects lies in the development of a multi-hazard early-warning system that supports end-to-end dissemination and risk communication. The multi-hazard assessment can further be strengthened by undertaking multi-hazard scenario-planning and risk-modelling to capture future risk patterns.
- Once the hazards are known, the associated underlying exposure and multi-dimensional vulnerabilities are to be assessed, which may range through various spatial and temporal scales, to understand the accumulation of risk that could eventually trigger a systemic failure. This assessment can support laying down effective and risk-informed land-use zonation and planning and using ecosystem-based approaches for minimizing the exposure of communities and infrastructure, with a focus on critical infrastructure. Similarly, the assessment helps the development of vulnerability-disaggregated databases, which supports laying down specific policies and safety nets and protection mechanisms for different vulnerable groups, for strengthening their overall well-being and resilience to complex risks – based on the leave-no-one-behind principle.
- All these dimensions of risk should be assessed, considering their manifestations at all geo-political scales and complexities therein. This should be done through the coordination and collaboration of all key stakeholders within and across geo-political boundaries and should be managed through varied appropriate approaches and mechanisms such as landscape planning, area-based approaches, metropolitan mechanisms, regional cooperation, etc. The focus should be on strengthening local governance and mechanisms.

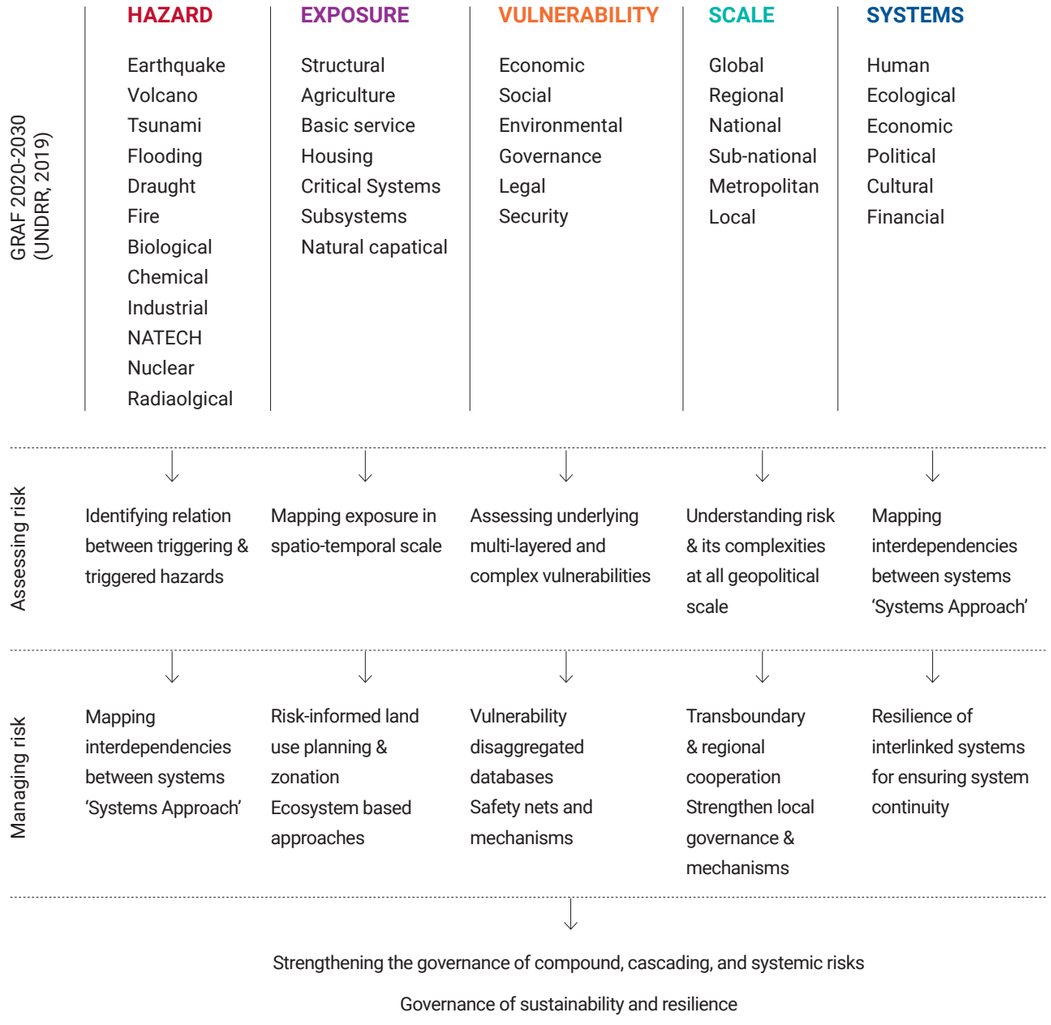

Figure 16: Framework for strengthening risk governance of compound, cascading, and systemic risks

- The final step of the proposed framework talks about mapping the interdependencies between systems through a systems approach and investigating how different dimensions of risk assessed above can affect these systems or cascade through them. This risk assessment through a systems approach is then used for strengthening the resilience of linkages, interlinked systems for ensuring their continued functioning, with a focus on service continuity of critical systems.

Overall, the framework envisages supporting governments and other key stakeholders in identifying, mapping, and addressing the new patterns of risk across systems and scales, thereby adequately laying down risk-informed policies, plans, and budgets, leading to sustainable and resilient development in the region.

The framework is further supported by the following proposed recommendations envisioned at three governing scales, namely, local, national and regional. The recommendations are laid down for different thematic areas specific to the four priorities of action of the Sendai Framework (Table 2). The same is schematically represented in Figure 17. At local level, building the capacity of the local communities is essential, so that scientific knowledge can be merged with the prevailing local, traditional and indigenous knowledge. At national level, establishing a strong multi-hazard risk and impact assessment system becomes the need of the hour, for which awareness and coordination between the different stakeholders are recommended. At regional level, transboundary and intergovernmental cooperation is to be fostered and used for effective management of compound, cascading and systemic risks.

Table 2: Thematic recommendations for the management of compound, cascading and systemic risks

Priorities for Action	Thematic areas	Local	National	Regional
Priority 1: Understanding risk	Technical assessment	L.1 Strengthening technologies for early detection of risk	N.1 Using new and emerging technologies to update the risk-assessment studies N.2 Strengthening of real-time surveillance and monitoring systems	R.1 Supporting data and information sharing on regional hazards and risk
	Applied research	L.1 Studying temporal changes in the local risk profile L.2 Undertaking evidence-based studies	N.3 Undertaking trans-disciplinary studies to understand all dimensions of risk and their inter-linkages	R.2 Mapping potential cascading risk factors in fragile landscapes and ecosystems
	Risk awareness	L.4 Integrating traditional and scientific knowledge	N.4 Strengthening vulnerability or exposure disaggregated databases (including maps)	
	Risk communication	L.5 Use of local languages for dissemination of alerts and warning L.6 Promotion of mass-communication systems and effective use of social media L.7 Developing source, hazard, vulnerability, exposure and risk maps		
Priority 2: Strengthening disaster risk governance to manage disaster risk	Risk informed policy and planning	L.8 Incorporating lesson learnt L.9 Developing sectoral plans and SOPs guided by multi-hazard risk assessment L.10 Promoting business continuity and contingency planning	N.5 Auditing and addressing gaps in DRR and sectoral policies N.6 Undertaking risk-sensitive land-use planning	R.3 Promoting terrain-based planning R.4 Developing transboundary policies for DRR
	Institutional mechanism	L.11 Strengthening the implementation mechanism and policy enforcement L.12 Strengthening multi-sectoral stakeholder coordination and mechanism L.13 Strengthening implementation of the latest building code	N.7 Earmarking roles and responsibilities of key line departments and stakeholders N.8 Bridging policy and praxis gap N.9 Establishment of effective communication channels across national and local level N.10 Strengthening implementation for risk-informed spatial planning	R.5 Promoting of transboundary mechanism, coordination and cooperation
	Data and information management	L.14 Strengthening mechanism for data recording and sharing L.15 Incorporating information of local disasters and risk	N.11 Promotion of data interoperability across departments and sectors	

Priorities for Action	Thematic areas	Local	National	Regional
Priority 3: Investing in disaster risk reduction for resilience	Technology-based solutions	L.16 Putting in place decision support systems L.17 Promotion of the use of ICT for multi-stakeholder collaboration	N.12 Strengthening multi-hazard early-warning systems N.13 Promotion of smart and green technologies N.14 Developing resilient infrastructure, supply chains and services	
	Nature-based solutions	L.18 Promoting locally appropriate and sustainable long-term mitigation and adaptation measures	N.15 Promoting ecosystem-based DRR through policies and financial provisions N.16 Promotion of sustainable landscape management to mitigate potential risk factors	
	Funding resources	L.19 Provisioning of contingency funds L.20 Using resources of local industries, corporates, etc.	N.17 Promoting engagement of private sector for resilience building N.18 Earmarking financial resources for DRR	
	Innovation		N.19 Promotion of social innovation through policies and financial provisions	
Priority 4: Enhancing disaster preparedness for effective response and to 'build back better' in recovery, rehabilitation and reconstruction	Capacity building	L.21 Strengthening of the cadre of trained and skilled personnel L.22 Enhancing resources for a prompt response L.23 Enhancing the surge capacities of key stakeholders for management of multiple disasters	N.20 Promoting practices for sustainable and green rebuilding and recovery	R.6 Leveraging resources for responding to transboundary risks
	Community-based disaster risk management	L.24 Promotion of community-based initiatives L.25 Strengthening of community-centric DRR planning and implementation	N.21 Strengthening the role of a facilitator in trust-building and multi-stakeholder engagement for connecting external resources with the local community	R.7 Promotion of inclusive engagement and diverse leadership (women, children, and youth, differently-abled, elderly, indigenous people, religious groups, etc.)
	Emergency facilities management	L.26 Establishing safe shelters, evacuation routes, and robust mechanisms for emergency logistics	N.22 Testing emergency procedures and facilities through scenario planning	

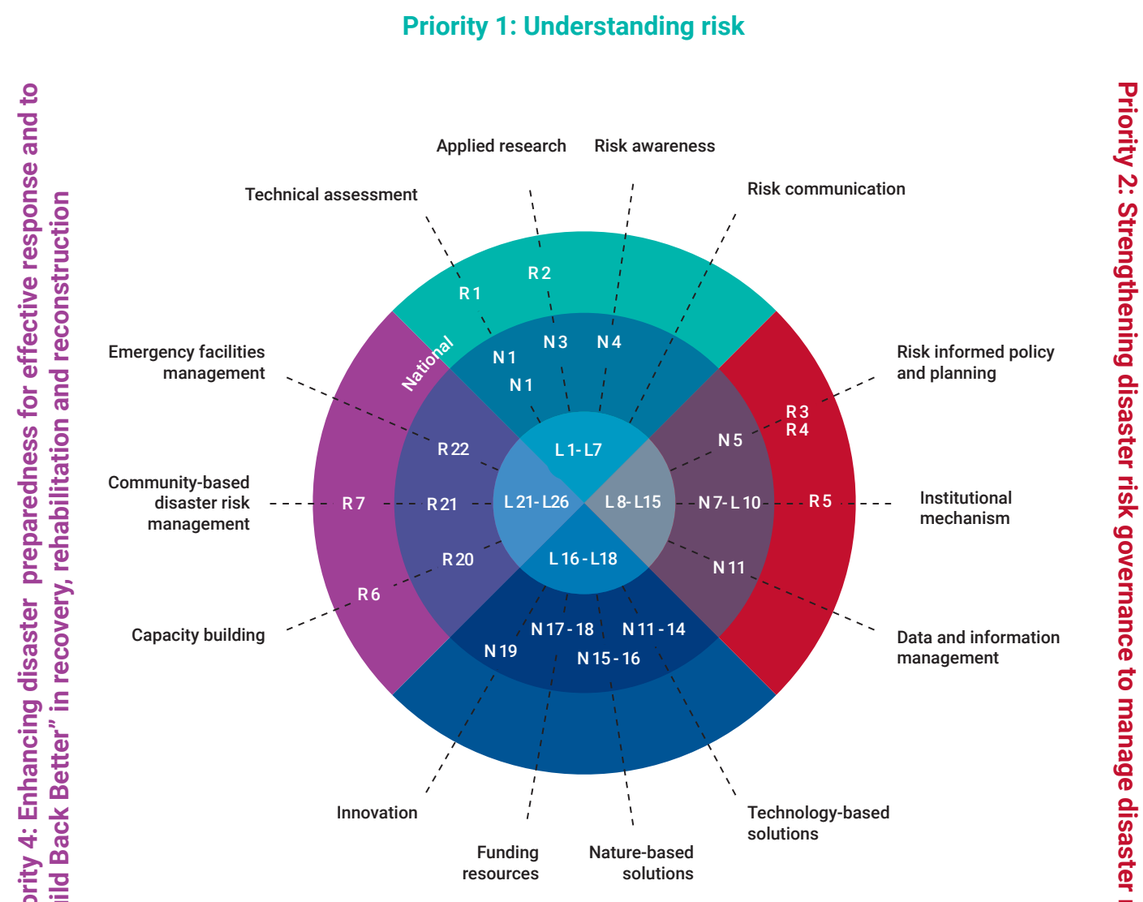

Figure 17: Schematic diagram showing the recommendations for the management of compound, cascading, and systemic risks

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ANNEXURE A: CASE STUDY TEMPLATE

1. Title of case study:
(Disaster name, place, year)

2. Select the type of risk discussed in the case study

   a. Cascading or compound disaster/risk
   b. Systemic risk
   c. Both

3. Key hazards involved (in bullets)

   In case of cascading or compound disaster/risk, also identify:

   Triggering hazard _____ Triggered hazards _____

4. Key systems involved (in bullets)

   Mention the key system(s) analysed in the case study. These may include food systems, health systems, infrastructure systems, economic systems, or ecological systems, etc. (Infrastructural, social, economic, environmental and informational systems)

5. Brief description of the disaster (300 words)

   In case of cascading or compound disaster/risk (if your answer to section 2 is 'a' or 'c'), include (i) The sequence of occurrence of different hazards; (ii) The underlying factors of exposure and vulnerabilities resulting in/triggering all the cascading effects.

   In case of systemic risk (if your answer to section 2 is 'b' or 'c'), include the underlying stressors, factors of exposure and vulnerabilities, and complex interactions that triggered the systemic failure. Highlight the tipping points, if possible

6. Impacts of disaster *(in bullets, whatever applicable)*

   Mortality & morbidity:

   Economic impacts:

   Social impacts:

   Environmental impacts:

   Impact on critical services, infrastructure, and businesses:

   Political impacts:

   Key sectors impacted:

   Medium, and long-term impacts, if any:

   In case of cascading or compound disaster/risk, mention how the nature and magnitude of impacts got exacerbated?
   (150 words)

   In case of systemic risk, discuss triggered impacts at local, national, transboundary & regional, and global.
   (150 words)

ANNEXURE A: CASE STUDY TEMPLATE

7. Steps undertaken prior to disaster towards prevention, mitigation, and management of disaster risk (500 words, in bullets)

Legislation/policy/guidelines/safety rules:

Prevention measures (structural & non-structural):

Mitigation measures (structural & non-structural):

Preparedness and capacity building measures:

Risk analysis and risk communication:

Also, briefly describe the level of understanding of systemic risk and/or cascading or compound disaster/risk prevailing prior to the disaster.

If available, include information on how successful/unsuccessful were these measures.

8. Steps undertaken to manage the disaster (300 words, whatever applicable)

Local level:

National level:

Regional/international level:

9. Role of key stakeholders (250 words)

Briefly identify the key stakeholders involved in pre-disaster, disaster response, and post-disaster phases along with the key roles (in bullets) which they fulfil in respective phases.

10. Key gaps and challenges in the management of systemic risk and/or cascading or compound disaster/risk (400 words, in bullets)

Related to risk prevention, reduction, and management, prior to disaster:

Faced during the management of the disaster:

Faced while planning/undertaking post-disaster recovery:

ANNEXURE A: CASE STUDY TEMPLATE

Among others, include the following aspects while identifying the gaps and challenges:

a. Institutional & financial mechanism

b. Legislations, policies & practices

c. Risk identification & warning

d. Risk assessment

e. Risk perception and communication

f. Capacity and resources for specialized response

g. Multi-sectoral/inter-ministerial mechanism

h. Transboundary policies and collaboration

i. Community (affected/at-risk) participation

j. Participation of private sector, academia, NGOs, etc.

11. Lessons learnt and recommendations (400 words)

How have the pre-disaster policy and practices been revised/developed since the disaster to include/ better address compound cascading, and systemic nature of risk:

Good practices and lessons learnt in the management of compound cascading, and systemic nature of risk:

Recommendations for enhancing the management of compound cascading, and systemic nature of risk:

12. Map

Provide a relevant map of the event's location

Sources

List the key sources used. Provide web links of the sources, wherever possible.

Additional reading material

Provide web links of additional reading material, if any recommended.

ANNEXURE B: LIST OF CASE STUDIES USED IN THE STUDY

No.	TITLE	KEY HAZARDS	COUNTRY
	COMPOUND AND CASCADING RISK		
1.	Monsoon Rainfall Floods in Pakistan, August 2020	Rainfall induced flash flood	Pakistan
2.	Coastal Flooding and Resilience of Sinking Bedono Village, Demak Coast, Central Java, 2000-2021	Coastal flooding	Indonesia
3.	A Cascade of Events: Cyclone, Floods, and Landslides in Sri Lanka, 2017	Cyclone induced floods, landslides	Sri Lanka
4.	The Kedarnath Tragedy, Uttarakhand, 2013	Cloud burst triggering floods and landslides	India
5.	Locust Attack Disaster in India, 2020	Cyclone induced locust attacks	India
6.	Forest Fires in India: A Case Study of Uttarakhand Forest Fire, 2020	Temperature-induced forest fire	India
7.	A Case Study of Similipal Forest Fire, Odisha, 2021	Temperature-induced forest fire	India
8.	Heat Waves 2020: A Case Study of Northern India	Heatwaves triggering health hazards, locust impacts	India
9.	Baghjan Oil Field Blowout, Baghjan, Assam, 2020	Fire explosion from oil reserves	India
10.	The Seti River Flash Flood Disaster in the Kaski District of Nepal, May 2012	Riverine and flash floods due to avalanche, glacial lake outburst, and rockslide	India
11.	Kerala Flood, 2018	Extreme rainfall triggering floods and landslides	India
12.	Mysterious Disease Outbreak in Eluru, Andhra Pradesh: A Case Study of December 2020	Heavy metal and pesticide pollution leading to health hazards during COVID-19 pandemic	India
13.	Cascading and Compounding Effect Exerted by Climate in Vanuatu	Climate change parameters CO_2 concentration, ocean acidification, sea-level rise, and extreme events triggering tropical cyclone, floods, heavy rainfall, coastal inundation due to sea level rise	Vanuatu
14.	Innovation and challenges in disaster risk management by youth - Heavy rain events during COVID-19, Japan, 2020 – 2021	Rainfall induced floods and landslides during COVID-19 pandemic	Japan
15.	Debris Flood Triggered by Cascading Hazard Phenomenon along Melamchi and Indrawati River Basins, Nepal	Heavy rainfall induced debris flow resulting in floods	Nepal
16.	Wenchuan Earthquake, 2008	Earthquake triggering chemical disaster	China
17.	Singapore Lightning Incident, 2018	Lightning induced industrial fire	Singapore
18.	Heavy Rainfall in Vietnam, 2015	Rainfall induced tailing dam failure, coal mine failure	Vietnam
19.	Disruption of Landfills and Water Treatment Plants Following Heavy Rainfall Events in Selangor, Malaysia, 2006	Rainfall induced landfilling hazard	Malaysia
20.	Oil Tank Fire in Pasir Gudan, 2006	Lightning induced industrial fire	Malaysia
21.	Great East Japan Earthquake and Tsunami, 2011	Earthquake triggering tsunami and nuclear disaster	Japan
22.	Uncontrolled Release of Untreated Sewage during 2011 Christchurch Earthquake, New Zealand	Earthquake triggering sewage release	New Zealand
	SYSTEMIC RISK		
23.	Chemical Explosion at Ming Dih Factory, Samut Prakan, July 2021	Chemical explosion	Thailand
24.	Successive droughts in Anantapur district, Andhra Pradesh	Drought	India
25.	Chennai Water Crisis of 2019 - A Systemic Risk	Water crisis/ stress/ scarcity	India
26.	Punjab Spurious Liquor Poisoning in August 2020: Case Study	Alcohol poisoning	India
27.	Loss of Ecosystem Services of the Manatuti River System, Metro Manila	Non-point source water pollution and associated hazards	Philippines
28.	Mumbai Landslide, July 2021	Rainfall induced landslides, floods	India
29.	LG Polymers India Pvt. Ltd. – Styrene Gas Leak Incident, Visakhapatnam, Andhra Pradesh, 2020	Styrene gas leak during lockdown	India

ANNEXURE B: LIST OF CASE STUDIES USED IN THE STUDY

No.	TITLE	KEY HAZARDS	COUNTRY
30.	The Use of River Geomorphology and Hydrology in Crafting Alternative Solutions to the Perennial Flood Problems in the Bislak Catchment, Luzon, Philippines	Monsoon rainfall triggered floods	Philippines
31.	Risk to Failure of a Functional Local Healthcare System: The Case of Cagayan de Oro City, Philippines	COVID-19 pandemic	Philippines
32.	Recurrent Flash Floods, Extent of Damages and Risk Management in the Upper Swat Valley, Pakistan	Flash floods	Pakistan
	COMPOUND AND CASCADING RISK + SYSTEMIC RISK		
33.	Mount Anak Krakatau Eruption and Sunda Strait Tsunami – Potential Affecting Industrial Zones in Cilegon City, Banten Province, Indonesia 2018	Volcanic eruption triggered landslides and tsunami	Indonesia
34.	Rajasthan Drought, 2020	Droughts	India
35.	Cascading Melamchi Flood Disaster, June 15, 2021 in Nepal	Floods	Nepal
36.	'Black Summer' Bushfires, Australia	Forest fire	Australia
37.	The Palu Earthquake, Flow Liquefaction and Tsunami, 2018	Earthquake triggering flow slide liquefaction, tsunami, landslide	Indonesia
38.	Chiplun Flood 2021, Maharashtra	Rainfall and dam release triggered flood, landslide	India
39.	Hospital Overcrowding, Metro Manila, April – August 2021	COVID-19 pandemic	Philippines
40.	Cyclone Early Warning and Early Action for Tropical Cyclone Yasa, 2020	Cyclone during COVID-19 pandemic triggering floods and landslides	Fiji

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ANNEXURE C: SUMMARY OF CASE STUDIES

CASE STUDY 1: MONSOON RAINFALL FLOODS IN PAKISTAN, AUGUST 2020

AUTHORS

Haishengh, Doctoral Candidate, School of Public Policy, Chiang Mai University, Thailand

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Rainfall-induced flash flood

COUNTRY

Pakistan

SUMMARY

The case study discusses the flash flooding in Pakistan, 2020. Because of heavy monsoon rainfall towards the end of the summer season, exacerbated by the poor urban drainage mismanagement, it claimed the lives of over four hundred people. The case study discusses the various aspects of the disaster, taking into account its impact on various sectors, such as the destruction of the standing crop agriculture that is a primary source of income for the locals, and displacement of commons. It discusses various prevention, mitigation and preparedness measures that have been undertaken for disaster risk management, such as promotion of school safety programmes, building of tolerant dykes and distribution of hygiene kits. The case study further discusses the response activities during the disasters, such as information management and legislative reviews, and sheds light on the challenges and gaps, such as lack of long-term plans, and challenges within the country's financial mechanisms. The authors conclude by suggesting various recommendations, such as the capacity building of national disaster-management authority, addressing the legislative gaps, staff-based performance assessment and improving the resources for an immediate response.

CASE STUDY 2: COASTAL FLOODING AND RESILIENCE OF SINKING BEDONO VILLAGE, DEMAK COAST, CENTRAL JAVA, 2000-2021

AUTHORS

Fatma Lestari, Occupational Health and Safety Department, Faculty of Public Health, Kampus Universitas, Indonesia/ Disaster Risk Reduction Center, Universitas Indonesia

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Coastal flooding.

COUNTRY

Indonesia

SUMMARY

The case study discusses the coastal flooding of the Bedono Village of Indonesia, which was caused by a combination of natural and anthropogenic factors, such as sea-level rise, poor absorbance capacity, conversion of natural barriers such as mangroves to fishing ponds, and incorporates a timeline-based analysis of impacts. The case study discusses the impact of the disaster on various sectors, such as community displacements, yearly losses in primary revenue associated with fishing, cultural shocks, loss of terrestrial ecosystem and saltwater intrusion. The authors discuss the pre-disaster risk management measures, such as the issuance of Demak Mayor Regulations focusing on the implementation of coastal flooding disaster management, land-use planning, school safety planning for coastal flooding, mitigation measures involving natural-based solutions by reforestation, and preparedness measures such as elevated houses and roads. The case study further discusses the disaster-management activities, such as projects for mangrove rejuvenation involving local, national, and international NGOs. Further, it identifies key gaps in the awareness and enforcement issues associated with conservation, risk knowledge and awareness. The authors conclude by highlighting key changes in the region after the disaster, such as land-use planning based on strict zonation, and suggest key recommendations for disaster rehabilitation and recovery such as promotion of traditional or scientific knowledge, coastal village-owned enterprises, integration of land-use planning with disaster indicators and ecosystem-based DRR.

CASE STUDY 3: A CASCADE OF EVENTS: CYCLONE, FLOODS, AND LANDSLIDES IN SRI LANKA, 2017

AUTHORS

Deepthi Wickramasinghe & Vihanga Amarakoon, Department of Zoology and Environment Sciences, University of Colombo, Sri Lanka

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Cyclone-induced floods, landslides

COUNTRY

Sri Lanka

SUMMARY

The case study discusses the floods and landslides because of cyclone Mora that brought heavy rainfall to Sri Lanka in 2017 and affected several provinces and districts in the wet zone of the island nation. The authors suggest that the flooding has implications for climate change, land-use changes, and sea-level rise, and discuss the impacts, response and recovery measures, and post-disaster developments associated with the hazards. In disaster impacts, the case study suggests that the mortality stands at over 200, and reports that over 3,000 houses and over 900 educational institutions were destroyed, affecting over 100,000 people. This is further complicated by the impacts on agriculture, critical infrastructures such as roads and power supply, and suggests that the overall losses account for over 30 billion {need to add currency?}. The case study discusses various pre-disaster risk management approaches at various levels, such as promoting institutional and legal structure and tools for Disaster Risk Management, flood-protection measures (structural measures using dykes), preparedness measures involving flood forecasting and warning using meteorological data, flood fighting, public-health measures, flood insurance and provision of relief. In emergency management, local-level governance focused on the identification of vulnerable communities and emergency response planning involving evacuation, while national level and international governance focused on disaster communication and issuing warnings, coordination with different agencies, framework and training. The case study highlights certain key drawbacks, focusing on response-focused institutional and financial mechanisms and lesser thrust on recovery and rebuilding, reduced community participation, lack of decision-support systems and poor planning of relief centres. The authors conclude by suggesting community-centric planning and promoting effective build-back-better options.

CASE STUDY 4: THE KEDARNATH TRAGEDY, UTTARAKHAND, 2013

AUTHORS

Shivani Chouhan, Research Scholar & Mahua Mukherjee, Professor, Centre of Excellence in Disaster Mitigation & Management, IIT Roorkee, India

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Cloudburst triggering floods and landslides

COUNTRY

India

ANNEXURE C: SUMMARY OF CASE STUDIES

SUMMARY

The case study discusses the tragedy of Kedarnath because of severe rainfall in June 2013 during the peak tourist season, that resulted in flooding and landslides. The case study suggests that these cascading events resulted in extensive damage and losses, with over 500 confirmed deaths and 5,000+ people missing, including foreigners. Besides these, the impacts on critical infrastructures were significant, resulting in damage to over 1,600 roads, over a dozen hydropower projects and thirty urban clusters, and resulted in a cumulative loss of 12,000 crores in the tourist industry alone in the year. The case study dwells further on the pre-disaster risk management measures such as the creation of an NPDRR or National Platforms for DRR at national level, involving multiple stakeholders, and discusses the key involvement of local governance, national authorities and international organizations to manage the emergency responses during disasters, such as the involvement of the army personnel. The case study discusses further the post-disaster initiatives, such as the Aapda Mitra programme on capacity building. The authors conclude by suggesting various reviews on urban planning measures involving settlements and hydroelectric projects, and suggest a well-coordinated system for effective management of future risks.

CASE STUDY 5: LOCUST ATTACK DISASTER IN INDIA, 2020

AUTHORS

Sanayanbi Hodam, Research Associate, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Cyclone-induced locust attacks

COUNTRY

India

SUMMARY

The case study discusses the cyclone-induced locust attacks that originated in parts of the Middle East, and eventually affected the northern states of India, exacerbated by favourable conditions. The study suggests the economic impact of the disaster has been significant, desecrating over 500,000 hectares in the state of Rajasthan alone. Further, the possible impact of preventive measures such as insecticides, and the impact on health and well-being, are highlighted in the case study. The study highlights the key legislative measures such as SOPs, early-warning measures, inter-country meets and capacity-building programmes enacted by the authorities prior to the disaster, and highlights the key role enacted by local, national and international governance through relief funds, scientific-technological interventions and diplomacy during disasters. The study concludes by recommending impact studies and research on pesticides, updated contingency planning and promoting guidelines on locust management.

CASE STUDY 6: FOREST FIRES IN INDIA: A CASE STUDY OF UTTARAKHAND FOREST FIRE, 2020

AUTHORS

Uzma Parveen & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Temperature-induced forest fire

COUNTRY

India

SUMMARY

The case study discusses the forest fires of Uttarakhand in 2020, that lasted around six months, adversely affecting the environment and socio-economic conditions of forest-dependent communities. It suggests the key root factors involving decreased precipitation, temperature increase, presence of char pine plant species and anthropogenic activities. The case study highlights significant impacts on the socio-economic, environmental and political sphere, highlighting aspects such as loss of livelihood, decrease in soil quality, CO2 emission and administrative challenges, further explaining the insights on the global implications to climate change and global warming. In pre-disaster management measures, the case study highlights key prevention, mitigation and preparedness measures, such as National Action Plan on Forest Fires, 2018, capacity-building programmes for local populations, and zone-wise database-generation on forest fires and vegetation. The case study further discusses the key challenges in disaster management, highlighting significant gaps in its phases, such as lack of ground surveillance, poor guidelines and lack of financial and technical resources that can aid the response, recovery, prevention, mitigation and preparedness. The case study recommends practices such as promoting funding initiatives, use of modern techniques and training of officials, and promoting vulnerability mapping and contingency plans for effective management of the hazard.

CASE STUDY 7: A CASE STUDY OF SIMILIPAL FOREST FIRE, ODISHA, 2021

AUTHORS

Anjali Barwal, Research Consultant, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Temperature-induced forest fire

COUNTRY

India

SUMMARY

The case study discusses the forest fires of the Similipal biosphere reserve of Odisha in 2021, that had been overwhelming, registering over 3,000 incidents in the year, with over 350 in its tiger reserves, challenging the environment and socio-economic conditions of forest and associated mechanisms. It suggests the key root factors, involving decreased precipitation, temperature increase, and the dry deciduous nature of the forest. The case study highlights significant impacts on the socio-economic, environmental and political sphere, highlighting aspects such as loss of livelihood, loss of natural vegetation and wildlife, CO2 emission and administrative challenges, further explaining the insights on the global implications to climate change and global warming. In pre-disaster management measures, the case study highlights key prevention, mitigation and preparedness measures such as Eco-Development Committees, mitigation measures involving Forest Information Technology Geomatic Cell for fire management, capacity building measures and availability of technical resources. The case study further discusses the key challenges in disaster risk management, highlighting significant gaps in its phases, such as poor administration and management, poaching issues, access to fire points, the tribal exclusion that can aid the response, recovery, prevention, mitigation and preparedness. The case study recommends practices such as strengthening satellite-based centralized information systems for early warnings, use of modern techniques and training of officials, incorporating traditional knowledge of indigenous communities, promoting capacity-building programmes and developing contingency plans for effective management of the hazard.

ANNEXURE C: SUMMARY OF CASE STUDIES

CASE STUDY 8: HEAT WAVES 2020: A CASE STUDY OF NORTHERN INDIA

AUTHORS

Pritha Acharya, Research Fellow, CAP-RES Project, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Heatwaves triggering health hazards, locust impacts

COUNTRY

India

SUMMARY

The case study discusses the heatwaves in northern India that are a result of cyclones and the summer season, and have been triggering various health hazards, locust attacks, and compounding the pandemic-stricken systems. The case study suggests significant impacts on socio-economic and environmental systems, such as increased morbidity conditions in the region, loss of livelihood options for daily wagers and unorganized sectors, and increasing cases of heat islands. In pre-disaster management measures, the case study highlights key prevention, mitigation and preparedness measures such as The National Guidelines for Preparation of Action Plan-Prevention and Management of Heat Waves, inclusions in the National Disaster Management Plan 2019, promotion of monitoring systems and promotion of colour-coding-based warning systems during heatwave impact. The case study further discusses the key challenges in disaster risk management, highlighting significant gaps such as data availability, unavailable city-level heat action plans, and limited evidence-based studies showcasing good practices and strategies to cope with and implement effective adaptation measures. The case study recommends practices such as improving mechanisms for real-time surveillance and monitoring, and planning for robust mechanisms focusing on long-term community resilience for effective management of the hazard.

CASE STUDY 9: LOCUST ATTACK DISASTER IN INDIA, 2020

AUTHORS

Michel Islary, Junior Consultant, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM.

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Fire explosion from oil reserves

COUNTRY

India

SUMMARY

The case study discusses the oil blowout and the subsequent explosion and fire in the Baghjan Oil Well, Assam in 2020. The case study discusses significant impacts on socio-economic, environmental, and political systems, such as about a trimester loss of livelihood options for the local fishing communities, damages to agriculture and live stocks, and cases of environmental impacts such as a decline in phytoplankton, accounting for a total of 250 billion rupee losses in the environment sector alone. In pre-disaster management measures, the case study highlights key prevention, mitigation and preparedness measures, such as the available legislations at national level, such as various acts, and suggests that the company did not receive consent for operations based on them. Further, it highlights the lack of policies, practices at the company on improving the prevention, mitigation, preparedness, and risk analysis that exacerbated the conditions. The case study highlights the significant local and national interventions during the disaster, such as relief camps, immediate national-level committees for investigation, and damage assessment. The case study further discusses the key challenges in disaster risk management, highlighting poor administrative and regulatory mechanisms. The case study recommends practices such as promoting expert committees for impact studies, encouraging stringent measures, and local-level capacity-building.

CASE STUDY 10: THE SETI RIVER FLASH FLOOD DISASTER IN THE KASKI DISTRICT OF NEPAL, MAY 2012

AUTHORS

Shobha Poudel & Bhogendra Mishra, Policy Research Institute, Nepal

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Riverine and flash floods due to avalanche, glacial lake outburst, and rockslide

COUNTRY

Nepal

SUMMARY

The case study discusses the heat River Seti Flood, 2012, that affected the Kharapani village of the Kaski district of Nepal, and has its key root factors linked to phenomena such as glacial lake outbreak, avalanche, and rockfall. The case study suggests significant impacts on socio-economic, environmental, political systems such as displacement of commons, loss of livelihood options and damages to the ecosystem, eventually affecting the community and registering an economic loss of around 82 billion Nepalese rupees in infrastructure. In pre-disaster management measures, the case study suggests the lack of comprehension of the disaster, as it was a novel challenge for the community, with no prior incidents. In the case of emergency management, effective early warning prior to the disaster, through mediums, helped in the casualty reduction and was further supported by immediate response measures from the administration. The case study further discusses the key challenges in disaster risk management, highlighting significant gaps, such as unavailability of immediate response team at local level, lack of easy access to the health facilities, local governmental challenges, issues of channel and challenges of impact assessment. The case study recommends practices such as improving mechanisms for early warning through mass-media platforms, promoting training and capacity-building measures, and improving the efficacy of local government for effective management of the hazard.

CASE STUDY 11: KERALA FLOOD, 2018

AUTHORS

Amir Ali Khan, Assistant Professor, NIDM & Safia Khatoon, Researcher & Intern, NIDM.

CATEGORY

Cascading or compound disaster/risk.

KEY HAZARDS

Extreme rainfall triggering floods and landslides.

COUNTRY

India

SUMMARY

The case study discusses the Kerala Floods of 2018 in India, that were a result of heavy incessant precipitation, and triggered floods and landslides in due process, resulting in extensive damage. The case study suggests significant impacts on socio-economic and environmental systems, such as large-scale displacement of local communities, agricultural losses close to a billion US dollars, and infrastructural losses involving over 11,000 houses, and 7,000+ square kilometres of road infrastructure. Further impacts were reported in the health sector, estimated close to $100 million in WASH alone. The case study highlights key prevention, mitigation and

ANNEXURE C: SUMMARY OF CASE STUDIES

preparedness measures prior to the disaster, such as state-level monsoon preparedness meetings and release of SOPs, surveillance measures on dams and reservoirs, and forecast and warning measures. The case study discusses emergency management measures at local, national, and international scales such as involvement of community groups, national or state-level mechanisms, and international organizations such as the World Bank in the relief, rescue and information management during the disaster. The case study further highlights significant gaps in different phases of disaster risk management, such as poor administration and lack of credible management, absence of flood forecasting stations at reservoirs, non-availability of local material for reconstruction and suitable land for relocation. The case study suggests various post-disaster developments, such as extensive policy and guideline revisions, and recommends practices such as risk-sensitive land-use planning, promoting effective technical resources for risk analysis and promoting build back better for effective management of the hazard.

CASE STUDY 12: MYSTERIOUS DISEASE OUTBREAK IN ELURU, ANDHRA PRADESH: A CASE STUDY OF DECEMBER 2020

AUTHORS

Atisha Sood, Research Fellow, ECDRM Division, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Heavy metal and pesticide pollution leading to health hazards during the COVID-19 pandemic

COUNTRY

India

SUMMARY

The case study discusses the heavy metal and pesticide pollution of 2020 in Andhra Pradesh, India, that resulted in significant impacts on the already overwhelmed pandemic-stricken system. The case study suggests significant impacts on socio-economic, environmental and political systems, such as morbidity challenges, health-sector impacts due to COVID-19 and a disrupted water-supply system. The case study highlights key prevention, mitigation and preparedness measures before the disaster, such as national policies and regulations on insecticides and pesticides, water-management programmes such as The National Water Quality Program. The case study discusses emergency management measures at local, national and international scales, such as dispatch of medical teams at local level and promotion of expert committees from national and international bodies' levels during the disaster. The case study further discusses the key challenges in disaster risk management, such as challenges of food security, and suggests certain challenges on patients monitoring during the ongoing pandemic. The case study suggests various post-disaster developments such as extensive policy and guideline revisions, and recommends practices such as administrative-level interventions for promoting effective water-resources management for risk reduction, such as testing and monitoring for the effective management of the hazard.

CASE STUDY 13: CASCADING AND COMPOUNDING EFFECT EXERTED BY CLIMATE IN VANUATU

AUTHORS

Bapon (Shm) Fakhruddin, Tonkin + Taylor, New Zealand

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Climate change parameters CO2 concentration, ocean acidification, sea-level rise, and extreme events triggering tropical cyclones, floods, heavy rainfall, coastal inundation due to sea-level rise

COUNTRY

Vanuatu

SUMMARY

The case study discusses the country of Vanuatu that is at high risk from climate change and is vulnerable to tropical cyclones, coastal and river flooding, drought, earthquakes, landslides, tsunami and volcanic eruptions, analysing the associated impacts through various examples. The case study suggests significant impacts on socio-economic, environmental and political systems due to climate change, such as deaths, displacements and infrastructural damages that are due to various hydrometeorological disasters associated with climate change, citing examples of 2015 cyclone Pam. The case study suggests various prevention, mitigation and preparedness measures for climate change, such as Vanuatu's Climate Change and DRR Policy, National Energy Road Map and early-warning systems. The case study discusses emergency management measures at local, national, and international scales, such as vulnerability assessments and international collaboration for climate change action. The case study further discusses the key challenges in disaster risk management, such as challenges in emergency preparedness, underdeveloped national systems for management, and poor post-disaster assessment. The case study suggests various good practices such as availability of mass communication systems and effective awareness measures revisions, and recommends practices such as establishing platforms for multi-stakeholder involvement, strengthening information-sharing mechanisms, and the whole-of-society approach for response planning, for the effective management of the hazard.

CASE STUDY 14: INNOVATION AND CHALLENGES IN DISASTER RISK MANAGEMENT BY YOUTH - HEAVY RAIN EVENTS DURING COVID-19, JAPAN, 2020 – 2021

AUTHORS

U-INSPIRE Japan – Sachi Suzuki, JFIT Coordinator, UNESCO Jakarta; Tomoko Takeda, Associate Researcher, University of Tokyo; Ryo Tsuchida, Ph.D. Student, Kyoto University; Yu Watanabe, Master student, Tohoku University; Misato Matsuda, Master student, Chuo University; Anna Shinka, Ph.D. student, Tohoku University; Kasumi Suehiro, Master student, Tokyo Metropolitan University.

CATEGORY

Cascading or compound disaster/risk.

KEY HAZARDS

Rainfall induced floods and landslides during the COVID-19 pandemic

COUNTRY

Japan

SUMMARY

The case study discusses the heavy rain events during COVID-19 in Japan during 2020 – 2021, that resulted in floods and landslides. The case study suggests significant impacts on socio-economic, environmental and political systems such as deaths, displacements and large-scale damage to infrastructure, alongside highlighting the challenges of COVID-19. The case study suggests prevention, mitigation and preparedness measures undertaken prior to the disasters, such as guidelines for emergency management during pandemics, promoting vertical evacuation through mass media and capacity building through volunteer platforms. The case study discusses emergency management measures at

ANNEXURE C: SUMMARY OF CASE STUDIES

local, national, and international scales, collaborative efforts from national and local governments and information dissemination through volunteer platforms. The case study further discusses the key challenges in disaster risk management, such as challenges in emergency preparedness involving human resource management, compounding the effect of COVID-19 challenges on the systems, lack of agreed mechanisms for informal assistance, post-disaster economic recovery challenges, and socio-economic disparities concerning ICT. The case study suggests various good practices such as the flexible interactions of the volunteer communities by using ICT for risk communication and management, and recommends practices such as promoting enabling environment for youth to contribute to the data collection and dissemination through private investments, for the effective management of the hazard.

CASE STUDY 15: DEBRIS FLOOD TRIGGERED BY CASCADING HAZARD PHENOMENON ALONG MELAMCHI AND INDRAWATI RIVER BASINS, NEPAL

AUTHORS

Binaya Raj Shivakoti, Institute for Global Environmental Strategies (IGES), Japan; Vishnu Prasad Pandey, Institute of Engineering (IOE), Tribhuvan University, Nepal; Anil Pohkrel, National Disaster Risk Reduction and Management Authority (NDRRMA), Nepal Government, Nepal; Rajendra Sharma, National Disaster Risk Reduction and Management Authority (NDRRMA), Nepal Government, Nepal; Sanjaya Giri, Deltaris, Delft, Netherlands; Nagendra Kayastha, Disaster Specialist, Delft, Netherlands.

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Hazards: Heavy rainfall-induced debris flow resulting in floods

COUNTRY

Nepal

SUMMARY

The case study discusses the cascading flooding events due to incessant rainfall in the Himalayan ranges of Nepal, which were already unstable due to earlier earthquakes and the historical sedimentation process, and which eventually escalated to a disaster, triggered by the 2021 heavy rain events. The case study suggests significant impacts on socio-economic, environmental and political systems such as deaths, displacements and large-scale damage to infrastructure, accounting for over 40 billion Nepalese rupees. The case study suggests prevention, mitigation and preparedness measures undertaken prior to the disasters, such as new institutional arrangements after the 2015 earthquake, proactive DRR policies and guidelines. The case study discusses emergency management measures at local, national, and international scales, such as national-level disaster monitoring and early warning, local-level planning measures and collaboration efforts with international donors for disaster risk management. The case study further discusses the key challenges in disaster risk management, such as establishing and operating adequate stations for monitoring rainfall, cascading risk comprehension challenges owing to its resource-intensive nature, disruption of lifeline infrastructures affecting the response measures and land-use planning. The case study recommends practices such as promoting robust mechanisms for multi-hazard risk assessments, and the systemic approach of integrated and participatory river-basin management by considering specific hydrological and geomorphological characteristics of the Himalayan region, for the effective management of the hazard.

CASE STUDY 16: WENCHUAN EARTHQUAKE, 2008

AUTHORS

Aleksandrina Mavrodieva, Keio University, Japan

CATEGORY

Cascading (NATECH)

KEY HAZARDS

Earthquake triggering chemical disaster

COUNTRY

China

SUMMARY

The case study discusses the earthquake and the subsequent cascading chemical disaster that affected the Wenchuan province in China in 2008. The case study suggests significant impacts on socio-economic, environmental, political systems such as large-scale deaths of over 70,000 people, industrial damages of around $240 million, large-scale hazmat release that affected the ecology, and infrastructural damages. The case study suggests the preparedness measures prior to the disasters were insufficient, as they were based on early analysis, and did not withstand the aggravated intensity of the earthquake hazard, coupled with significant structural challenges. The case study further notes that the response measures were halted by the critical infrastructural damages, affecting effective disaster risk management. The case study concludes by suggesting good post-disaster practices such as retrofitting and utilizing high-degree calculations, and recommending realistic and continuous risk assessments, for the effective management of the hazard.

CASE STUDY 17: SINGAPORE LIGHTNING INCIDENT, 2018

AUTHORS

Aleksandrina Mavrodieva, Keio University, Japan

CATEGORY

Cascading (NATECH)

KEY HAZARDS

Lightning induced industrial fire

COUNTRY

Singapore

SUMMARY

The case study discusses the lightning hazard and the subsequent cascading oil storage-tank fire on Pulau Busing Island in Singapore in 2018. The case study suggests no significant impacts on socio-economic, environmental and political systems, except infrastructural damages reported on the oil tank storage. The case study suggests the preparedness measures prior to the disasters, such as available firefighting capacities in the state, or training on response programmes and fire codes, that helped in the further inhibition of the technological disaster. The case study concludes by highlighting good practices such as a high level of preparedness of the private sector and the continuous training of respondents and multi-level response as the major factors for the effective management of the hazard.

CASE STUDY 18: HEAVY RAINFALL IN VIETNAM, 2015

AUTHORS

Aleksandrina Mavrodieva, Keio University, Japan

CATEGORY

Cascading (NATECH).

KEY HAZARDS

Rainfall induced tailing dam failure, coal mine failure

ANNEXURE C: SUMMARY OF CASE STUDIES

COUNTRY

Vietnam

SUMMARY

The case study discusses the 2015 spill of toxic substances from Quang Nihn coal mines in Vietnam due to incessant rainfall, eventually resulting in large-scale impacts. The case study suggests significant impacts on socio-economic, environmental and political systems affecting over 200,000 people, industrial damages of around $92 million, large-scale hazmat release that affected the ecology, and infrastructural damages. The case study suggests the preparedness measures prior to the disasters were unclear, and suggested large-scale land-cover changes and resource exploitation in the region that may have affected the resilience. The case study further notes that the immediate response measures were undertaken by the local and national authorities and investors, which helped in effective disaster risk management. The case study concludes by suggesting good post-disaster practices such as novel policies for renewable energy, resources monitoring and multi-stakeholder discussions for the effective management of the hazard.

CASE STUDY 19: DISRUPTION OF LANDFILLS AND WATER TREATMENT PLANTS FOLLOWING HEAVY RAINFALL EVENTS IN SELANGOR, MALAYSIA, 2006

AUTHORS

Nurul Syazwani Yahaya & Joy Jacqueline Pereira, Universiti Kebangsaan Malaysia

CATEGORY

Cascading (NATECH)

KEY HAZARDS

Rainfall induced landfilling hazard

COUNTRY

Malaysia

SUMMARY

The case study discusses the two consecutive events of rainfall-induced landfilling hazard that led to the disruption of critical infrastructure (water systems) of the Selangor province of Malaysia in 2006. The case study suggests the leachate overflow from the landfill polluted the River Selangor, and resulted in drinking-water issues for over a million citizens. The case study suggests the administrative-level hazard-management measures prevented further health hazards and related challenging measures, and suggested that the administration had imposed closure and shutdowns in future events. The case study concludes by recommending practices such as weather-sensitive landfill planning, incorporating the challenges through structural and non-structural measures for the effective management of the hazard.

CASE STUDY 20: OIL TANK FIRE IN PASIR GUDAN, 2006

AUTHORS

Shohei Matsuura, Disaster Preparedness and Prevention Center (DPPC), Universiti Teknologi Malaysia, Malaysia

CATEGORY

Cascading (NATECH)

KEY HAZARDS

Lightning-induced industrial fire

COUNTRY

Malaysia

SUMMARY

The case study discusses the lightning hazard and the subsequent cascading oil storage tank fire on Pasir Gudan in 2006. The case study suggests no significant impacts on socio-economic, environmental and political systems, except infrastructural damages reported on the oil tank storage. The case study suggests the preparedness measures prior to the disasters existed such as legislations and rules, and presence of mutual aid membership groups for improved coordination, but suggests that there had been poor understanding of NATECH risk-comprehension management at administrative level, alongside resource insufficiency that affected the response measures, that raises concerns. The case study concludes by recommending good practices such as a novel outlook on existing legislation and resources mobilization, for the effective management of the hazard.

CASE STUDY 21: GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI, 2011

AUTHORS

Maria Camila Suarez Paba & Ana Maria Cruz, Disaster Prevention Research Institute, Kyoto University.

CATEGORY

Cascading (NATECH)

KEY HAZARDS

Earthquake triggering tsunami and nuclear disaster .

COUNTRY

Japan

SUMMARY

The case study discusses the 2011 Tohoku earthquake that cascaded into a tsunami and subsequent nuclear meltdown. The case study suggests significant impacts on socio-economic, environmental, political systems such as over 16,000 deaths, damages of around $210 billion, large-scale hazmat release that affected the population and ecology, and infrastructural damages. The case study highlights preparedness measures prior to the disasters, such as laws and guidelines, and highlights key response measures such as the large-scale evacuation of vulnerable communities, and immediate aid. The case study concludes by suggesting good post-disaster practices such as realistic and continuous risk assessment of critical infrastructure, awareness generation, multi-hazard preparedness and response strategies, and designing effective communication channels for the effective management of the hazard.

CASE STUDY 22: CHEMICAL EXPLOSION AT MING DIH FACTORY, SAMUT PRAKAN, JULY 2021

AUTHORS

Miranda Booth, Lecturer & Akhilesh Surjan, Associate Professor, Humanitarian, Emergency and Disaster Management Studies, Charles Darwin University, Australia

CATEGORY

Cascading (NATECH)

KEY HAZARDS

Earthquake triggering sewage release

COUNTRY

New Zealand

SUMMARY

The case study discusses the 2011 Christchurch earthquake and the associated uncontrolled release of untreated sewage, resulting in critical issues in the region. The case study suggests significant impacts on socio-economic, environmental and political systems such as over 185 deaths, poor air quality, and infrastructural damages (about NZ$40 billion), resulting in a large-scale sewage release that raised critical issues for the population and ecology, such as unavailability of water, and poor health conditions. The case study highlights preparedness measures prior to

ANNEXURE C: SUMMARY OF CASE STUDIES

the disasters such as formulation of administrative bodies, guiding laws and regulations, and administrative lapses concerning implementation, as well as poor infrastructure design, which aggravated the impacts. The study highlights further key response measures such as activation of an Emergency Operations Centre, critical infrastructure damage assessment, and alternative solutions to address the situation. The case study concludes by suggesting good post-disaster practices such as consultation and review of administrative response measures for effective planning, compilation of lessons learned, and use of chemical toilets for the effective management of the hazard.

CASE STUDY 23: CHEMICAL EXPLOSION AT MING DIH FACTORY, SAMUT PRAKAN, JULY 2021

AUTHORS

Ecological Alert and Recovery – Thailand (EARTH)

CATEGORY

Systemic risk

KEY HAZARDS

Chemical explosion

COUNTRY

Thailand

SUMMARY

TThe case study discusses the chemical explosion at Ming Dih Factory, Samut Prakan, Thailand, and studies the impact, challenges and future recommendations associated with the risk. The study notes that there have been significant impacts of the hazard on socio-economic, environmental and political systems, such as acute contamination of the atmosphere, poor management of workforce, infrastructural damages to properties, and health hazards. The case study suggests prevention, mitigation and preparedness measures undertaken prior to the disasters, such as government regulations pertaining to industries, such as the Factory Act (1992), and the Ministry of Industry's (MOI) Regulation number 2 (1992) under the Factory Act (1992), that has mandates on factory construction and its impact on the surroundings. The case study discusses emergency-management measures at local, national, and international scales, such as conducting risk assessment, evacuation announcements, coordinated emergency responses and bringing important resources. The case study further discusses the key challenges in disaster risk management, such as the acute problem involved in the implementation of planning laws and regulations, factories' production capacity, knowledge dissemination concerning hazardous chemicals, non-universal evacuation and worker mismanagement. The case study highlights the role of local communities and volunteer groups in disaster response management, and recommends practices such as improved administrative monitoring and regulation, for the effective management of the hazard.

CASE STUDY 24: SUCCESSIVE DROUGHTS IN ANANTAPUR DISTRICT, ANDHRA PRADESH

AUTHORS

Nihal Ranjit, Vineetha Nalla, Gargi Sen, & Teja Malladi, Indian Institute of Human Settlements (IIHS), India

CATEGORY

Systemic risk

KEY HAZARDS

Drought

COUNTRY

India

SUMMARY

The case study discusses the chronic drought situation in the Anantpur district of Andhra Pradesh, India, and has analysed the economic and social issues associated with the hazard. The study notes that the hazard has triggered a large-scale impact on socio-economic, environmental and political systems such as acute indebtedness due to failing agriculture, land degradation and poor fodder supply, trickling down to serious societal challenges such as farmer suicides, human trafficking of young women at national and international scales, and large-scale migration. The case study suggests various measures undertaken at local and national scales for drought-risk management, such as local employment generation programmes, drought monitoring and mitigation measures, and community-level drought-mitigation models. The case study further discusses the key challenges in disaster risk management, such as the lack of social safety nets to the farming communities, long-term management plans, and lack of comprehension of systemic risk. The case study concludes by highlighting the importance of long-term resilience-building models involving locals, and recommends the promotion of such sustainable models and practices, such as improved administrative monitoring and regulation, for the effective management of the hazard.

CASE STUDY 25: CHENNAI WATER CRISIS OF 2019 - A SYSTEMIC RISK

AUTHORS

Aditi Madan, Associate Fellow, Institute for Human Development (IHD) & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Systemic risk

KEY HAZARDS

Water crisis, stress and scarcity

COUNTRY

India

SUMMARY

The case study discusses the imminent water crisis in Chennai metropolitan area, India, that was linked to climate-deficit monsoon rainfall, rapid urbanization, unplanned growth and lack of effective planning for water scarcity management. The study notes that the hazard has triggered a large-scale impact on socio-economic, environmental and political systems, such as acute stress on females and marginalized communities, and farmers' indebtedness due to failing agriculture, trickling down to serious societal challenges such as rural-urban political conflicts, economic challenges due to business closures, and farmer suicides. The case study suggests prevention, mitigation and preparedness measures undertaken, such as the purchase of riparian rights, promoting acts, guidelines to address the water demand prior to the crisis and suggests that these did not have a positive impact because of poor urban management. The case study suggests various measures undertaken at local and national scales for wate- crisis management, such as government and private-run water tankers for drought management, and installation of a tertiary sewage plant. The case study further discusses the key challenges in risk management, such as the failure of the monitoring and evaluation system, lack of risk perception and long-term sustainable strategies, and innovation challenges. The case study concludes by highlighting the importance of law enforcement, long-term resilience-building models involving locals, and recommends the promotion of awareness campaigns for people and capacity-building programmes and innovative management programmes, for the effective management of the risk.

CASE STUDY 26: PUNJAB SPURIOUS LIQUOR POISONING IN AUGUST 2020: CASE STUDY

AUTHORS

Richa Srivastava, Research Consultant, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Systemic risk

ANNEXURE C: SUMMARY OF CASE STUDIES

KEY HAZARDS

Alcohol poisoning

COUNTRY

India

SUMMARY

The case study discusses the Punjab alcohol poisoning in 2020, that has been linked to the illicit liquor chain, and has affected the socio-economic-political fabric of the state. The study notes that the hazard has triggered a large-scale impact on socio-economic, environmental and political systems such as deaths, political tensions, and revenue losses. The case study suggests prevention, mitigation and preparedness measures undertaken such as promotion of acts and regulations, strict penalties and treatment camps. The case study further discusses the key challenges in risk management, such as the lack of proper rehabilitation programmes and awareness. The case study concludes by highlighting the importance of law enforcement, long-term resilience-building models involving locals, and recommends the promotion of affordable and safe liquor, long-term support schemes for affected families, unifying liquor laws, and awareness campaigns to prevent the illicit alcohol mafia, for the effective management of the risk.

CASE STUDY 27: LOSS OF ECOSYSTEM SERVICES OF THE MANATUTI RIVER SYSTEM, METRO MANILA

AUTHORS

Celso B. Dulce, CARE Philippines.

CATEGORY

Systemic risk

KEY HAZARDS

Non-point source water pollution and associated hazards

COUNTRY

Philippines

SUMMARY

The case study discusses the Malabon-Navotas-Tullahan-Tinajeros (Manatuti) river system that has been deemed unfit for use since 1990, and its impacts on the region. The study notes that the river system has been subject to poor ecosystem management, and has triggered flooding due to solid-waste contamination, resulting in a large-scale impact on socio-economic, environmental and political systems, such as damage to critical infrastructure and health, and deaths. The case study suggests prevention, mitigation and preparedness measures undertaken such as contingency plans, local climate change action plans, multi-stakeholder capacity-building activities prior to the crisis. The case study suggests various measures undertaken at local and national scales for water-crisis management, such as activation of contingency plans, mainstreaming of integrated risk management, early flood-warning systems. The case study further discusses the key challenges in risk management, such as the challenges in institutional, financial and community-level mechanisms that affect the overall risk management across all phases of disaster management. The case study concludes by highlighting the novel efforts concerning the harmonization between national, sub-national, and local-level plans, and integrated risk management, and recommends the promotion of community involvement in local area planning, for the effective management of the risk..

CASE STUDY 28: MUMBAI LANDSLIDE, JULY 2021

AUTHORS

Fatima Amin, Young Professional, ECDRM Division, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Systemic risk

KEY HAZARDS

Rainfall-induced landslides, floods

COUNTRY

India

SUMMARY

The case study discusses the series of landslides that occurred during torrential rainfall in Mumbai, India, in 2021, that has been linked to continuous deforestation, hillside construction, and flattening of hillsides, resulting in multiple landslide-prone zones in the city. The study notes that the hazard had triggered a large-scale impact, resulting in public and private property damage of around 400 billion INR, and suggests that the landslide has resulted in intangible losses such as real-estate depreciation and reduction in land taxes. The case study further highlights the generic measures to be advocated before, during, and after landslides and key developments..

CASE STUDY 29: LG POLYMERS INDIA PVT. LTD. – STYRENE GAS LEAK INCIDENT, VISAKHAPATNAM, ANDHRA PRADESH, 2020

AUTHORS

Kopal Verma, Junior Consultant, ECDRM Division, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM.

CATEGORY

Systemic risk

KEY HAZARDS

Styrene-gas leak during lockdown

COUNTRY

India

SUMMARY

The case study discusses the styrene gas leak at Vishakhapatnam during the pandemic lockdown, exacerbated by e existing administrative and regulatory lapses in the handling of the styrene gas, such as the insufficiency of chemical inhibiting self-polymerization, and lack of proper checks, resulting in significant impacts around the region. The study notes that the hazard has triggered impacts on socio-economic, environmental and political systems such as morbidity conditions, farming losses, ecological damage, infrastructural impacts and health hazards. The case study suggests prevention, mitigation and preparedness measures undertaken, such as ISO certifications and presence of alarms, , but highlights the poor organizational management in maintenance, that has exacerbated the risk. The case study suggests various measures undertaken at local and national scales for crisis management, such as immediate rescue services from stakeholders and expert committees for investigations. The case study further discusses the key challenges in risk management, such as regulatory lapses, poor emergency procedural lapses from the stakeholders and lapses in risk analysis. The case study concludes by highlighting the importance of law enforcement, local safety, and long-term resilience-building models involving locals, and recommends the promotion of administrative capacity-building programmes for addressing the challenges and for effective management.

CASE STUDY 10: THE SETI RIVER FLASH FLOOD DISASTER IN THE KASKI DISTRICT OF NEPAL, MAY 2012

AUTHORS

Shobha Poudel & Bhogendra Mishra, Policy Research Institute, Nepal.

CATEGORY

Cascading or compound disaster/risk

KEY HAZARDS

Riverine and flash floods due to avalanche, glacial lake outburst, and rockslide

COUNTRY

Nepal

ANNEXURE C: SUMMARY OF CASE STUDIES

SUMMARY

The case study discusses the styrene gas leak at Vishakhapatnam during the pandemic lockdown, exacerbated by e existing administrative and regulatory lapses in the handling of the styrene gas, such as the insufficiency of chemical inhibiting self-polymerization, and lack of proper checks, resulting in significant impacts around the region. The study notes that the hazard has triggered impacts on socio-economic, environmental and political systems such as morbidity conditions, farming losses, ecological damage, infrastructural impacts and health hazards. The case study suggests prevention, mitigation and preparedness measures undertaken, such as ISO certifications and presence of alarms, , but highlights the poor organizational management in maintenance, that has exacerbated the risk. The case study suggests various measures undertaken at local and national scales for crisis management, such as immediate rescue services from stakeholders and expert committees for investigations. The case study further discusses the key challenges in risk management, such as regulatory lapses, poor emergency procedural lapses from the stakeholders and lapses in risk analysis. The case study concludes by highlighting the importance of law enforcement, local safety, and long-term resilience-building models involving locals, and recommends the promotion of administrative capacity-building programmes for addressing the challenges and for effective management.

CASE STUDY 30: THE USE OF RIVER GEOMORPHOLOGY AND HYDROLOGY IN CRAFTING ALTERNATIVE SOLUTIONS TO THE PERENNIAL FLOOD PROBLEMS IN THE BISLAK CATCHMENT, LUZON, PHILIPPINES

AUTHORS

C.P. David, P.L.M Tolentino, & E. Guardian, University of the Philippines Diliman, Quezon City, Philippines; R.D. Williams, University of Glasgow, United Kingdom

CATEGORY

Systemic risk

KEY HAZARDS

Monsoon-rainfall-triggered floods

COUNTRY

Philippines

SUMMARY

The case study discusses the rainfall that triggered flooding of Bislak River in Ilocos Norte, Philippines, in 2018 and 2019, damaging pipe culverts and wall protection, resulting in the overflow of irrigation canals, and flooding of the towns of Vintar and Bacarra. The study notes that there have been significant impacts of the hazard on socio-economic, environmental and political systems, such as agricultural losses, infrastructural damages and registering an overall regional loss of PhP 1.1 billion in 2019 alone. The case study suggests prevention, mitigation and preparedness measures undertaken prior to the disasters, such as structural measures, early-warning and capacity-building measures by the authorities, and suggests that the disaster management focuses mostly on hard engineering and has poor comprehension of the river morphology. The case study further discusses the key challenges in disaster management, such as the acute administrative problem involved in the comprehension of changing river patterns that affect the nature of flooding, and suggests that these have resulted in redundant structural measures that were based on initial assumptions. The case study recommends flood management through practices such as catchment-widening, upstream river management and source managementd.

CASE STUDY 31: RISK TO FAILURE OF A FUNCTIONAL LOCAL HEALTHCARE SYSTEM: THE CASE OF CAGAYAN DE ORO CITY, PHILIPPINES

AUTHORS

Itchon Gina S, Lo Dexter S, & Vallente Jefferson Jr R, Xavier University, Ateneo de Cagayan, Philippines

CATEGORY

Systemic risk

KEY HAZARDS

COVID-19 pandemic

COUNTRY

Philippines

SUMMARY

The case study discusses the instance of COVID-19 in the Cagayan de Oro City of the Philippines, and analyses the immediate impacts, challenges and way forward for the city that had significant infrastructural gaps prior to the pandemic, especially in the health system. The study notes that the hazard has triggered a large-scale impact on socio-economic, environmental and political systems, such as immediate stress on health infrastructures, business closures and economic crisis. The case study suggests prevention, mitigation and preparedness measures undertaken, such as available legislation for proactive risk management, and adaptive social-protection programmes. The case study suggests various measures undertaken at local and national scales for emergency management and post-disaster recovery, such as the provision of city isolation units to quarantine COVID suspects, donation of RT-PCR machines, vaccine drives and information dissemination. The case study further discusses the key challenges in risk management, such as the failure of the monitoring and evaluation system concerning COVID-19and a lack of risk perception concerning health hazards. The case study concludes by recommending practices such as risk-informed planning and addressing capacity constraints, for the effective management of the risk.

CASE STUDY 32: RECURRENT FLASH FLOODS, EXTENT OF DAMAGES AND RISK MANAGEMENT IN THE UPPER SWAT VALLEY, PAKISTAN

AUTHORS

Liaqat Ali Khan & Atta-ur-Rahman, Department of Geography, University of Peshawar, Pakistan; Rajib Shaw, Keio University, Japan

CATEGORY

Systemic risk

KEY HAZARDS

Flash floods

COUNTRY

Pakistan

SUMMARY

The case study discusses the recurrent flood instances in the upper Swat valley, Pakistan, during the decade from 2010. The study notes that there have been significant impacts of the hazard on socio-economic, environmental and political systems such as mortalities (mostly children), large-scale livelihood issues, damages to critical infrastructure and impacts on sectors such as tourism. The case study suggests various steps undertaken for disaster risk management such as the formation of the National Disaster Management Authority, regulations and acts concerning disaster management, and further assembly of district disaster management unit. The case study further discusses the key challenges in disaster management, such as the acute institutional challenges concerning human resources, financial challenges resulting in the non-availability of adequate funds or financing for the DRR measures, and preference of short-term policies over long-term measures. The case study recommends flood management through accurate risk assessment modelling, strengthened institutional mechanisms and public awareness.

ANNEXURE C: SUMMARY OF CASE STUDIES

CASE STUDY 33: MOUNT ANAK KRAKATAU ERUPTION AND SUNDA STRAIT TSUNAMI – POTENTIAL AFFECTING INDUSTRIAL ZONES IN CILEGON CITY, BANTEN PROVINCE, INDONESIA 2018

AUTHORS

Farah Mulyasari, Department of Communication Science, Faculty of Communication and Diplomacy, Universitas Pertamina, Jakarta

CATEGORY

Both

KEY HAZARDS

Volcanic-eruption-triggered landslides and tsunami

COUNTRY

Indonesia

SUMMARY

The case study discusses the volcanic eruption of Mount Anak Krakatau, which cascaded into a tsunami due to the landslides generated as a result of the volcanic eruption. The study notes that the hazard has triggered a large-scale impact on socio-economic, environmental and political systems such as mortality, large-scale displacement of around 16,000 people, and collapse of critical infrastructure. The case study suggests prevention, mitigation and preparedness measures undertaken, such as city-wide preparedness and contingency plans, computer-based modelling of poisonous gases, three-tier emergency response measures in collaboration with the industries, risk-mapping of the chemical industries, and quantitative fire and explosion risk analysis. There had been poor development in community preparedness measures and risk assessment prior to the incident. The lack of coordination and multi-stakeholder assessment for effective delivery proved an impediment during disasters. The case study identifies effective multi-stakeholder participation as the major gap in post-disaster management and recommends the promotion of participatory technological assessment (PTA) tool that is multi-diverse, with a focus on Natech DRR, for the effective management of the risk.

CASE STUDY 34: RAJASTHAN DROUGHT, 2020

AUTHORS

Sreeja S. Nair, Consultant, UNDRR & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Systemic risk

KEY HAZARDS

Drought

COUNTRY

India

SUMMARY

The case study discusses the drought disaster in Rajasthan, India, and has analysed the economic and social issues associated with the hazard. The study notes that the hazard has triggered a large-scale impact on socio-economic, environmental and political systems, such as failing agriculture and significant crop losses, hydroelectric power losses, unemployment and debt issues, land degradation, and ecological challenges, such as fodder unavailability for the cattle. The case study suggests various measures undertaken at local and national scales for drought-risk management, such as crisis-management plans, promotion of long-term mitigation through the adoption of sustainable agronomic and conservation practices, and geospatial analysis. The case study further discusses the key challenges in disaster risk management, such as the administrative lapses in implementation, lack of risk-assessment measures, and lack of comprehension of systemic risk. The case study concludes by recommending various structural and non-structural measures, such as efficient rainwater-harvesting models, afforestation, and technological interventions, for the effective management of the hazard.

CASE STUDY 35: CASCADING MELAMCHI FLOOD DISASTER, JUNE 15, 2021 IN NEPAL

AUTHORS

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CATEGORY

Both

KEY HAZARDS

Floods

COUNTRY

Nepal

SUMMARY

The case study discusses the cascading Melamchi flood disaster on June 15, 2021 in Nepal, that was due to compounding incidents of glacial lake outbreak that triggered lake-dam outburst flood, and resulted in landslides and riverbank erosion, all of these contributing to flooding in the Melamchi settlement zones. The case study suggests significant impacts on socio-economic, environmental political systems, such as loss of livelihood options, and damages to critical infrastructure eventually affecting the community. In pre-disaster prevention, mitigation and preparedness measures, the case study suggests the lack of prevention and mitigation measures, even though evidence suggested the susceptibility of the region. In the case of emergency management, the case study highlights the effective evacuation and information management between locals helped in casualty reduction, and was further supported by immediate response measures from the administration. The case study further discusses the key challenges in disaster risk management, highlighting significant gaps in the phases of disaster management, such as unavailability of emergency evacuation planning, poor comprehension of cascading effects and lack of expertise in multi-hazard management. The case study recommends practices such as improving land-use policies, and advocating studies on river topography promoting mechanisms for early warning for effective management of the hazard.

CASE STUDY 36: 'BLACK SUMMER' BUSHFIRES, AUSTRALIA

AUTHORS

Kylie Ledger & Iftekhar Ahmed, School of Architecture and Built Environment, University of Newcastle, Australia

CATEGORY

Both

KEY HAZARDS

Forest fire

COUNTRY

Australia

SUMMARY

The case study discusses the 'black summer' bushfires of 2019 - 2020 in Australia, that were triggered by events such as prolonged droughts, dry lightning storms and heatwaves, and resulted in catastrophic, climate-driven bushfires for six months. The case study suggests significant impacts on socio-economic, environmental and political systems, such as high cases of mortality and morbid patients, large-scale economic losses involving around Aus$2billion in insurance, critical infrastructural damage, damage to national parks and associated ecology, and CO2 emissions, eventually exposing the political systems. The case study suggests prevention, mitigation and preparedness measures prior to the disasters, such as promotion of guidelines

ANNEXURE C: SUMMARY OF CASE STUDIES

and frameworks, insurance, and business-continuity strategies, fire prediction and modelling systems for risk analysis, but suggests that there existed a complicated system that was overburdened by frameworks, committees and other bodies. The case study suggests various measures undertaken at local and national scales for crisis management, such as immediate rescue services from the stakeholders, rescue efforts from state and interstate personnel, and assistance from other countries. The case study further discusses the key challenges in risk management, such as under-insurance issues, lack of administrative interoperability and challenges due to the onset of COVID-19 just after the crisis. The case study concludes by highlighting the importance of clearer emergency and disaster response roles of stakeholders, improved risk comprehension, and promotion of administrative capacity-building programmes for addressing the challenges and for effective management.

CASE STUDY 37: THE PALU EARTHQUAKE, FLOW LIQUEFACTION AND TSUNAMI, 2018

AUTHORS

Nuraini Rahma Hanifa, U-INSPIRE Indonesia / Research Center for Geotechnology, National Research and Innovation Agency (BRIN); Annisa Triyanti, Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands; Mizan Bisri, Kobe University, Japan/ U-INSPIRE Indonesia; Aruminingsih, BAPPENAS, Indonesia; Irina Rafliana, Indonesian Institute of Sciences (LIPI), Indonesia/ German Development Institute, Bonn, Germany; Rahmadiyah Tria Gayathri, Forum Sudut Pandang Community, Palu, Indonesia/ U-INSPIRE Indonesia; Endra Gunawan, Institut Teknologi Bandung, Indonesia; Gusti Ayu Ketut Surtiari, Indonesian Institute of Sciences (LIPI), Indonesia; Jonatan Lassa, Charles Darwin University, Australia; Mohamad Isnaeni Muhidin, Nemu Buku, Palu, Indonesia; Riyanti Djalante, ASEAN Secretariat, Indonesia

CATEGORY

Both

KEY HAZARDS

Earthquake triggering flow slide liquefaction, tsunami, landslide

COUNTRY

Indonesia

SUMMARY

The case study analyses the cascading and systemic risks associated with the Palu disaster of Indonesia in 2018 that was triggered by an earthquake and subsequent events such as flow liquefaction and tsunami, eventually resulting in a global re-evaluation of tsunami risk. The case study suggests significant impacts on socio-economic, environmental, political systems, such as 4,000+ cases of mortality and large-scale economic losses involving around $1.3 million, critical infrastructural damage to water and irrigation systems and transport infrastructures, trickling down to serious issues such as agricultural damage due to disrupted irrigation systems, and slope instability generating novel risk contributing to subsequent hazards such as flash floods. The case study suggests prevention, mitigation and preparedness measures prior to the disasters, such as hazard-mapping and updating of building codes, but highlights there existed a significant gap in research, policy, and implementation on various aspects of emerging risks and resilient infrastructures, a knowledge gap in systemic risk comprehension and challenges in risk-assessment mechanisms, that aggravated the intensity of the disaster. The case study suggests various measures undertaken at local and national scales for crisis management, such as immediate rescue services from stakeholders such as state, national and international personnel, such as ASEAN and UNDAC, in the form of assistance, tools, and mechanism delineation of no-development zones and relocation plans, alongside highlighting challenges such as limitations of multi-hazard early-warning systems, loss of public trust in leadership, and chaos. The case study concludes by highlighting key good post-disaster practices, such as multi-stakeholder-based hazard-mapping, and improved standardization for build-back-better solutions, and recommends intensive multi-hazard research, multi-stakeholder policy planning, investments in earthquake resilience, and nature-based solutions, for the effective management of the hazard.

CASE STUDY 38: CHIPLUN FLOOD 2021, MAHARASHTRA

AUTHORS

Sweta Baidya, CAP-RES, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM

CATEGORY

Both

KEY HAZARDS

Rainfall and dam release triggered flood, landslide.

COUNTRY

India

SUMMARY

The case study analyses Chiplun Flood 2021 of Maharashtra, India, which was triggered by incessant rainfall and a subsequent dam release that resulted in floods and landslides in the Chiplun town in Maharashtra. The case study suggests significant impacts on socio-economic, environmental political systems, such as large-scale commercial losses involving around $500 million, critical infrastructural damage to water and irrigation systems and interstate road transport infrastructure, trickling down to serious cross-boundary issues concerning connectivity for the nearby states, affecting their functions. The case study suggests prevention, mitigation and preparedness measures prior to the disasters, such as national-level legislation, and suggests there existed significant gaps in local-level planning, such as lack of awareness, lack of local-level legislation on disaster management, and poor early warning, local-level risk analysis and risk communication, that aggravated the intensity of the disaster. The case study suggests various measures undertaken at local and national scales for crisis management, such as immediate rescue services from local, state and national stakeholders in the form of assistance, but suggests that there had been a significant gap in emergency management and post-disaster recovery, such as lapses in the national aid and lack of intersectional coordination. The case study concludes by highlighting key good post-disaster practices such as proposing resilient infrastructures for disaster mitigation, multi-stakeholder-based hazard-mapping, and improved standardization for build-back-better solutions, and recommends resource building and drainage for the effective management of the hazard.

CASE STUDY 39: HOSPITAL OVERCROWDING, METRO MANILA, APRIL – AUGUST 2021

AUTHORS

John Earnest Jose, Architecture Without Ego, Philippines

CATEGORY

Both

KEY HAZARDS

COVID-19 pandemic

COUNTRY

Philippines

SUMMARY

The case study analyses the impacts on the health system after COVID-19 lockdown easement, and the subsequent challenges arising from the delta

ANNEXURE C: SUMMARY OF CASE STUDIES

variant. The case study suggests significant impacts on socio-economic, environmental political systems associated with health infrastructures, such as poor medical attention, economic challenges for health workers, governmental overspending for response measures, and mental issues, trickling down to serious issues such as failing critical infrastructure systems due to overloading. The case study suggests prevention, mitigation and management measures prior to the second wave, such as vaccine drives, quarantine facility management measures and Covid-19 modular hospitals, that addressed the existing COVID-19 challenge. The case study suggests that there had been a significant gap in emergency management and post-disaster recovery, such as lapses in the payment of essential workers, poor COVID-19 relaxation protocols, and political corruption. The case study concludes by highlighting key good post-disaster practices, such as addressing capacity challenges; multi-stakeholder-based planning and pandemic-sensitive designs, for the effective management of the hazard.

CASE STUDY 40: CYCLONE EARLY WARNING AND EARLY ACTION FOR TROPICAL CYCLONE YASA, 2020E STUDY OF DECEMBER 2020

AUTHORS

Bapon (Shm) Fakhruddin, Tonkin + Taylor, New Zealand

CATEGORY

Both

KEY HAZARDS

Cyclone during COVID-19 pandemic triggering floods and landslides

COUNTRY

Fiji

SUMMARY

The case study analyses the tropical cyclone Yasa that affected Fiji during the COVID-19 pandemic and subsequently resulted in floods and landslides. The case study suggests significant impacts on socio-economic, environmental and political systems, such as large-scale displacements, infrastructure, crop and livestock losses of about $53 million, trickling down to serious issues such as compounding poverty challenges with COVID-19 impacts, and coping-capacity challenges for the overstressed health infrastructure. The case study suggests prevention, mitigation and preparedness measures prior to the disasters, such as early-warning systems like coastal inundation forecasting systems, structural mitigation measures and cyclone shelters, but highlighted that there existed income disparities that prevented the underprivileged from safe constructions. The case study su--------ggests various measures undertaken at local, national and international scales for crisis management, but suggests that there had been a significant gap in emergency management and post-disaster recovery, such as lapses in information flow, lack of community-resilience measures, intersectional coordination and post-recovery maintenance issues. The case study concludes by recommending further enhancement of impact-based early-warning systems for multi-hazards, risk awareness and capacity building, for the effective management of the hazard.

OUTBREAK IN ELURU, ANDHRA PRADESH: A CASE STUDY OF DECEMBER 2020

AUTHORS

Atisha Sood, Research Fellow, ECDRM Division, NIDM & Anil Kumar Gupta, Professor & Head, ECDRM Division, NIDM.

ANNEXURE D: EXPERTS' CONSULTATIONS

The draft report was provided to key experts within and outside AP-STAG, and their written feedback was sought using a template for guided consultation. The feedback from the following experts was received and duly incorporated while finalizing the report:

1. Ailsa Holloway, Auckland University of Technology, ailsa.holloway@aut.ac.nz
2. Mahua Mukherjee, IIT Roorkee, mahua.mukherjee@ar.iitr.ac.in
3. Nuraini Rahma Hanifa, U-INSPIRE Indonesia/ Research Center for Geotechnology, National Research and Innovation Agency (BRIN), rahma.hanifa@uinspire.id; nura010@brin.go.id
4. Antonia Loyzaga, National Resilience Council/ Manila Observatory, aloyzaga@observatory.ph
5. Prof Emily Chan, Faculty of Medicine, Chinese University of Hong Kong, emily.chan@cuhk.edu.hk
6. Iria Touzon Calle, UNDRR, iria.touzoncalle@un.org
7. Andrew Spezowka, UNDRR
8. Rhea Katsanakis, UNDRR

The template used is placed below.

NAME AND AFFILIATION OF REVIEWER:

EMAIL ID:

Please provide your feedback and suggestions on the following sections of the study.

SECTIONS	FEEDBACK AND SUGGESTIONS	SUGGESTIVE ADDITIONAL LITERATURE/LINKS
Literature review on compound, cascading, and systemic risks		
Conceptual framework and analysis		
Identified gap areas		
Identified lessons learnt		
Basic Principles for management of compound, cascading, and systemic risks		
Framework for strengthening of risk governance		
Recommendations for strengthening of risk governance at the local, national, and regional scale		
Figures and tables used		
Any additional feedback and suggestions on the overall report		

ANNEXURE E: RESULTS FROM THE FRAMEWORK FOR RISK ANALYSIS AND MANAGEMENT

1. RESULTS FROM THE FRAMEWORK FOR RISK ANALYSIS

The results from the analysis done with respect to Figure 11, and the associated discussions, are put forward in this section. The key types of hazards covered in the case studies include meteorological and hydrological, geohazards, environmental, chemical, biological, and technological. Studies related to societal and extra-terrestrial hazards were not received and thus not considered in the analysis of this scoping study.

- **Distribution of the type of triggering hazards**
From the 40 case studies analysed, it can be inferred that meteorological and hydrological (or hydrometeorological) hazards are the most prevalent type of triggering hazard. They have been reported as triggering hazards in 44 per cent of the case studies (Figure 18). Meteorological and hydrological hazards originate due to hydrometeorological conditions. These include hazards such as cyclones, floods, drought, heatwaves and storm surges, and can trigger other hazards such as landslides, wildfires, epidemics and dispersal of toxic substances. Geohazards, such as earthquakes, were reported as triggering hazards in 20 per cent of case studies; followed by biological hazards (13 per cent). Environmental and technological hazards triggered other hazards in 10 per cent of the cases, whereas chemical hazards in 3 per cent of the cases. (UNESCAP, 2020) notes that the Asia Pacific region is largely affected by hydrometeorological hazards, especially floods, followed by geophysical hazards such as earthquakes and landslides. Additionally, the (UNDRR, 2020) Hazard Definition and Classification Review (referred to as the Hazard Review Report from here onwards) reports that 38 per cent of the total hazards, 56 per cent of the deaths, and 75 per cent of the economic losses globally, occur due to hydrometeorological hazard induced disasters. This is similar to the results obtained from the analyses of the case studies and puts forward the fact that weather, climate and water-related hazards occur more frequently, and therefore can trigger other hazards, leading to cases of compound, cascading and systemic risks.

- **Distribution of the type of triggered hazards**
From the 40 case studies analysed, it can be inferred that technological hazards are the most triggered ones (35 per cent). This is followed by hydrometeorological (32 per cent) and environmental (16 per cent) hazards. Geohazard, chemical, and biological hazards were seen to occur the least (9 per cent, 5 per cent, and 3 per cent respectively) (Figure 19).
Based on the Hazard Review Report (UNDRR, 2020), 25 per cent of the total hazards globally are technological in nature. Technological hazards are triggered more often, owing to industrial conditions, dangerous procedures, infrastructure failures or specific human activities, such as industrial pollution, nuclear radiation, toxic wastes, dam failures, transport accidents, factory explosions, fires and chemical spills. The 2011 Great East Japan earthquake and tsunami which, coupled with underlying vulnerabilities, triggered the nuclear accident, and the Chernobyl disaster of 1986 (triggered by human activities), are two severe nuclear accidents that can be categorized as technological disasters triggered by other hazard events. The specific category of cascading hazard events, where technological disaster is triggered by a natural hazard, is known as Natech, or Natural Hazards Triggering Technological Disasters.

- **Relationship between types of triggering and triggered hazards**
The frequency of the six types of hazards triggering the other types of hazards is depicted in Figure 20. The numbers mentioned in the respective circles represent the number of times a particular hazard type has triggered the other hazard type, as captured in the case studies. Therefore, it can be inferred that

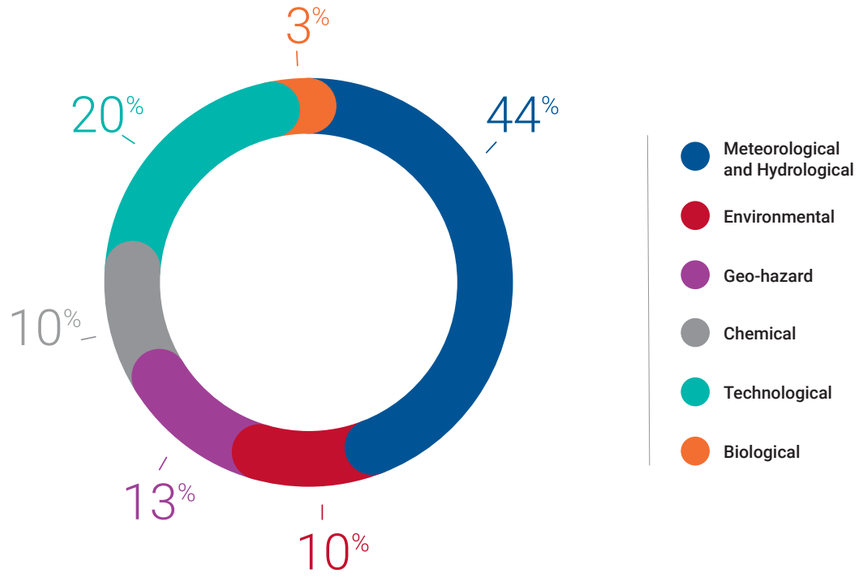

Figure 18: Distribution of the type of triggering hazards

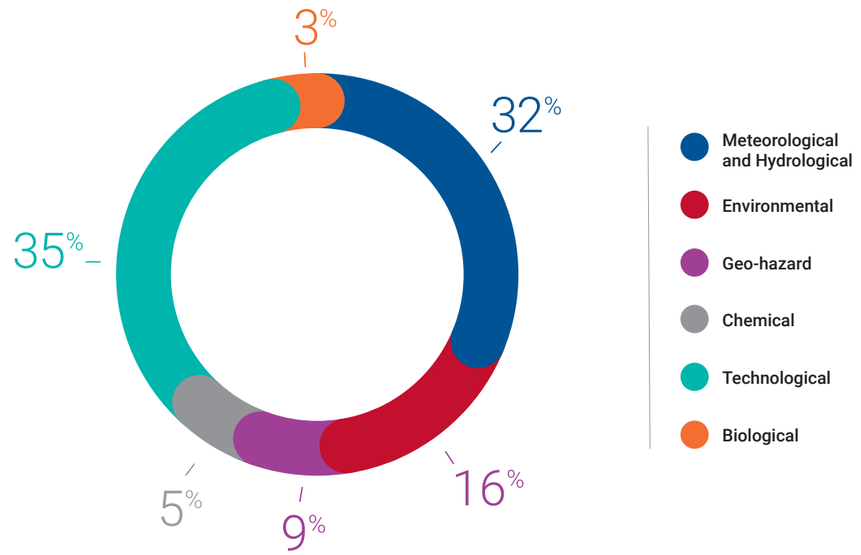

Figure 19: Distribution of the type of triggered hazards

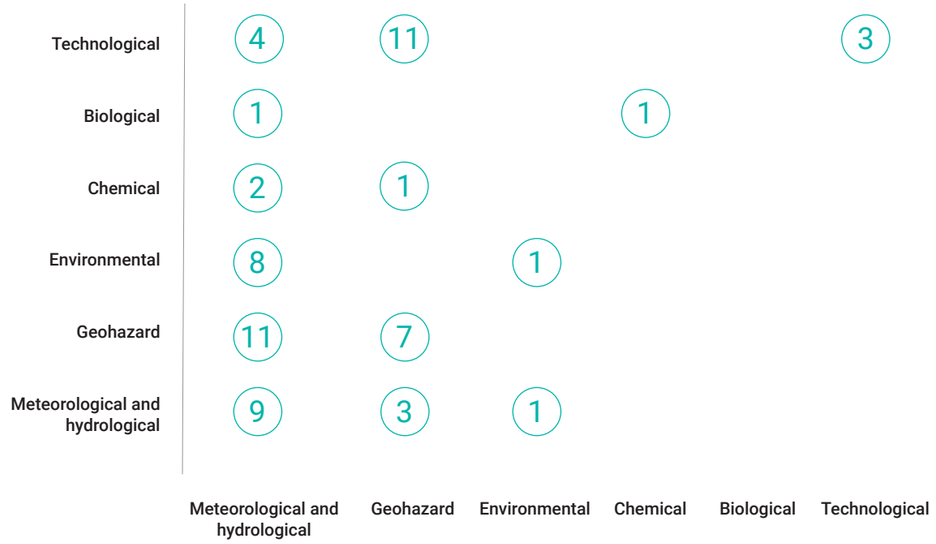

Figure 20: Relationship between types of triggering and triggered hazards

hydrometeorological and geohazards have been instrumental in triggering the most types of hazards (all six types). Besides, hydrometeorological hazards have triggered geohazards the most, followed by hydrometeorological hazards themselves and environmental hazards. Geohazards have triggered the technological hazards the most, followed by geohazards themselves.

Several cases of Natech were also recorded where technological hazards were triggered by natural hazards such as meteorological and hydrological and geohazards, as represented in Figure 20. UNDRR and APSTAG (2020) note that the Great East Japan earthquake and tsunami of 2011 and the triggered nuclear accident, had stimulated the studies on understanding and managing Natech risks. The report further highlights that, as per estimations, around 5 per cent of the total industrial accidents reported (up to the last 20 years) account for Natech events. However, such events continue to be under-reported even today. This under-reporting is also reflected in the disaster databases, which enlist the single disaster induced by natural or technological hazards, but often do not list the compound and cascading hazard events, thus creating a void of scientific evidence for better informing thedecision-makers on the evolving landscape of risk.

- **Speed of onset of triggering hazards**
From the case studies, it can be inferred that 79 per cent of the reported triggering hazards are fast-onset or sudden, such as earthquakes and flash floods, and only 21 per cent of the case studies cited slow-onset hazards such as droughts, sea-level rise or epidemics (Figure 21). The speed of onset of a disaster is important because it can characterize the event altogether and guide practitioners in responding and managing the hazard.
The nature of a slow-onset disaster is such that its actual severity is far from how it is perceived. It is difficult to set up aproactive early-warning response system for slow-onset disasters, due to which timely generic DRR actions cannot be practically taken up by the authorities (Staupe-Delgado, 2019). The slow-onset disasters, despite their potential to cause loss of life, disruption, and destruction, fail to gather much attention and focus in comparison to the rapid-onset disasters.Robinson (2021) highlights that fast-onset disasters "rapidly emerge, peak, and cause devastation with little warning" and tend to attract international attention, which is not the case with slow-onset disasters. The analysis further highlights this gap that slow-onset disasters and their impacts often fail to get adequately reflected and integrated into disaster studies and databases. For example, SEI (2021) notes that the Asia Pacific region witnessed approximately 19.1 million new disaster-induced displacements in the year 2019. However, displacement triggered by slow-onset hazards such as sea-level rise, droughts and environmental degradation, which tend to displace a larger number of people, that too 'repeatedly and for longer periods', are not accounted for in this.
A positive step in this direction is the first-time inclusion of the cost of slow-onset disasters such as droughts in the Asia Pacific Disaster Report 2019 (UNESCAP, 2019). This is significant, as the accounting of the losses incurred due to slow-onset disasters has led to a four-fold increase in economic losses due to disasters as against the earlier estimates. This reflects the possibility of laying down misinformed policies and interventions if such crucial information is not accounted for and duly reflected in disaster databases and studies.

- **Type of underlying vulnerabilities** The complex interactions between the hazards and the associated vulnerability play a defining role in triggering compound, cascading and systemic risks. The case studies were examined for five different types of vulnerability, namely, physical, social, economic, institutional or governance, and environmental and interactions therein. The analysis suggests that in most of the cases studied, more than one type of vulnerability and their interactions played a defining role in aggravating disaster impacts, as depicted in Figure 22. 23 out of 40 cases (58 per cent) relate to a single type of vulnerability. The remaining 42 per cent of the cases are associated with two or more vulnerabilities. This shows the complex interplay between different underlying vulnerabilities, wherein one type of vulnerability can aggravate the other one. Further, the analysis suggests that maximum case studies showcased environmental vulnerability followed by physical vulnerability and

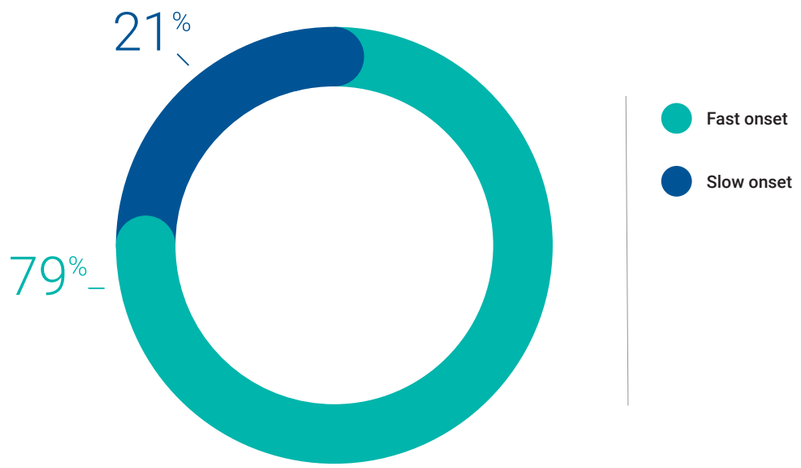

Figure 21: Speed of onset of triggering hazards

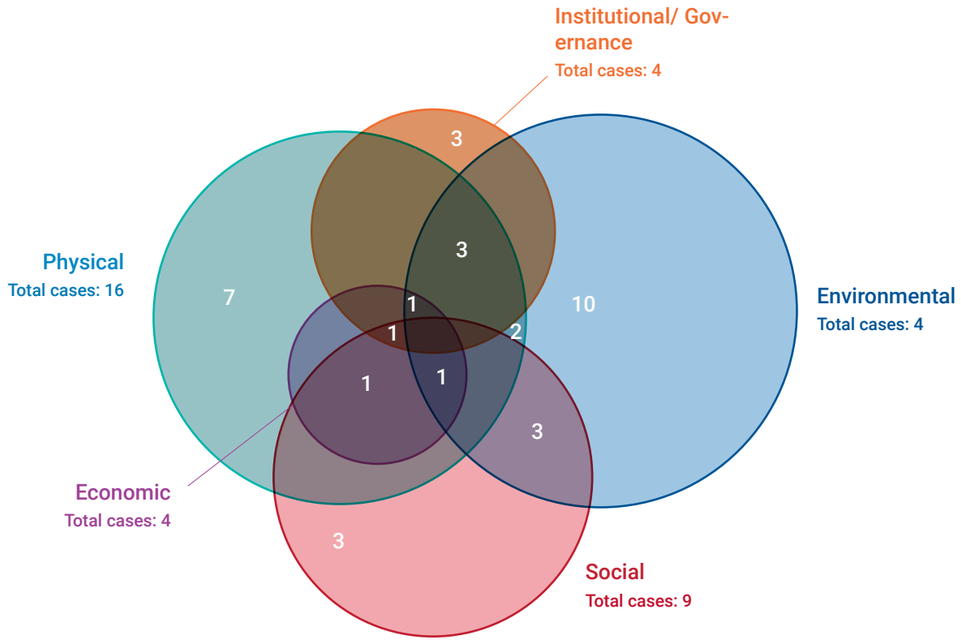

Figure 22: Type of underlying vulnerabilities

social vulnerability. A few case studies focused on aspects of institutional vulnerability, such as poor governance policies, that exacerbated the risks. Similar findings are underscored in UNESCAP (2019), which highlights those various recentdisasters, particularly the ones triggered by climate change and environmental degradation, have demonstrated significant deviations from their earlier characteristics with increased intensity, frequency, complexity and uncertainty. The Asia-Pacific Disaster Report 2019 demonstrates that the key risk hotspots in the region have emerged at the convergence of fragile ecosystems and socio-economic vulnerabilities (UNESCAP, 2019). This has created situations for disasters to further worsen the socio-economic well-being of the already poor, marginalized and disempowered groups. This brings forth the complex interactions and overlapping across different dimensions of vulnerabilities, and the resultant vulnerability to compound, cascading and systemic risks. Thus, the need for capturing these complex interactions and having in place a multi-layer vulnerability assessment process and disaggregated databases, cannot be overemphasized. In the backdrop of the environmental vulnerabilities and fragile ecosystems increasingly acting as drivers of risk, ecosystem-based DRR (eco-DRR) may provide some sustainable solutions. Nature-based solutions are based on the scientific understanding of the interconnectedness of nature and people (UNDRR, 2021) and can, thus, be effective at addressing the complex nature of risk, which thrives on the interconnectedness of systems and their networks. This suggests that understanding risk at a landscape and ecosystem level may provide sustainable nature-based solutions for mitigation and management of compound, cascading and systemic risks. Thus, there is a need for the integration of ecosystem-based approaches such as eco-DRR and ecosystem-based adaptation (EbA) for understanding, mitigating, managing and adapting to emerging complex risks.

Further, the aspect of physical vulnerability as a key driver of risk resonates in the Economic and Social Survey of Asia and the Pacific 2021, which reflects that the impacts of natural-hazards-induced disasters are more profound in countries that possess low-quality physical infrastructures (UNESCAP, 2021b). It further emphasizes that the adverse effects of climate change are likely to further disrupt the access of the poor and vulnerable communities to critical infrastructure systems and services. Similarly, UNESCAP (2020) notes that a few Indian states are at high risk from cascading disasters, with almost 150 million people exposed to the underlying vulnerabilities. The report further suggests that of the available 20,000 hospitals (a critical infrastructure) in these states of India, over 6 per cent fall in flood- prone zones, thereby suggesting the associated compound, cascading and systemic risks. The physical vulnerability of critical infrastructure can be a major impediment in reducing and managing cascading risk (which is often closely associated with critical infrastructures). Around 28 per cent of the energy, 34 per cent of information and communication technology (ICT) infrastructure in the Asia Pacific region is prone to several hazards (CDRI, 2021).

- **Systems impacted**
  The case studies covered various systems such as cultural, ecological, economic, food, health, infrastructural, institutional and governance, and social systems. The percentages of case studies where the mentioned systems were affected, is shown in Figure 23. The complexity of the interactions among the eight key systems affected in the referred case studies is depicted in Figure 24. The font size of a system's name is directly proportional to the number of case studies where the particular system has been affected. The blue lines and the polygons linking the systems depict the combination of interaction between differentaffected systems. The thickness of the lines and polygon is directly proportional to the frequency of these combinations, as per the case studies. The top three combinations of systems affected are – (i) ecological, economic and infrastructural systems; (ii) economic, infrastructural and social systems; (iii) economic, infrastructural and food systems.

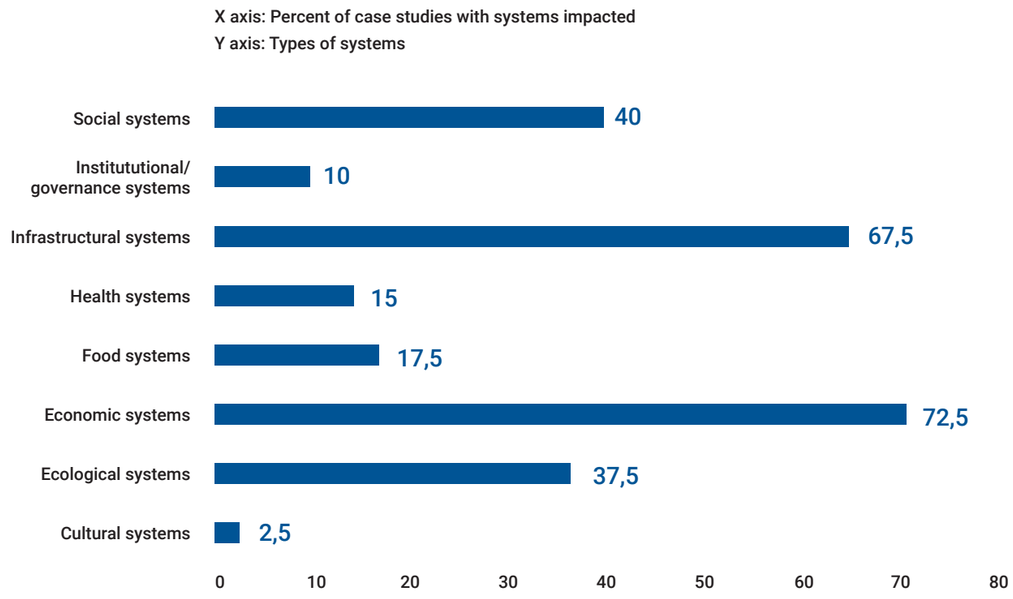

Figure 23: Percent of case studies with different systems impacted

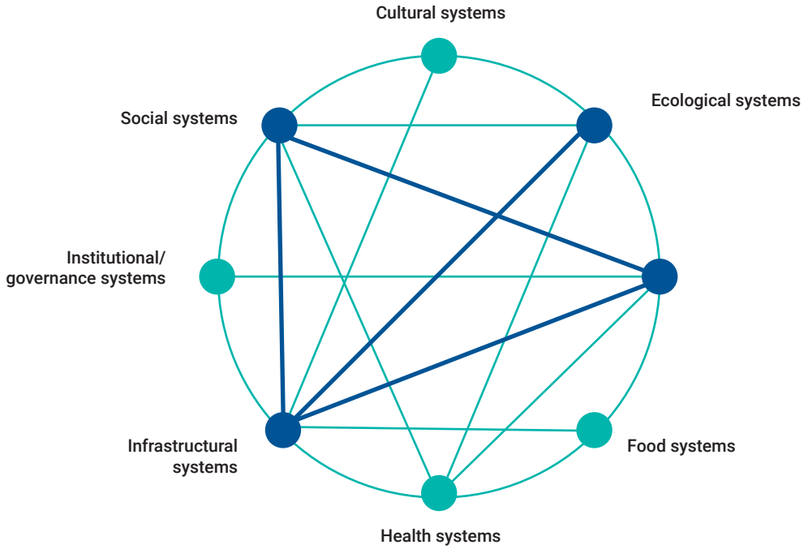

Figure 24: Systems impacted and interactions therein

It is observed that economic systems were affected in around 73 per cent of the case studies, followed by infrastructural systems in around 68 per cent of cases, while cultural systems are affected in around only 3 per cent of cases. Similar to the findings, UNESCAP (2019) notes that almost 40 per cent of disaster impacts in the Asia Pacific region are on the social sector (housing, education) and economic sectors such as agriculture, livestock and fisheries, which can be linked to production and livelihood. The high impact of disaster risks on economic systems is also reflected in the UNESCAP (2021c), which talks about the economic cost of cascading hazards and climate change. It provides estimates on the same by accounting for the adverse impact of climate change (Figure 25). It notes that while hydrometeorological hazards and geophysical hazards currently account for an annual loss of $780 billion in the UNESCAP region, the same is estimated to shoot to around $1.1 trillion under the worst-case[7] climate change scenario.

Further, the literature suggests that the term 'cascading failure' is widely used in the case of critical infrastructure failure, where damage to a single infrastructure could cascade and cause a breakdown in multiple infrastructures. This can be inferred from the results of case studies where economic and infrastructural systems are closely related, and the impacts on one cause an impact on the other as well. This is a defining characteristic of compound, cascading and systemic risks, where multiple effects to the system can be observed in an interrelated and complex manner. The case studies also indicate that the failure of various types of infrastructure has exacerbated the risk of technological hazards. As highlighted in earlier sections, the majority of the case studies exhibit physical vulnerability, which underscores the need for enhancing the resilience of infrastructural systems with a focus on critical infrastructure.

7 Calculated at Representative Concentration Pathways (RCP 8.5)

For doing so, it is crucial to undertake scenario planning for capturing the potential effects of cascading, compound and systemic risks with due considerations for the present and worst-case climate change scenarios. UNESCAP (2021c) brings forth a few of the worst-case climate change scenarios for critical infrastructure in the region, with alarming results.

For instance, one such scenario demonstrates that around 43 per cent of healthcare facilities in Myanmar are situated in areas of extreme multi-hazards risk. Similarly, Nepal accounts for around 93 per cent of the power grid and 98 per cent of hydropower capacity being exposed to multi-hazard risks.

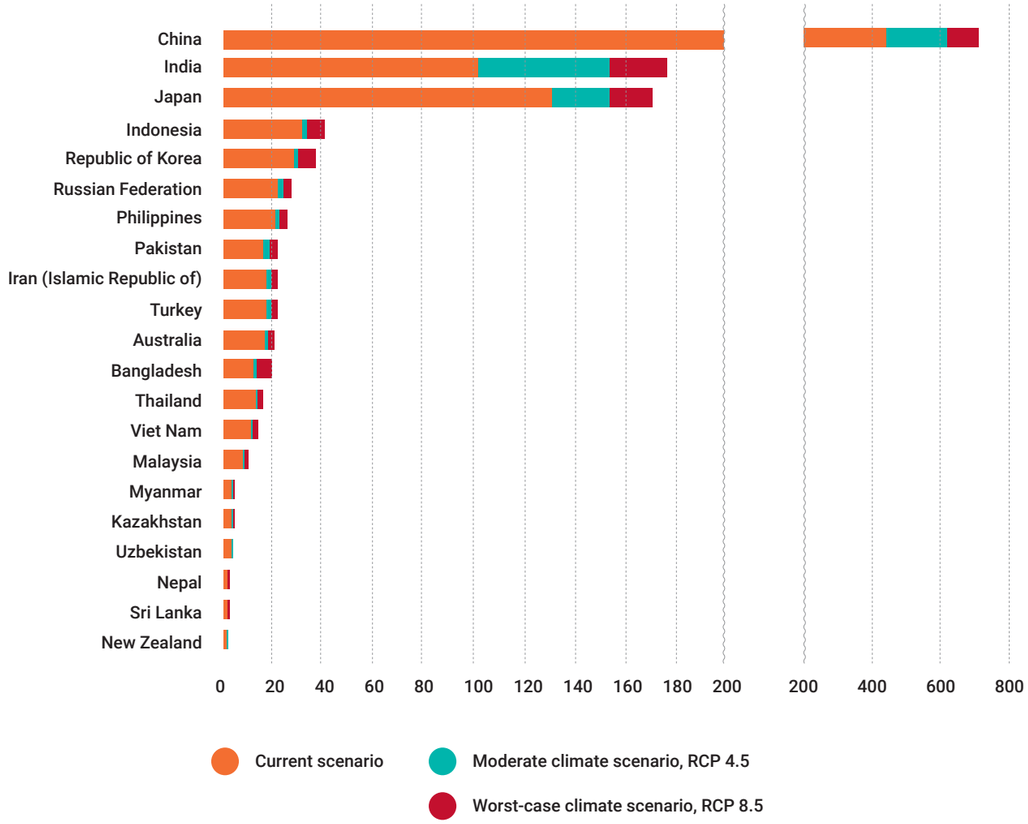

Figure 25: Average annual losses from cascading risk and climate change
(Source: UNESCAP, 2021c)

- **Characteristic of cascading risk**

  › **Presence of a chain of events**
  It has already been established in Section 2 that cascading risks consist of one or more than one chain of events that affect interdependent systems and also have the potential to become a systemic failure. The Great East Japan earthquake and tsunami of 2011, coupled with underlying vulnerabilities, led to a nuclear breakdown – this is an unfortunate example of the presence of a chain of events that has managed to leave an impact on the global scenario even after 10 years have passed. In the presence of a chain of events, as exhibited by the case studies, many components of the urban system are at risk of being damaged or facing total collapse. For example, many critical infrastructure systems got disrupted due to impact on the power grid, food security and supply chain, or drought leading to crop and livelihood losses. Each of the events in the chain may have a stand-alone impact on the system and involve multi-sector vulnerability, thereby increasing the risks associated.

- **Characteristics of systemic risk**

  › **High complexity**
  Literature and case studies suggest high complexity as one of the key characteristics of systemic risk. A complex system exhibits emergent properties that arise from interactions among its constituent parts (UNDRR, 2019). The complexity involved in systemic risk can be defined by components associated with the risk, such as triggering and triggered hazards, different dimensions of underlying vulnerability, or interactions among the system of systems. As per OECD (2003), a risk becomes systemic when a society's essential systems, such as telecommunications, transport and healthcare, are potentially threatened. This perspective focuses on the perpetuation of society and implies that contextual factors originating in the domains of demography, ecology, technology and socio-economic structures have a significant influence on systemic risk. Furthermore, these contributing factors are often related to each other, leading to interdependencies and increased complexity. These interdependencies impede comprehensive risk analysis and, consequently, pose a major stumbling block for risk management.

  The case studies' analysis suggests that inadequate understanding of complex interactions and also mismanagement of these interactions caused the impacts from the primary event to further exacerbate, leading to a disruption or complete breakdown of the systems.
  The underlying complexity may be sufficiently intricate that quantification and prediction of risk may not be easy. In many instances, the capacity to make pertinent real-world observations is limited or absent, and yet an improved understanding of systems' dynamics is required to elaborate estimates that are valid for improved decision-making. In this context, most prevailing risk-management tools assume underlying systems are complicated[8], rather than complex. In fact, these tools are often deliberately designed to suppress complexity and uncertainty. This approach is increasingly outdated and potentially harmful in a globalizing and increasingly networked world, and is likely to produce results that simply fail to capture the rising complexity of the topology of risks.

  › **Transboundary and global in nature**
  The existing knowledge base suggests that systemic risk is transboundary and global in nature, in the sense that a systemic failure at a local, national or regional level, can have repercussions across boundaries. The functioning of the highly interconnected globalized society depends substantially on connectivity and supply chains. Systemic risk may have a glaring impact on supply chains with the potential to affect society on a global scale. Moreover, the supply chain isn't a single process but rather a complex system of interconnected and interdependent relationships. As such, disruptive events resulting from systemic risk can trigger a domino effect up and down the supply chain, even causing adjacent industry failures. Systemic risks do not take turns; they often trigger one another and can materialize all at once. However, the case studies illustrate that systemic risk does not always manifest at transboundary or global scale only. Most of the case studies focus only on the local-scale impacts due to systemic risk. While some of these are local impacts, those pertaining to disruption in supply chains and economic losses, have the potential to trigger transboundary effects. The same is not explicitly captured in all the case studies. This does provide an alternate viewpoint on the transboundary and global characteristic of systemic risk which is also underscored in (UNDP, 2021).

  › **Stochastic, random and unexpected relationship between trigger and effects**
  A complicated system can be (dis-)assembled and understood as the sum of its parts (UNDRR, 2019)This nature of the systemic risk was comparatively difficult to analyse through the case studies received. It was challenging to identify if the relationship between the trigger and effects was stochastic, which indicates randomness. A clear example of randomness would be the Great East Japan nuclear accident of 2011, where critical infrastructure unexpectedly broke down after being triggered by an earthquake and a tsunami. However, the analysis of other case studies highlights that there is a need to further simplify this characteristic of systemic risk so that it could be easily understood, and hence effectively used, by policymakers and risk management practitioners.

  › **Non-linear and has trigger or tipping points**
  Systemic risk is non-linear and includes trigger or tipping points that cause secondary effects. A system collapse may also happen at this point. The case studies exhibit that in many instances, secondary impacts such as income disparities, health hazards, impact on the environment or loss of vegetation, were caused due to the lack of specific sector-related policies and mismanagement. This illustrates that a high level of interconnectedness and interdependence prevailing amongst the sectors and systems has the potential to create conditions for systemic failure in case of any major change in the dynamics of their interactions. Trigger or tipping points often alter these prevailing dynamics, making them non-linear in nature. The case studies illustrate that trigger or tipping points can either be hazard events or existing socio-economic, ecological conditions, such as a series of droughts or climate change.

  › **Underestimated in public policy arenas and public perception due to uncertainties of point of occurrence and extent of damage**
  This nature of systemic risk can be attributed to its characteristic of being random as well. Owing to this latent nature, policymakers and risk-management practitioners face challenges in timely identification, and consequently, in framing adequate risk-management policies and measures to address systemic risk. A clear example of such an unnoticeable risk is soil liquefaction[9] with the potential to cause earthquakes. This latent nature of systemic risk can also be associated with some risks being new or emerging and hence being unknown, and not well-documented earlier. It is also possible that systemic risk goes unnoticed in case it is associated with hazards with longer return periods or those for which the risk perception of stakeholders, including policymakers and community, is low. However, one of the case studies, that of Anantapur district, Andhra Pradesh, India, presents the case of the regular occurrence of droughts over past decades and highlights the lack of implementation of adequate drought-management policies leading to the manifestation of systemic risk. This clearly illustrates that systemic risk is not always caused by latent conditions, but aspects such as lack of adequate policies and their degree of effectiveness may also create conditions for systemic risk to go unnoticed and unregulated.

8 A complicated system can be (dis-)assembled and understood as the sum of its parts (UNDRR, 2019)

9 Liquefaction is the conversion of soil into a fluid-like mass during any seismic event.

2. RESULTS FROM THE FRAMEWORK FOR RISK MANAGEMENT

The results from the analysis of case studies done with respect to Figure 12, and the associated discussions, are put forward in this section.

- **Elements of risk governance included in pre-event measures**
  As per the case studies' analysis, among the 10 identified elements of risk governance (Figure 12), the element of 'DRR policies and guidelines' (72.5 per cent) forms the most prevalent element included in pre-event measures, followed by the element of 'risk perception and communication' (32.5 per cent). These elements cover aspects such as rules,regulations, plans, and studies that are developed by the governments at local and national. 'Stakeholder management' (22.5 per cent) is another important element that reflects pre-event resilience building for effective management of the risk (Figure 26). The analysis suggests that authorities rely on prevailing legislation, policies and plans, which often aim at reducing and managing risk arising out of single hazard events and associated vulnerabilities, rather than considering those arising out of the interplay of multiple hazards, varied dimensions of vulnerabilities, and interconnected systems at risk. This brings out a major gap in current risk-management policies and plans, which may not suffice to manage the compound, cascading and systemic risks which involve the interplay of multiple hazards and underlying vulnerabilities. For example, the nuclear accident cascading from the Great East Japan earthquake and tsunami of 2011, suggested that the then-existing nuclear safety regulations that focused on protecting the power plant from natural hazards, were not adequate. Thus, the regulatory framework must be able to cover various types of hazards, including their combinations, and associated vulnerabilities. Designing mitigation and

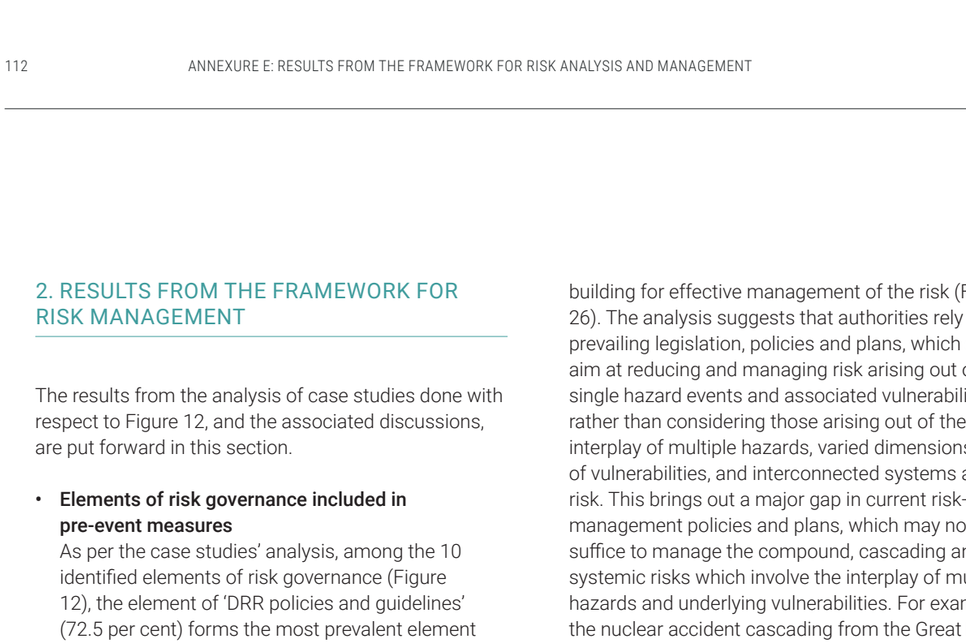

Figure 26: Elements of risk governance included in pre-event measures

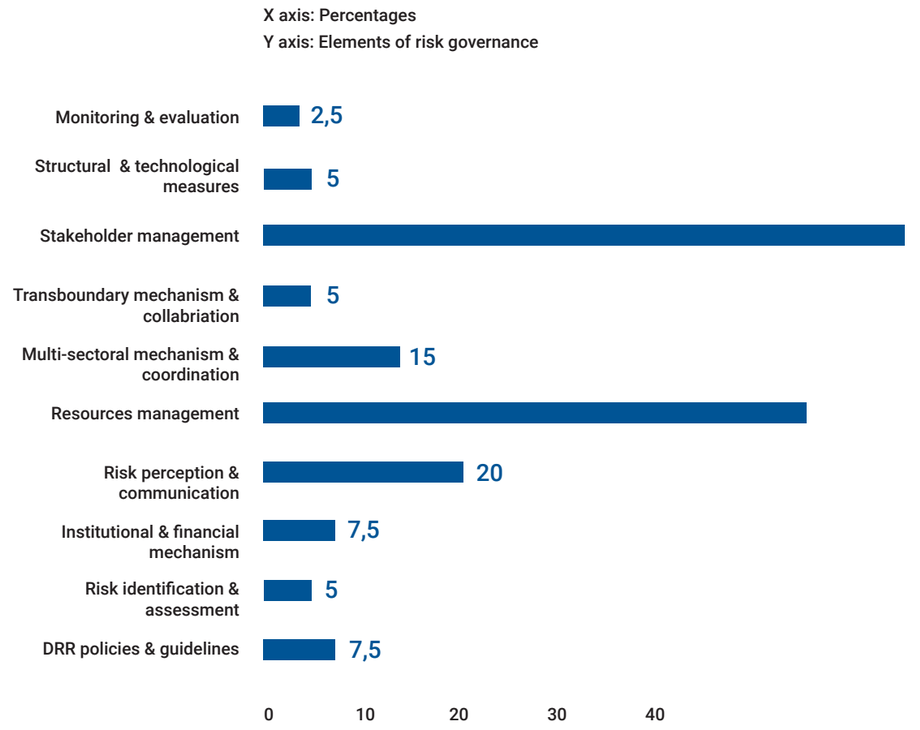

Figure 27: Elements of risk governance included in during-event measures

response measures is also required. Similarly, the Palu earthquake, flow liquefaction and tsunami, Indonesia, in 2018, resulted in a global re-evaluation of understanding of tsunami risk due to strike-slip faulting (lateral movement of the tectonic plate) in the bay or offshore regions.

Moreover, the analysis suggests that risk perception and communication should be accurate and detailed to ensure effective dissemination and use at the last mile. These should be guided by both scientific and evidence-based studies and ground-level contexts. Besides, policies and strategies targeted at risk perception and communication should acknowledge the cultural and other perceptions of risks prevailing in the community, so that effective and contextualized measures can be undertaken. Combinations of scientific knowledge (systems science), attitudes toward technology, perceptions, belief systems, social capital and trust networks influence the decision-making of state, institutional, sectoral and individual actors. This was most apparent in typhoon Haiyan, and recently in the Palu earthquake and tsunami. Effective and accurate approaches to risk communication (written, verbal and visual) should be undertaken to exchange information about the prevailing and emerging risks, or else, limited access to facts coupled with rumours and speculation may lead to panic and an unstable environment (Substance Abuse and Mental Health Administration, 2019). The pre-event measures undertaken, as in the case studies, illustrate a limited focus on risk governance elements such as resource management, monitoring and evaluation, institutional and financial mechanism, multi-sectoral mechanism and coordination, transboundary mechanism and collaboration, and structural and technological measures.

- **Elements of risk governance included in during-event measures**
  As per the case study analysis, among the 10 identified elements of risk governance (Figure 12), 'stakeholder management' (65 per cent) forms the most prevalent element included in during-event measures. Stakeholder management during an event includes measures such as working closely with different stakeholders for the identification of population likely to be affected, planning for their evacuation, seeking their support for issuing warnings, ensuring coordination at various scales for emergency response and immediate relief, and using mutual-support groups. Stakeholder management is followed by the element of 'resource management' (55 per cent), both closely linked to the response, search and rescue, and immediate aids during disasters (Figure 27). This is intuitive, as authorities tend to focus on the crisis at hand. This should be supplemented by documenting the operational issues during such disasters. Another common element of during-event measures is 'risk perception and communication' (20 per cent), whereby activities related to effective risk communications during disasters play an integral role in reducing potential cascading and other effects. However, in the aftermath of the Palu earthquake, flow liquefaction and tsunami, Indonesia, 2018, it was found that the existing early-warning system for tsunami detection (seismographic sensors, buoys, tidal gauges, GPS) was unable to adequately predict the scale of the tsunami, thus contributing to the toll of losses. All this highlights the need for constant re-evaluation of existing mechanisms (UNDRR and UNESCO-IOC, 2019).

- **Elements of risk governance included in post-event measures**
  As per the case study analysis, among the 10 identified elements of risk governance (Figure 12), 'risk identification and assessment' (25 per cent) forms the most prevalent element in post-event measures. Many case studies bring forth elements of risk identification and assessment included in post-event measures, such as assessing and monitoring water resources for potential contamination, assessing aquaculture and food products for heavy metals and contamination, assessing land stability leading to land zonation, assessment studies on river hydrology for offering solution to flooding, and undertaking risk assessments for multi-hazard threats in the area. Post-disaster need and damage assessment form a strong basis for using or offsetting funds for reconstruction and recovery. However, the case studies analysed do not strongly reflect this among the key post-event measures undertaken.

Further, some case studies suggest there had been poor comprehension in this aspect, affecting the recovery of the citizens and essential services. The element of risk identification and assessment is followed by the element of 'stakeholder management' (20 per cent) (Figure 28). The elements of stakeholder management and 'resource management' (7.5 per cent) are closely linked to post-disaster rehabilitation and rebuilding.

Further, the case studies suggest measures undertaken were widely covered under the elements of 'structural and technological measures' (17.5 per cent) and 'multi-sectoral mechanism and coordination' (15 per cent). It is to be noted that the elements of 'transboundary mechanism and collaboration' was not covered, and 'institutional and financial mechanism' was poorly covered in post-event measures in the case studies, indicating the need for strengthening their inclusion.

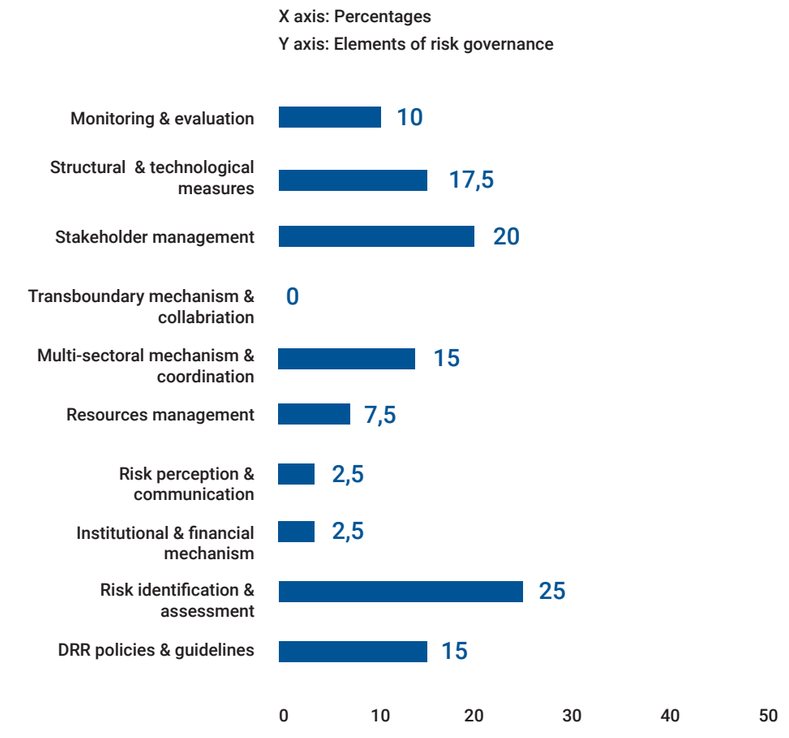

Figure 28: Elements of risk governance included in post-event measures

- **Overall frequency of pre, during, and post-event measures**
  The overall frequency of various elements of risk governance as per the case study analysis is depicted in Figure 29. As per ADB (2020), disasters between 2005 and 2017 in the Asia-Pacific region accounted for an economic loss of 43 per cent of the global total, which was more than its global share in gross domestic product (GDP). Evidently, the measure of institutional and financial mechanism was also seen to be the least prevalent among the case studies referred to. Any transboundary mechanism and collaboration measure was seen to be absent across the pre- event, during-event, and post-event measures. As evident from the case studies, varied sectors are affected and, in certain cases, even exacerbate the risk, resulting in the manifestation of compound, cascading and systemic risks across geopolitical boundaries. Thus, the central element to understanding and managing compound, cascading and systemic risks is rooted in the transboundary and whole-of-society approach of disaster risk management, involving active engagement and cooperation of varied stakeholders. Further, it was observed that the element of multi-sectoral mechanism and coordination was more prevalent in the post-event and during-event categories, although such an element should be put in place and used through pre-event measures also, for effective management of risk.

Multi-sectoral mechanism and coordination, along with transboundary mechanism and collaboration measures, may warrant the smooth operation of relief, rescue, and aid during disasters. As an example, Kim et al. (2021) describe that responsive measures (such as transparent management of information, inclusive governance, and the extensive use of innovative technologies), have played a key role in managing systemic risk effectively due to COVID-19 in the Republic of Korea. This aided in drastically flattening the curve in the country within one month of the implementation of measures. Kim et al., (2021) have therefore put forward two key recommendations for strengthening risk governance – (i) Strengthening the national response framework and the risk assessment tools by considering the managerial challenges caused by systemic risk; and (ii) Understanding the risk management flow for strengthening the disaster response management system.

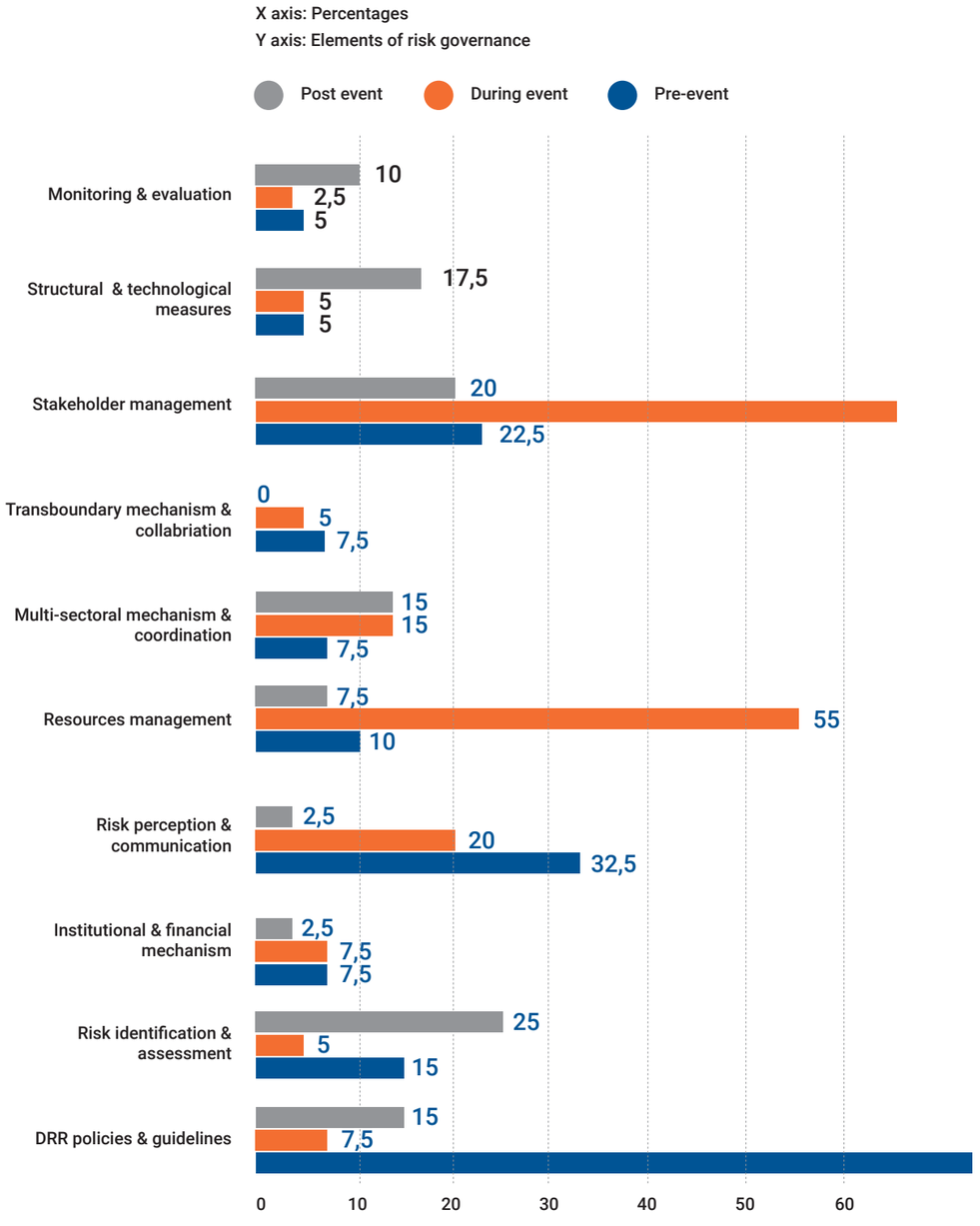

Figure 29: Frequency of elements of risk governance included in pre-, during, and post-event measures

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