Saeid Eslamian
Faezeh Eslamian *Editors*

Handbook of Disaster Risk Reduction for Resilience

New Frameworks for Building Resilience to Disasters

Springer

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Preface

> Working hand in hand with the 2030 Agenda, the Sendai Framework for Disaster Risk Reduction 2015-2030 is the roadmap for how we make our communities safer and more resilient to disasters. – United Nations Office for Disaster Risk Reduction

Disaster risk reduction (DRR) aims to prevent new – and reduce existing – disaster risk, strengthening the resilience of people, systems and approaches. These disasters mainly arise from climate change, human displacement, urbanization, pandemics, protracted crises and financial systems collapse.

The United Nations System Chief Executives Board for Coordination, at its 2011 Spring Session, committed to mainstream DRR in the programmes and operations of the UN system through the development of a common agenda, and to raise DRR to the highest political support. The United Nation Office for Disaster Risk Reduction Strategic Framework 2016–2021 is designed to support countries and societies in its implementation, monitoring and review of progress; the prevention of new and reduction of existing disaster risk and strengthening resilience through successful multi-hazard disaster risk management.

The Sendai Framework aims to achieve substantial reduction of disaster risk and loss of life, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries, by 2030.

The Sendai Framework includes seven targets and four priorities for action:

The *Seven Global Targets* are summarized as follows:

(a) Substantially reduce global disaster mortality by 2030
(b) Substantially reduce the number of affected people globally by 2030
(c) Substantially reduce direct disaster economic loss in relation to GDP by 2030
(d) Substantially reduce disaster damage to critical infrastructure, including health and educational facilities
(e) Substantially increase the number of countries with local disaster risk reduction strategies by 2030
(f) Substantially enhance international cooperation to developing countries through adequate and sustainable support
(g) Substantially increase the availability of the access to multi-hazard early warning systems by 2030

The *Four Priorities for Action* are as follows:

Priority 1. Understanding disaster risk
Priority 2. Strengthening disaster risk governance to manage disaster risk
Priority 3. Investing in disaster risk reduction for resilience
Priority 4. Enhancing disaster preparedness for effective response

The series entitled “Handbook of Disaster Risk Reduction for Resilience (HD3R)” attempts to fill theory and practice gaps in the Sendai Framework through publishing six proposed books. There is an aspiration that through this series, the readership will find useful support to assist in working towards several Sendai targets and priorities for action. This series, contracted by Springer, could be extended beyond these six books through further publications within the series up to 2030.

The other titles within this handbook are given as follows:

I. Disaster Risk Reduction for Resilience: New Frameworks for Building Resilience to Disasters
II. Disaster Risk Reduction for Resilience: Disaster Risk Management Strategies
III. Disaster Risk Reduction for Resilience: Disaster and Social Aspects
IV. Disaster Risk Reduction for Resilience: Disaster Economic Vulnerability and Recovery Programs
V. Disaster Risk Reduction for Resilience: Climate Change and Disaster Risk Adaptation
VI. Disaster Risk Reduction for Resilience: Disaster Hydrological Resilience and Sustainability

The current handbook is the first book of this series, is concerned with new frameworks for building resilience to disasters for risk reduction and includes 20 chapters as summarized as follows:

Key concepts for understanding DRR and resilience are described, and then type, definition and classification of natural hazards are defined. This is followed by chapters concerned with developing partnerships for building resilience, building disaster resilience through primary and higher education and the role of early warning systems for building community resilience. Other chapters focus on the urban context, principles regarding urbanization, and its disaster risks and resilience, and reducing risk through urban architectural design.

Multiple risk reduction and resilience for overcoming cascading disasters have also been examined, including dealing with uncertainty using probabilistic risk assessment for decision-making. Also defined are the computational methods for disaster resilience and distribution systems as are the factors for ecohydrological resilience.

There are case studies on hazard evacuation management and resilience (in the United States), on spatio-temporal distribution of landslides (in Nepal) and on coral reefs for safeguarding natural ecosystems through an innovative conservation funding mechanism (in Mexico).

This book allows the reader to consider past disasters in order to prepare for the future through DRR, reflecting that mainstreaming education into disaster management and supporting the principles of sustainable development are also important themes running through this series.

***

The primary audience is considered to be full- and part-time students, and their course instructors, lecturers and professors.

The secondary audience includes those from industry (earthquake preparedness, pollution control, chemical, construction and transportation sectors), policymakers, consulting engineers, researchers (civil engineering, geosciences, natural geography, environmental science and engineering, hydrologic engineering, atmospheric sciences, environmental sanitation, applied sciences, statistics, information technology), national hazard centers, national weather services, insurance companies, international donors (multilateral and bilateral) and the UN agencies, community resilience centers, emergency management agencies and disaster risk managers.

Isfahan, Iran — Saeid Eslamian
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About the Editors

Saeid Eslamian is a full professor of environmental hydrology and water resources engineering in the Department of Water Engineering at Isfahan University of Technology, where he has been since 1995. His research focuses mainly on statistical and environmental hydrology in a changing climate. In recent years, he has worked on modeling natural hazards, including floods, severe storms, wind, drought, pollution, water reuses, sustainable development and resiliency, etc. Formerly, he was a visiting professor at Princeton University, New Jersey, and the University of ETH Zurich, Switzerland. On the research side, he started a research partnership in 2014 with McGill University, Canada. He has contributed to more than 600 publications in journals, books and technical reports. He is the founder and chief editor of both the *International Journal of Hydrology Science and Technology* (IJHST) and the *Journal of Flood Engineering* (JFE). Eslamian is now associate editor of four important publications: *Journal of Hydrology* (Elsevier), *Ecohydrology and Hydrobiology* (Elsevier), *Journal of Water Reuse and Desalination* (IWA) and *Journal of the Saudi Society of Agricultural Sciences* (Elsevier). He is the author of approximately 35 books and 180 chapter books.

His professional experience includes membership on editorial boards, and he is a reviewer of approximately 100 Web of Science (ISI) journals, including the ASCE *Journal of Hydrologic Engineering*, ASCE *Journal of Water Resources Planning and Management*, ASCE *Journal of Irrigation and Drainage Engineering*, *Advances in Water Resources*, *Groundwater*, *Hydrological Processes*, *Hydrological Sciences Journal*, *Global Planetary Changes*, *Water Resources Management*, *Water Science and Technology*, *Ecohydrology*, *Journal of American Water Resources Association*, *American Water Works Association Journal*, etc. UNESCO has also nominated him for a special issue of the *Ecohydrology & Hydrobiology* Journal in 2015.

Professor Eslamian was selected as an outstanding reviewer for the *Journal of Hydrologic Engineering* in 2009 and received the EWRI/ASCE Visiting International Fellowship in Rhode Island (2010). He was also awarded outstanding prizes from the Iranian Hydraulics Association in 2005 and Iranian Petroleum and Oil Industry in 2011. Professor Eslamian has been chosen as a distinguished researcher of Isfahan University of Technology (IUT) and Isfahan Province in 2012 and 2014, respectively. In 2016, he was a candidate for national distinguished researcher in Iran.

He has also been the referee of many international organizations and universities. Some examples include the US Civilian Research and Development Foundation (USCRDF), the Swiss Network for International Studies, the Majesty Research Trust Fund of Sultan Qaboos University of Oman, the Royal Jordanian Geography Center College and the Research Department of Swinburne University of Technology of Australia. He is also a member of the following associations: American Society of Civil Engineers (ASCE), International Association of Hydrologic Science (IAHS), World Conservation Union (IUCN), GC Network for Drylands Research and Development (NDRD), International Association for Urban Climate (IAUC), International Society for Agricultural Meteorology (ISAM), Association of Water and Environment Modeling (AWEM), International Hydrological Association (STAHS) and UK Drought National Center (UKDNC).

Professor Eslamian finished Hakimsanaei High School in Isfahan in 1979. After the Islamic Revolution, he was admitted to IUT for a BS in water engineering and graduated in 1986. After graduation, he was offered a scholarship for a master's degree program at Tarbiat Modares University, Tehran. He finished his studies in hydrology and water resources engineering in 1989. In 1991, he was awarded a scholarship for a PhD in civil engineering at the University of New South Wales, Australia. His supervisor was Professor David H. Pilgrim, who encouraged him to work on "Regional Flood Frequency Analysis Using a New Region of Influence Approach." He earned a PhD in 1995 and returned to his home country and IUT. In 2001, he was promoted to associate professor and in 2014 to full professor. For the past 24 years, he has been nominated for different positions at IUT, including university president consultant, faculty deputy of education and head of department. Eslamian is now director for center of excellence in Risk Management and Natural Hazards (RiMaNaH).

Professor Eslamian has made three scientific visits to the United States, Switzerland and Canada in 2006, 2008 and 2015, respectively. In the first, he was offered the position of visiting professor by Princeton University and worked jointly with Professor Eric F. Wood at the School of Engineering and Applied Sciences for one year. The outcome was a contribution in hydrological and agricultural drought interaction knowledge by developing multivariate L-moments between soil moisture and low flows for northeastern US streams.

Recently, Professor Eslamian has published the editorship of ten handbooks published by Taylor & Francis (CRC Press): the three-volume *Handbook of Engineering Hydrology* in 2014, *Urban Water Reuse Handbook* in 2016, *Underground Aqueducts Handbook* (2017), the three-volume *Handbook of Drought and Water Scarcity* (2017), *Constructed Wetlands: Hydraulic Design* (2020) and *Handbook of Irrigation System Selection for Semi-Arid Regions* (2020). *An Evaluation of Groundwater Storage Potentials in a Semiarid Climate and Advances in Hydrogeochemistry Research* by Nova Science Publishers (USA) is also his book publication in 2019 and 2020, respectively.

Faezeh Eslamian holds a PhD in Bioresource Engineering from McGill University. Her research focuses on the development of a novel lime-based product to mitigate phosphorus loss from agricultural fields. Faezeh completed her bachelor's and master's degrees in Civil and Environmental Engineering from Isfahan University of Technology, Iran, where she evaluated natural and low-cost absorbents for the removal of pollutants such as textile dyes and heavy metals. Furthermore, she has conducted research on the worldwide water quality standards and wastewater reuse guidelines. Faezeh is an experienced multidisciplinary researcher with interest in soil and water quality, environmental remediation, water reuse and drought management.

Chapter 1
Understanding Disaster Risk Reduction and Resilience: A Conceptual Framework

Sanober Naheed

Abstract Disaster risk reduction and resilience should be seen as a concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events. The major threat emanates from an increasingly interconnected and interdependent social, technical, and biological systems and complex risk landscape. In developing countries, disasters represent a major source of risk for the poor and can potentially destroy development gains and accumulated wealth.

It should be noted that while the term "disaster reduction" is sometimes used, the term "disaster risk reduction and resilience" provides a better recognition of the ongoing nature of disaster risks and the ongoing potential to reduce these risks. At a time when climate change is increasing the frequency and severity of extreme weather events, disasters will continue to be major impediments to sustainable development so long as the economic incentives are to develop in hazard-prone locations. Integrating disaster risk reduction into investment decisions is the most cost-effective way to reduce these risks; investing in disaster risk reduction is therefore a precondition for developing sustainably in a changing climate.

In this chapter, an attempt has been made to simplify our understanding of the core idea and processes involved in disaster risk reduction and resilience with an intention to disseminate it into an ever-expanding community of students, researchers, and professionals. A historical approach has been attempted by way of illustrations and data tabulation. It seeks to increase the likelihood that this chapter is fully taken advantage of at the above-stated scales of interest.

Keywords Disaster risk reduction · Resilience · Sustainability · Awareness-raising · Preparedness · Strategies · Conceptual framework

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1 Introduction

Disasters have always threatened human communities (Brunsma and Picou 2008). Disaster events and catastrophes have become routine in the twenty-first century, for example, hurricane Katrina in 2005, the Wenchuan earthquake in 2008, and the Tohoku earthquake off the Pacific coast of Japan in 2011 (Wang et al. 2019) to just name a few. The period between 2019 and the first quarter of 2020 has witnessed the deadly European heat waves, floods in Asia, wildfires in California and Australia, and man-made fire in Amazonia. At a regional level, Asia was the most vulnerable continent with 40% of all disaster events, accounting for 45% of the total deaths and 74% of the people affected by disasters globally (CRED 2020) to the recent cyclonic onslaughts of tropical cyclones battering on both the Indian coasts, cyclone Amphan in the eastern coast of India and Bangladesh, leaving a trail of damage and destruction on one of the poorest global communities.

It is such devastations which leave scars and question the credibility of the political systems and their policies related to disaster risk reduction. They have a moral obligation to provide timely information and credible knowledge base to the afflicted. Their incompetency to deliver timely relief and manage sustainably is alarming.

Estimates have shown that approximately 3.8 million km^2 and 790 million individuals are exposed to at least two natural hazards, while 0.5 million km^2 and 105 million individuals are exposed to three or more natural hazards. In particular, climate change has demonstrated an increase in the magnitude, frequency, and geographic distribution of natural disasters (Maleksaeidi et al. 2017). These statistics demonstrate the critical multi-hazard environment to which the global population is exposed. The combination of human and economic losses, together with reconstruction costs, makes natural disasters both a humanitarian and an economic crisis (Bronfman et al. 2019; Dilley et al. 2005). The underlying processes for both risk and resilience exist within the social order itself; societies, communities, and organizations have the power to reduce risk and become more resilient. Citizen preparedness strategies play a key role in reducing the effects of hazards that cannot be mitigated. Nevertheless, a more concerted effort and focus on managing disasters is the present demand. To manage the underlying process that creates risk, to have a clear approach and understanding towards handling an impending risk and disaster. So a conceptual shift from responding to events to managing risk must be at the fore, acting collectively in handling an existing and a potential risk factor (Olson et al. 2020; Bronfman et al. 2019). Future global catastrophes also threaten the human community as the pandemic spread of diseases and the inevitable daily threat of armed conflict pose risks for the future.

However, scientific study and research in DRR confirm the non-linear change threatening all social, environmental and economic aspects of sustainable development. The Global Assessment Report (GAR 2019) has warned about the correlations of the emerging risks across multiple dimensions and scales. The major threat emanates from an increasingly interconnected and interdependent social, technical, and biological systems and complex risk landscape.

A turning point in the history of disaster risk reduction (DRR) was the intergovernmental commitment through the United Nations to foster disaster risk management (DRM) during the International Decade for Natural Disaster Reduction (1990–1999). The first World Conference on Natural Disaster Reduction in 1994 paved the way for the adoption of the Yokohama Strategy and Plan of Action for a Safer World: Guidelines for Natural Disaster Prevention, Preparedness and Mitigation. The international community prioritized the urgency to tackle frequent occurrence of extreme events through preparedness and recovery. One of the main policy outcomes was the Hyogo Framework for Action 2005–2015 (HFA) (Aitsi-Selmi et al. 2016). The Sendai Framework was endorsed by the United Nations General Assembly following the third United Nations World Conference on Disaster Risk Reduction, held in Sendai, Japan, in March 2015, as the successor to the HFA (UNFCCC 2017).

The United Nations Office for Disaster Risk Reduction (UNISDR) has defined DRR as "the conceptual framework of elements considered with the possibilities to minimize vulnerabilities and disaster risks throughout a society, to avoid (prevention) or to limit (mitigation and preparedness) the adverse impacts of hazards, within the broad context of sustainable development" (UNISDR 2010).

Disaster risk is an intrinsic characteristic of human society, arising from the combination of natural and human factors and subject to exacerbation or reduction by human agency. Disasters have an enormous impact on human development. Globally, events such as earthquakes, floods, and droughts contribute to tens of thousands of deaths, hundreds of thousands of injuries, and billions of dollars in economic losses each year. In developing countries, disasters represent a major source of risk for the poor and can potentially destroy development gains and accumulated wealth (World Bank 2014; O'Brien et al. 2008; Hardin 1968). Since the beginning of the 1990s, the United Nations has been promoting efforts to change the paradigm of disasters, advocating for the incorporation of disaster risk reduction efforts worldwide as a way to reduce the effects of natural hazards on vulnerable communities.

This has been recognized by the UN member states around the world which led to the adoption of the Sendai Framework for Disaster Risk Reduction 2015–2030. Between 2015 and 2030, member states around the world are expected to conduct a variety of efforts within the context of the four priority areas contained in the Sendai Framework, as a way to reduce risks with the goal of minimizing losses due to the manifestation of hazards of natural origin. The four priority areas are as follows:

(i) Understanding disaster risk
(ii) Strengthening disaster risk governance to manage disaster risk
(iii) Investing in disaster risk reduction for resilience
(iv) Enhancing disaster preparedness for effective response and to "build back better" in recovery, rehabilitation, and reconstruction (UN-SPIDER 2019)

Together, these four priorities aim for "the substantial reduction of disaster risk and losses in lives, livelihoods and health in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries" (UNFCCC

2017). The Sendai Framework solidifies a paradigm shift from managing disasters to managing current and future risks, bringing in resilience-building as the core target to be reached by 2030.

The scientific nature of the Sendai Framework visibly calls for stronger understanding of disaster risks and root causes, access to reliable data at the scales where action needs to be taken, developing risk assessment and maps at local level, and long-term multi-hazard and solution-oriented research, strengthening scientific capacity to assess risks (including vulnerability and exposure). It further recommends timely interpretation and use of risk information and cooperation between scientists, policy-makers, and stakeholders to support the science-policy interface through evidence-based decision-making, thereby providing a broader global awareness of the social and economic consequences of natural disasters.

The limiting factor to appropriate implementation of disaster resilience is compounded by poor planning and weak policies. Although the science is well documented, the absence of related data and case studies pertaining to any particular disaster study is a challenge in itself. Sufficient financial support and training for any ongoing DRR research will be a way forward in establishing a strong database for the research community.

Moreover, disasters are avoidable interruption which requires effective systems and sustainable strategies (Turnbull et al. 2013), most developing countries lack the tools, expertise, and instruments to effectively manage and monitor the potential impacts of disasters into their investment decisions (Miyan 2014). The idea of a paradigm shift in understanding DRM as continuum rather than in phases, between pre-, during, and post-disaster situations in countries, which are regularly exposed to hazards, has been proposed by Baas et al. (2008).

In this chapter, the author has not endeavored to create a new knowledge but has rather compiled the existing knowledge on disaster risk reduction and resilience, with an intention to disseminate it into an ever-expanding community of students, researchers, and professionals. It seeks to increase the likelihood that the paper is fully taken advantage of at the above-stated scales of interest.

2 Conceptual Framework for Disaster Reduction

Disasters, caused by natural and man-made hazards, are more frequent, long-lasting, and far more destructive than the previous one. Recognition of the increased impacts of disasters led to the creation of the International Strategy for Disaster Reduction (UNISDR) in December 1999, which serves as secretariat for the International Strategy for Disaster Reduction (ISDR) system and was adopted by the United Nations member states in 2000 (de la Poterie and Baudoin 2015).

The 2030 global policy agenda, comprising the Sendai Framework for Disaster Risk Reduction, the 2030 Agenda for Sustainable Development, the Addis Ababa Action Agenda, the Paris Agreement on Climate Change, the New Urban Agenda, and the Agenda for Humanity, together has strengthened the understanding of the issue of risk and the means to dealing with them. The common message they convey is on understanding the core aspects of risk creation and propagation – exposure and vulnerability, as well as the hazard characteristics and their dynamic interactions – all aimed at sustainable development and resilience (Aitsi-Selmi et al. 2016).

More recently, in 2019, Mami Mizutori, the Special Representative of the UN Secretary-General for Disaster Risk Reduction, has reflected on the issue succinctly: "The Sendai Framework can be seen as the connecting tissue for all 2030 agreements with its goal on the reduction of existing risks, prevention of the creation of new risks, and building long-term resilience" (Mizutori 2019).

Disaster risk reduction (DRR) is the concept and practice of reducing disaster risks through systematic efforts to analyze and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events (UNDRR 2018). DRR describes the development and application of policies, strategies, and practices that minimize vulnerabilities and disaster risks throughout a society, to avoid (prevent) or to limit (mitigate and adapt to) the adverse impacts of hazards, within the broad context of sustainable development.

Sharing information and experience for the purposes of public information and all forms of education and professional training is important for creating a culture of safety. Equally, the crucial involvement of local community action and new forms of partnership can be motivated by the acceptance of shared responsibilities and cooperation. Traditionally, disaster management follows four phases of an emergency event such as mitigation (preplanning), preparation, response, and recovery (ISDR 2004).

However, DRM includes and goes beyond DRR by adding a management perspective that combines prevention, mitigation, and preparedness with response. In fact, DRR efforts such as prevention, mitigation, preparedness, networking, local-level insurance, shelter protection, and water provision contribute to poverty reduction, while poverty reduction efforts such as job and livelihood creation and protection could also help to reduce disaster risks. For instance, water and environmental management have emerged as prominent links between DRR and poverty reduction. On a global scale, DRM should be incorporated into poverty reduction policies and initiatives. DRR uses a wide range of options including legal, institutional, and policy frameworks, administrative mechanisms, and procedures related to risk reduction of current and future disasters.

The Hyogo Framework for Action (HFA) has outlined the roadmap for DRR, encompassing governance, risk assessment and early warning, knowledge and education, and reduction of underlying risk factors in the context of development and disaster preparedness and response. The HFA has set five priorities for promoting DRR which are as follows:

- Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.
- Identify, assess, and monitor disaster risks and enhance early warning.

- Use knowledge, innovation, and education to build a culture of safety and resilience at all levels.
- Reduce the underlying risk factors.
- Strengthen disaster preparedness for effective response at all levels.

Hence, the International Council for Science (ICSU), the International Social Science Council (ISSC), and the United Nations International Strategy for Disaster Reduction (UNISDR) have taken a global, multi-, and interdisciplinary program, entitled Integrated Research on Disaster Risk (IRDR) to addressing the challenge of natural and human-induced environmental hazards, mitigating their impacts, and improving related policy-making mechanisms. Strategic goals of the IRDR program (2013–2017) are as follows:

- Promote integrated research, advocacy, and awareness-raising
- Characterization of hazards, vulnerability, and risk
- Understanding decision-making in complex and changing risk contexts
- Reducing risk and curbing losses through knowledge-based actions
- Networking and network building
- Research support

Attainment of these goals would lead to a better understanding of hazards, vulnerability, and risk; the enhanced capacity to model and project risk into the future; greater understanding of the decision-making choices that lead to risk and how they may be influenced; and how this knowledge can effectively lead to disaster risk reduction.

Strategies for DRR include hazard, vulnerability, and capacity assessments. Local-level strategies should be linked with appropriate top-down strategies and local government interventions. Successful DRR creates resilient communities, while ensuring that vulnerability is not increased through development efforts or other externally initiated activity. Therefore, multiple actions with multiple stakeholders are needed for managing the risk of disasters in a way that also promotes development (Begum et al. 2014).

The disaster risk management approach, as represented in Fig. 1.1, is generally accepted to consist of the following:

- Risk assessment and analysis
- Risk management
- Risk communication

2.1 Risks Assessment and Analyses

Risk assessment includes the identification of hazard agents (seen as hazard risk factors, e.g., tsunamis, flooding, oil leakage, and urban fires), exposure and consequence assessment, and risk characterization.

Risk assessment can play a critical role in impact modeling before an event strikes (e.g., in the days leading up to a cyclone), or it can provide initial and rapid

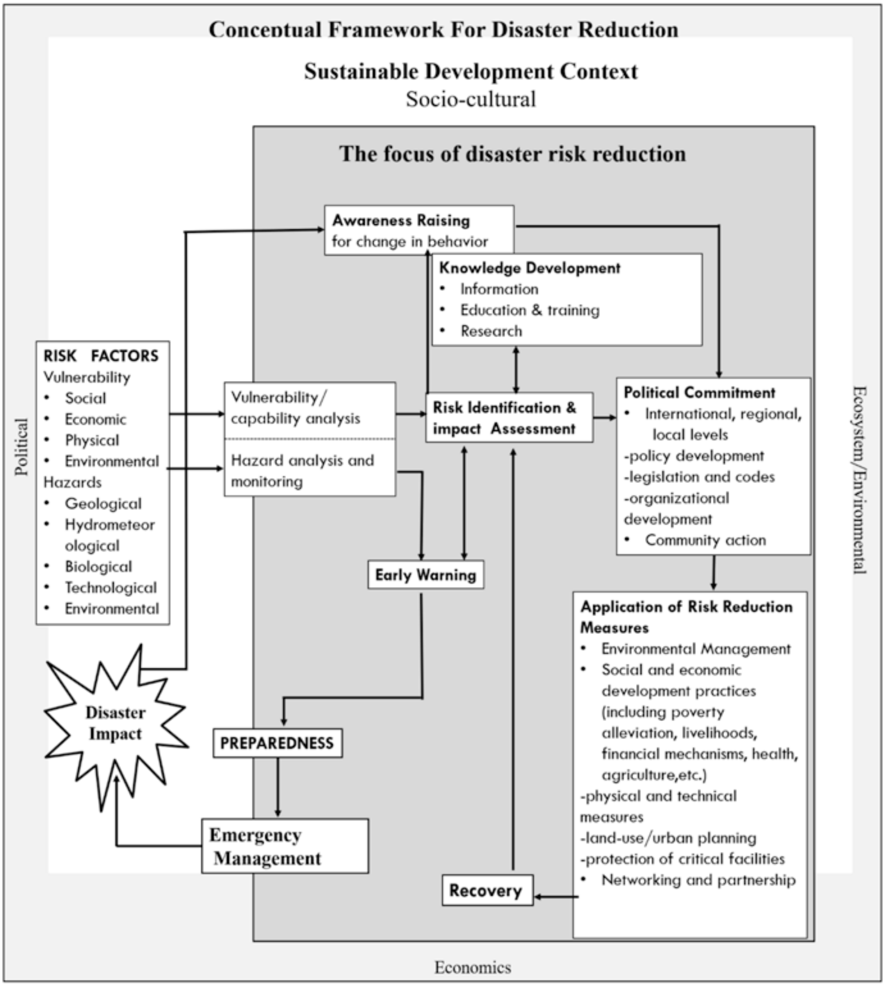

Fig. 1.1 A framework for disaster risk reduction. (*Source:* ISDR 2004, pp. 15)

estimates of human, physical, and economic loss in an event's immediate aftermath. Moreover, risk information for resilient reconstruction needs to be available before an event occurs, since after the event there is rarely time to collect the information needed to inform resilient design and land-use plans (GFDRR 2014).

2.2 Risk Management

Risk management encompasses all those activities required to reach and implement decisions on risk reduction or elimination. Once a risk has been characterized, an informed decision can be made as to what control measures, if any, are needed to reduce the risks or eliminate the hazard. Control measures can consist of any action for risk reduction or elimination. Often control measures involve reducing the probability of occurrence or the severity of an incident.

Risk management also must start at the lowest possible level of government administration and community with each level accepting responsibility for an appropriate level of mitigation, preparedness, and response and/or recovery activity. This includes strengthening and supporting community-level initiatives on disaster risk reduction and encouraging active participation or involvement of people in the process of risk assessment, planning, and implementation of disaster risk management strategies and activities.

An increase in the frequency of disasters and consequent impact on lives and livelihoods has led communities to develop some coping mechanism/strategies based on their existing capacities.

2.3 Risk Communication to the Public

The risk management process cannot be successful without a plan for providing and receiving information to and from the public, and such end-to-end systems need to be established and effectively functioning well before an emergency occurs.

The Sendai Framework promotes a people-centered approach and the use of a participatory process in decision-making that responds to the needs of users and is sensitive to social and cultural aspects, gender, and age. The severity of the impacts of a disaster depends strongly on the level of exposure and vulnerability (Terry and Goff 2012) in the affected area. Evidence indicates that overall risk has increased worldwide, largely due to increases in the exposure of persons and assets and possibly increases in inequality, which is a shaper of vulnerability, thus calling for greater attention to these dimensions of risk (Cavallo and Ireland 2014).

3 Disaster Scenario

Since the 1980s, there has been an increasing trend in disaster-related losses as total reported losses amounted to US$3.8 trillion. Such events further trap more people in poverty as poor and marginalized households tend to be less resilient and are faced with greater difficulties to recover from their impacts. Disaster risk is increasing mainly as a result of growing exposure of people and assets to natural hazards (World Bank 2019; CRED 2018).

Records maintained by Centre for Research on the Epidemiology of Disasters (CRED) show that disaster frequency appears to be increasing, from about 100 events per decade in the 1900–1940, to 650 per decade in the 1960s, to 2000 per decade in the 1980s. By the 1990s this number had reached almost 2800 events per decade. The increase in reported disasters can be partly explained by a higher number of small- and medium-level events that are related to natural and human-induced or socio-natural phenomena. While the number of geophysical disasters has remained fairly steady, the number of hydrometeorological disasters has increased significantly over the decades. An increase in global costs of weather-related disasters alone have increased from an annual average of USD 8.9 billion in 1977–1986 to USD 45.1 billion in the 1997–2006 period (O'Brien et al. 2008).

Recent estimates by CRED (2018) show that between 1998 and 2017 climate-related and geophysical disasters killed 1.3 million people and left a further 4.4 billion injured, homeless, displaced, or in need of emergency assistance. In 1998–2017 disaster-hit countries also reported direct economic losses valued at US$ 2908 billion, of which climate-related disasters caused US$ 2245 billion or 77% of the total. This is up from 68% (US$ 895 billion) of losses (US$ 1313 billion) reported between 1978 and 1997.

In absolute monetary terms, over the last 20 years, the USA recorded the biggest losses (US$ 945 billion), reflecting high asset values as well as frequent events. China, by comparison, suffered a significantly higher number of disasters than the USA (577 against 482) but lower total losses (US$ 492 billion). As economic data for such losses are hard to get, the World Bank has calculated that the real cost to the global economy is a staggering US$ 520 billion per annum, with disasters pushing 26 million people into poverty every year. Inequality is even greater than available losses data suggest because of systematic underreporting by low-income countries.

Georeferencing an analytical technique is being employed by CRED, to have an in-depth understanding of EM-DAT data to reveal the relative vulnerabilities of rich and poor and quantify how the human cost of disasters increases in cases where national income levels decline. This has helped reveal the high proportion of loss in low-income countries (130 people per million) to only 18 in high-income countries. This proves that people exposed to natural hazards in the poorest nations were more than seven times more likely to die than equivalent populations in the richest nations (UNDRR 2018; ESCAP/CDR 2017; O'Brien et al. 2008) (Tables 1.1 and 1.2).

3.1 Drivers of Disaster Risk

There is a strong correlation between disaster and development. Inappropriate development can increase levels of vulnerability to disaster risk, and disasters negatively affect poor countries' development. In addition to climate change, the main drivers of risk are poorly planned and managed urbanization, environmental degradation, poverty and weak governance, and gender inequality (UNISDR-WMO 2012).

The major drivers to disaster risk have been the substantial growth of population and assets in at-risk areas. Migration to coastal areas and the expansion of cities in flood plains, coupled with inappropriate building standards, are among the main reasons for the increase. As reported climate-related disasters accounted for 74% (US$2.6 trillion) of total reported losses, 87% (18,200) of total disasters, and 61% (1.4 million) of total lives lost (CRED 2018; World Bank 2014).

Table 1.1 Death toll by disaster type (2018 vs. average twenty-first century)

Event	2018	Average (2000–2017)
Drought	0	1361
Earthquake	4321	46,173
Extreme temperature	536	10,414
Flood	2859	5424
Landslide	282	929
Mass movement (dry)	17	20
Storm	1593	12,722
Volcanic activity	878	31
Wildfire	247	71
Total	10,733	77,144

Source: CRED-UNSIDR (2019)

Table 1.2 Total number of people affected by disaster type (2018 vs. average twenty-first century)

Event	2018	Average (2000–2017)
Drought	9,368,345	58,734,128
Earthquake	1,517,138	6,783,729
Extreme temperature	396,798	6,368,470
Flood	35,385,178	86,696,923
Landslide	54,908	263,831
Mass movement (dry)	0	286
Storm	12,884,845	34,083,106
Volcanic activity	1,908,770	169,308
Wildfire	256,635	19,243
Total	61,772,617	193,312,310

Source: CRED-UNSIDR (2019)

In support of these estimations, based on Intergovernmental Panel on Climate Change (IPCC) reports, it is projected that climate change will increase the frequency and intensity of the most severe weather-related hazards over the decades. In addition to climate change, the main drivers of risk are poorly planned and managed urbanization, environmental degradation, poverty, and weak governance. Disaster vulnerability can be reduced as a direct product of sound development. Effective risk management strategies can help in reducing disasters in the short to medium term, while reducing vulnerability over the longer term. Few countries have the tools, expertise, and mechanisms to consider the potential impact of disaster risk on their investment decisions. They rarely account for disaster losses, collect data, and assess risks systematically. As a result, they are not able to direct the necessary resources to protect their investments and reduce their exposure to future disaster impacts (World Bank 2014).

Over the past decade, more than 1.5 billion people have been affected by disasters that have cost at least US$ 1.3 trillion. Climate change, weak governance, and an increasing concentration of people and assets in areas exposed to natural hazards are driving disaster risk upward, especially in poor and fragile countries (CRED-UNISDR 2018).

Another major underlying driver to disaster risk is the prevailing gender inequality. Research has shown that women are more at risk of being affected by disasters and their aftermath. The multiple levels of discrimination that women are prone to (in education, healthcare, employment, and control of property) are some notable drivers that inevitably make women more vulnerable in and after a crises (Aitsi-Selmi et al. 2016). They are likely to suffer increased poverty rates, higher rates of sexual violence, and a lack of adequate housing in the aftermath of a disaster (Henrici et al. 2010). Likewise, women are not adequately represented in the decision-making authorities, and the sociocultural attitudes and norms hinder their participation when it comes to decision-making (Chineka et al. 2019).

3.2 Disaster Risk Reduction: A Shared Responsibility

In today's world, societies are confronted with rapid change. Therefore, the value of disaster risk reduction can only be realized through rigorous identification and continuous evaluation of the relationships that exist between the beliefs and conditions in which people live, the changing environment people inhabit and depend upon for their livelihoods, and the forces of nature (ISDR-RAED 2011).

Most importantly, disaster risk reduction relies on the consequences of collective decisions made and individual actions taken or not taken. The emergence of a disaster reduction culture is conditioned by the following contexts and processes:

- Political context
- Sustainable development in its three related contexts: sociocultural, economic, and environmental
- Regional considerations linking disaster reduction and sustainable development (ISDR 2004)

In this context, it can be noted that "shared responsibility" attributes to increased responsibility for all. It recommends that state agencies and municipal councils adopt increased or improved protective, emergency management and advisory roles. In turn, communities, individuals, and households are expected to take greater responsibility for their own safety and to act on advice and other information given to them by the government agencies. Shared responsibility is not about equal responsibility; there are some areas in which the state is bound to be more responsible than the community (Wilkins and McCarthy 2009).

4 DRR and Sustainability

Promoting sustainability in disaster reduction means recognizing and making the best use of connections among social, economic, and environmental goals to reduce significant hazard risks. This entails abilities to reduce exposure and aid recovery from infrequent large-scale, but also more common smaller-scale, natural and human-driven events.

The bottom line for any country, especially the poorest, is to build sustainable communities with a social foundation that provides for health, respects cultural diversity, is equitable, and considers the needs of future generations. All countries require a healthy and diverse ecological system that is productive and life sustaining and a healthy and diverse economy that adapts to change and recognizes social and ecological limits. This cannot be achieved without the incorporation of disaster reduction strategies, one of six principles of sustainability supported by strong political commitment. The motivation to invest in disaster risk reduction is very much a poverty reduction concern. It is about improving standards of safety and living conditions with an eye on protection from hazards to increase resilience of communities.

A safer society to withstand disasters may be argued as a case of ethics, social justice, and equity. It is also motivated by economic gains. Socioeconomic development is seriously challenged when scarce funds are diverted from long-term development objectives to short-term emergency relief and reconstruction needs. Environmentally unsound practices, global environmental changes, population growth, urbanization, social injustice, poverty, conflicts, and short-term economic vision are producing vulnerable societies. The impact of development on disasters in an increasingly unstable world should be fully embraced if disaster risk reduction is to yield its expected benefits.

This takes on particular urgency in the face of long-term risks brought about by climate change which goes much beyond environmental degradation or mismanagement of natural resources. Development as usual is blind to risk and fuels disasters which threaten further development (ISDR 2004).

UN Development Programme's (UNDP) disaster risk reduction efforts aim to risk-inform development in line with the goals and targets of the Sustainable Development Goals (SDGs) and the Sendai Framework for Disaster Risk Reduction. This poses a critical threat to achieving the Sustainable Development Goals (SDGs). Specifically, UNDP works with country partners to strengthen national and subnational policy and legal and institutional systems, foster greater coherence of disaster risk reduction and climate adaptation efforts, provide access to risk information and early warning systems, and strengthen preparedness and response measures. Together, these efforts strengthen the resilience of countries and urban and rural communities (UNDP 2020) (Table 1.3).

5 Approaches to Reduce Disaster Risk: International Strategies and Frameworks for Action

5.1 The Yokohama Strategy

The Yokohama Strategy and Plan of Action for a Safer World was adopted in 1994 following the United Nations World Conference on Natural Disaster Reduction, held in Yokohama, Japan. It is the first document providing guidelines at the international level for preparation for and prevention and mitigation of disaster impacts.

Table 1.3 Targets on disaster risk resilience in the Sustainable Development Goals

Sustainable Development Goals	Targets on disaster risk resilience
Goal 1: Ending poverty in all its forms everywhere	Target 1.5: By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social, and environmental shocks and disasters
Goal 2: End hunger, achieve food security and improved nutrition, and promote sustainable agriculture	Target 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production that help maintain ecosystems; that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding, and other disasters; and that progressively improve land and soil quality
Goal 3: Ensure healthy lives and promote well-being for all at all ages	Target 3d: Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction, and management of national and global health risks
Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Target 4a: Build and upgrade education facilities that are child, disability, and gender sensitive and provide safe, nonviolent, inclusive, and effective learning environments for all
Goal 9: Build resilient infrastructure, promote sustainable industrialization, and foster innovation	Target 9.1: Develop quality, reliable, sustainable, and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all
Goal 11: Make cities and human settlements inclusive, safe, resilient, and sustainable	Target 11.5: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
Goal 13: Take urgent action to combat climate change and its impacts	Target 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
Goal 15: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Target 15.3: By 2030, combat desertification; restore degraded land and soil, including land affected by desertification, drought, and floods; and strive to achieve a land degradation-neutral world

Source: ESCAP/CDR (2017)

The Yokohama Strategy was a product of the International Decade for Natural Disaster Reduction (1990–2000) and, more specifically, of the World Conference on Natural Disaster Reduction held in 1994. The importance of community involvement in DRR has been enshrined in these two international events.

5.2 The Hyogo Framework for Action 2005–2015

The following decade (2000s) represents a shift in the way DRR is perceived, moving from a strong focus on coping capacities and relief interventions to an increased attention brought to risk preparedness and prevention.

Hence, DRR became a popular idea with the World Conference on Disaster Risk Reduction held in Kobe, Hyogo, Japan, in mid-January 2005. The conference coincidentally took place in the aftermath of the 2004 tsunami in the Indian Ocean, which affected millions of people and raised public awareness about the so-called "natural" disasters, their risks, and their serious impacts. The outcome of the conference, the Hyogo Framework for Action 2005–2015 (HFA), is probably the most significant international document popularizing the notion of DRR. The 2000–2009 decade is also critical in terms of shifting concerns around disaster issues, with an increased focus on risk preparedness. The focus of this approach is seen evolving both in academia and among major organizations working in the field of DRR (de la Poterie and Baudoin 2015).

5.3 The Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR)

The HFA was a 10-year action plan, effective from 2005 to 2015. During this decade, disasters around the world continued to produce human, economic, infrastructure, and ecological losses, especially in the most vulnerable and poorest nations. A review of the HFA resulted in the Sendai Framework for Disaster Risk Reduction 2015–2030. The scope of the Sendai Framework is broader than the HFA, with an enhanced focus on "large and small, sudden and slow onset of disasters caused by natural and man-made hazards and related environmental, technological, and biological hazards." Thus, commitments to support DRR were renewed when HFA came to an end (Tiernan et al. 2019).

It comprises a voluntary set of targets and priorities to foster increased resilience to present and future hazards and to prevent setbacks to development as the result of small and large disasters. In addition, SFDRR also intends to reflect new challenges that characterize today's world, namely, climate change, increased globalization, and the development of new technologies and expertise in the field of risk prediction and early warning systems (de la Poterie and Baudoin 2015).

6 What Is Disaster Resilience?

Disaster resilience is part of the broader concept of resilience – "the ability of individuals, communities and states and their institutions to absorb and recover from shocks, while positively adapting and transforming their structures and means for living in the face of long-term changes and uncertainty"(Combaz 2014) (Box 1.1).

Box 1.1 Definitions of Disaster Resilience
The Sendai Framework (2015): "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (UNFCCC 2017).

Department for International Development (DFID 2011): "the ability of countries, communities and households to manage change, by maintaining or transforming living standards in the face of shocks or stresses – such as earthquakes, drought, or violent conflict – without compromising their longterm prospects."

Hyogo Framework for Action (UNISDR 2005): "the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure" (Combaz 2014).

Resilience can be conceptualized as a characteristic of a system when considered as a whole. Traditionally a "stable" system was defined as strong, static, and resistant to change (Manyena 2006). Now, a stable system is understood as one that is flexible and able to adjust to stress, remaining more or less the same within a range of conditions. A resilient system is one with the best adaptive capacity in the face of extreme stress (Tiernan et al. 2019). It can well be understood as a system which:

(i) Remain stable in the face of external perturbations and stresses
(ii) Recover following a major disruption
(iii) Adapt to new circumstances

This equilibrium- and response-based understanding of resilience has similarly persisted in its application to public policy, where resilience has become an increasingly prevalent expression for understanding the persistence and stability of social systems.

It is hence obvious that the present social science research on resilience often takes on a macrolevel systemic approach which is nearly similar to the study of resilience in natural systems. Resilience is well understood and adopted in ecological and environmental studies which have not found parallels in other disciplines. System is increasingly the subject of analysis in ecology and environmental studies, which has been seen being borrowed by social sciences (Capano and Woo 2017).

This is clearly visible as many international development agencies have used resilience as the basis for linking actions on climate change adaptation (CCA), disaster risk reduction (DRR), social protection, humanitarian response, peace building, and food security programming. Nevertheless, resilience can be seen as a link by having created a common language and goal setting in the diverse post-2015 agreements: the Sendai Framework for Disaster Risk Reduction, the United Nations Sustainable Development Goals (SDGs), the Paris Agreement on Climate Change, and the World Humanitarian Summit framework (Tanner et al. 2017).

6.1 Components of Disaster Resilience

Manyena (2006) opined that disaster resilience has been described as both an *outcome* and a *process*. Practices focused on *outcome* have tended to adopt top-down reactive approaches which can favor the state of affairs and take attention away from inequalities resulting from insecurity and disaster. As a *process*, building disaster resilience involves supporting the capacity of individuals, communities, and states to adapt through assets and resources relevant to their context. Also it may be considered as enhancing people's rights and addressing socioeconomic, gender, and environmental inequalities that exacerbate vulnerability (Combaz 2014) (Table 1.4).

6.2 Resilience in the Global Development Frameworks

Disaster risk and resilience received insufficient emphasis in the original Millennium Development Goals (MDG) agenda, despite the close relationship between disaster impacts and sustainable development. Resilience is a precondition for sustainable development in general and more specifically for fighting poverty, hunger, and malnutrition (UNISDR 2015).

Building on the Yokohama strategy and in recognition of the need to address the multidimensional aspects of disaster risk from a development perspective, the Hyogo Framework for Action (HFA) 2005–2015 provides a strategic and systematic approach to reducing vulnerabilities and risks to hazards, involving the identification of ways to build the resilience of nations and communities to disasters. Although the progress varies from one country to another, the main global achievement is the change of mind-sets from crisis management to risk reduction with an emphasis on prevention and preparedness. The multi-stakeholder and multi-sector nature of the Hyogo Framework for Action provides guidance on how disaster risk reduction contributes to sustainable development (UNSIDR-WMO 2012). Soon after HFA, the Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030 besides other areas has focused on the prioritization of health risks from hazards and the need to focus on health resilience. It promotes collaboration among the disaster risk reduction, climate change adaptation, and science communities to develop strategies that protect and manage health risks arising from extreme weather and climate events (Tiernan et al. 2019).

Table 1.4 The core elements of disaster resilience as depicted in DFID's framework

Context	Whose resilience is being built – such as a social group, socioeconomic or political system, environmental context, or institution
Disturbance	What shocks (sudden events like conflict or disasters) and/or stresses (long-term trends like resource degradation, urbanization, or climate change) the group aims to be resilient to
Capacity to respond	The ability of a system or process to deal with a shock or stress depends on exposure (the magnitude of the shock or stress), sensitivity (the degree to which a system will be affected by, or will respond to, a given shock or stress), and adaptive capacity (how well it can adjust to a disturbance or moderate damage, take advantage of opportunities, and cope with the consequences of a transformation)
Reaction	A range of responses are possible, including bounce back better, where capacities are enhanced, exposures are reduced, and the system is more able to deal with future shocks and stresses; bounce back, where preexisting conditions prevail; or recover, but worse than before, meaning capacities are reduced. In the worst-case scenario, the system collapses, leading to a catastrophic reduction in capacity to cope with the future

Source: Combaz (2014), pp. 2

The global development frameworks adopted in 2015 and 2016 are structured around six separate but interrelated agreements: (a) Sendai Framework for Disaster Risk Reduction 2015–2030, (b) 2030 Agenda for Sustainable Development, (c) Paris Agreement under the United Nations Framework Convention on Climate Change, (d) Agenda for Humanity, (e) New Urban Agenda, and (f) Addis Ababa Action Agenda of the Third International Conference on Financing for Development. Building resilience to disasters is a common theme in these frameworks. Collectively, they provide a comprehensive global framework for the secretary general's call for a "shared understanding of sustainability, vulnerability and resilience" (ESCAP/CDR 2017).

Resilience is featured prominently throughout the Sustainable Development Goals and is regarded as a quality to be "built," "developed," and "strengthened," as a tool to reduce the exposure of people to hazards, and as a foundation for inclusive economic growth and prosperity. The term is also used in relation to inclusive and safe cities and high-quality and reliable infrastructure. Disaster risk reduction and resilience is clearly embedded in nine of the goals and associated targets. These goals and targets are expected to stimulate action over the next 15 years in areas of critical importance for a sustainable and resilient future (ESCAP/CDR 2017).

6.3 Rationale for a Resilience Approach to Disasters

Disaster resilience programming aims to save lives while protecting infrastructure, livelihoods, social systems, and the environment. There is a growing recognition of both the severity of natural and man-made disasters and of the inadequacy of international efforts to reduce vulnerability to them, as can be gathered from the following as put forward by Combaz (2014):

- *The frequency and severity of weather-related hazards is increasing*. Climate change "contributes to more frequent, severe, and unpredictable weather-related hazards such as droughts, tropical cyclones, floods, and heat waves."
- *Exposure to all hazards is increasing*. Exposure to natural and man-made disasters has increased and is likely to continue to increase with the effects of climate change. Over the next two to three decades, increasing exposure and vulnerability due to economic and urban development "will have a greater influence on disaster risk than climate change."
- *Disasters have set back development*. It is well documented that disasters have set back development gains, aggravated poverty, and increased vulnerability. Such negative impacts reflect and worsen inequalities, such as gendered and generational inequalities.
- *Disasters and resilience related to natural hazards, violent conflict, or state fragility share commonalities and connections, but interventions generally treat these contexts separately.* For instance, state fragility, vulnerability to climate change, and the risk of mortality from drought seem closely associated. Yet conflict prevention and DRM are treated separately, with limited crossover and little documented integration.
- *Disaster resilience has historically been underfunded.* Spending on emergency humanitarian assistance has been growing over the years. It has been argued that greater emphasis should be placed on building capacities to reduce vulnerability and support communities to recover themselves.
- *Traditional humanitarian and development approaches have been inadequate.* Humanitarian relief is targeted primarily at saving lives rather than reducing vulnerabilities; development assistance has not been sufficiently focused on building community capacity for adaptation; and approaches to DRR have often been decoupled from development, rights, and power imbalance.
- *Responsibilities and roles need to be better balanced between the fields of development and humanitarian action.* Disaster prevention requires long-term development expenditures in addition to humanitarian aid in emergencies.

6.4 Benefits of Disaster Resilience

Responses to disaster risk are enhanced with resilience which gives a careful consideration for hazards, exposure, risk, vulnerability, and capacity. Building resilience to natural hazards can have far-reaching positive effects in fragile states and violent conflicts. Evidence from a range of countries supports the potential contribution of disaster resilience to the following:

Saving lives Disaster prevention has helped limit loss of life to disasters in a number of developed and developing countries. In Bangladesh, for example, the fact that far fewer people were killed by a cyclone in 2008 (3000) than by a similar one in 1970 (almost 500,000) is attributed to better disaster prevention.

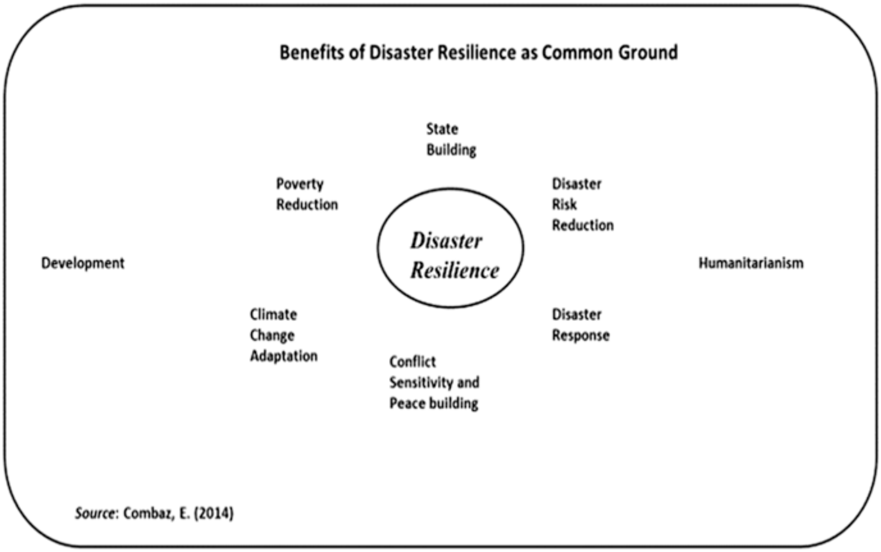

Fig. 1.2 Benefits of disaster resilience. (*Source*: Combaz 2014, pp. 7)

Protecting infrastructure and livelihoods A careful implementation of disaster prevention techniques has been found to curtail the cost of property damage from all hazards.

Protecting social systems Community-based DRR has had a positive impact on social resilience through altering attitudes and behaviors toward risk.

Protecting the environment Increased disaster resilience has in some cases been associated with behaviors that preserve the natural environment.

Supporting broader resilience in contexts of violent conflict or fragility Countries with well-performing institutions are better able to both prevent disasters and reduce the likelihood of disaster-related conflict (Fig. 1.2).

7 Challenges for Development Policies

Evidence has it that a multidisciplinary approach to disaster management which involves partnerships of various organizations and community groups plays a critical role during times of disaster (Malalgoda et al. 2010). As the situations confronted by policy-makers have increased in complexity, resilience has increasingly become a topic of interest to governments.

Leadership is sought to drive improvements in disaster resilience. The responsibility for leadership is binding upon all partners within their sphere of influence in a coordinated manner, so as to maximize the benefits from limited resources. The increasing complexity surrounding disasters calls for a more coordinated effort among all stakeholders by widening the circle of responsibility. By collaborating and strengthening existing partnerships among governments, businesses, the non-government sector, and communities, it can help authorities and civilians alike in disaster prevention, preparedness, response, and recovery (Wilkins and McCarthy 2009).

New data are continuously being generated about hazard and risk assessment science with a potential to improving our knowledge for hazardous events. This knowledge will not lead to significant reductions in losses from natural disasters if it is improperly transferred from science to policy. This transfer can be hindered by difficulties in the communication of scientific results and in their use for decision-making purposes (De Marchi 2014). The process of knowledge transfer from science to policy and the implementation of multi-risk assessments can be also hindered by existing institutional barriers and features of the existing governance systems. In the science domain, the implementation of multi-risk hazard is hindered by existing patterns of exchange among researchers and practitioners. Historically, the process of risk assessment for geological hazards evolved differently from meteorological hazards.

Currently, the comparison of different risks and their integration into a multi-risk assessment, as well as communications among different risk communities, present a number of difficulties due to differences in methodologies and the levels of uncertainty in hazard and risk assessment, different languages, definitions of concepts, and the manner in which risk and hazard are represented. The efficiency of governance systems to address multi-risks depends not only on regulatory and institutional frameworks but also on the capacities of the systems at different levels, from local to global, that are called upon to deal with risks and to entail risk policy and politics (Komendantova et al. 2016).

The rising burden of losses related to disaster and crises suggests that more compelling business cases are needed for investments to build resilience and protect human and environmental systems from damage. Cost-benefit analysis (CBA) has traditionally been used for more straightforward single investments (such as whether to build a new bridge), where data can either be readily estimated from existing documentation or easily measured from observable phenomena (Shreve and Kelman 2014). Some types of investment in resilience lend themselves more easily than others to strong business cases. This can lead to bias in decision-making, with the choice reflecting the available data rather than the best course of action.

In the literature, there are arguments which blame inherent administrative weaknesses. The local governments do not include or work with the people and which has left gaps for improvement further making it difficult to make decisions regarding the provision of reasonable solutions for disaster-related problems. Local governments are experiencing competing priorities along with limited resources, governments fail to allocate financial resources to disaster management programs, and this will affect the proactive decision-making process related to mitigation and preparedness activities (Tanner et al. 2017).

8 Criticism for Disaster Resilience

As noted by Combaz (2014), there have been criticisms from various quarters with regard to the implementation of disaster resilience. It has been opposed on the ground that it's been a relabeling of long-standing approaches as resilience building, if this has no meaningful effect on how humanitarian or poverty reduction programs are implemented. Moreover, as a concept, disaster resilience has been depoliticized, placing too much responsibility on the individual and wider society rather than on state, who have the political power to address the underlying causes of vulnerability to disasters. It has also been suggested that the discourse of disaster resilience could stigmatize individuals and communities with low levels of resilience.

While there have been substantial and enabling investments in climate science, neither science-funding bodies nor educational foundations have made resources available for "risk and resilience science," particularly in low- and middle-income countries where students cannot easily pursue DRR as a field of study or research. Evidence shows that this represents one of the most substantial obstacles to advancing the field (Ofir and Mentz 2015).

9 Summary and Conclusions

The rise in disasters globally makes careful planning and a holistic approach to DRR critical. Disasters are now believed to be a manifestation of poor planning and weak policies. Focusing on all elements of disaster risk management (all four phases of the disaster cycle, i.e., mitigation, preparedness, response, and recovery) helps to consider how a wide range of activities associated with technology, development, governance, risk management, risk communication, and local capacity influence and approach disaster risk.

Factors such as climate change and globalization mean that actions in one region may have an impact on disaster risk in another and vice versa. This is compounded by growing vulnerability resulting from unplanned urbanization, underdevelopment, and competition for scarce resources and points to a future where disasters will increasingly threaten the world's economy and population. A disaster's severity depends on how much impact a hazard has on society and the environment. The scale of the impact in turn depends on the choices made in life and for the environment. These choices are related not only to the adoption of means for growing food, or where to build homes, but most importantly the nature of governance, from how the top officials and financial system work and even what are being taught in schools. Each decision and action makes the system more vulnerable to disasters – or more resilient to them.

The purpose of disaster risk management is to reduce the underlying factors of risk and to prepare for and initiate an immediate response should disaster hit. The concept of "building back better" implies to initiate DRR activities also during recovery and rehabilitation. The paradigm shift to conceptualize DRM as continuum (and no more in phases) reflects the reality that the transition between pre-, during, and post-disaster situations is fluid, particularly in countries, which are regularly exposed to hazards.

There is a strong correlation between disasters and development. Inappropriate development can increase levels of vulnerability to disaster risk, and, in turn, disasters can negatively affect poor countries' development. On the other hand, unsound development policies will increase disaster risk – and disaster losses. DRR which involves every part of society, every part of government, and every part of the professional and private sector seeks to restrict such losses. Integrating disaster risk reduction into investment decisions is the most cost-effective way to reduce these risks; investing in disaster risk reduction is therefore a precondition for developing sustainably in a changing climate.

The countries with the highest exposure to disaster risk often have low capacity to mitigate them. Since 1980, more than two million people and over $3 trillion have been lost to disasters caused by natural hazards, with total damages increasing by more than 600% from $23 billion a year in the 1980s to $150 billion a year currently.

However, if countries should act decisively, they can save lives and assets. Most developing countries lack the tools, expertise, and instruments to effectively manage and monitor the potential impacts of disasters into their investment decisions.

Disaster risk assessment has multiple dimensions and is now best understood by considering interdependencies between disciplines. This has created a positive synergy toward multidisciplinary research involving collaboration between geophysical, social, and engineering scientists. Moreover, it is expected that scientific training in the future should facilitate the development of scientific and technical skills that can integrate knowledge from different disciplines and produce holistic risk and impact information that addresses hazards, exposure, vulnerability, and capacity building. This integrated research with participation of at-risk communities will help co-produce knowledge related to hazards and disasters.

In the global context, under the prevailing pandemic and global lockdowns and economic downturns, one of the best practices has been observed by an increasing participation of the nongovernment and community organizations in meeting societal needs. They have come forward in providing relief in the form of food aid to the underprivileged most of whom have lost their jobs and means of livelihoods, in the aftermath of the super cyclone Amphan hitting the eastern coast of India in the state of West Bengal, which has crippled the lifeline and infrastructure. In these challenging times, the activities undertaken by these NGOs and community organizations are commendable. It is through their endurance that relief in the form of food, clothes, and tarpaulins to provide shelter has reached the affected people deep in the deltaic areas of the Sundarbans where maneuvering through wet soil and decimated resources was by itself daunting.

It can be concluded on the note that disaster resilience is not a stand-alone activity that can be achieved in a set timeframe nor can it be achieved without a joint commitment and concerted effort by all sectors of society. But it is an effort that is worth making, because building a more disaster-resilient nation is an investment into the future.

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Chapter 2
Types, Definition and Classification of Natural Disasters and Threat Level

David Teh and Tehmina Khan

Abstract In this chapter, various types of natural disasters, their classifications and threat levels are considered. Natural disasters vary widely in predictability and impact. A widely used natural disaster typology has been considered as the starting point for covering natural disaster classifications and their threat levels. Threat levels have been analysed from two perspectives – social and economic – to identify their impacts. The threat levels associated with social and economic impacts of natural disasters can be significantly high where a large number of people are affected; and total economic losses can range in hundreds of billions every year from the damages caused by natural disasters. In terms of occurrences, climate-related disasters also dominate the picture, accounting for 91% of all 7255 major recorded events between 1998 and 2017. Floods, 43.4%, and storms, 28.2%, are the two most frequently occurring disasters. It is found based on a detailed literature review that social and economic impacts vary, not only for specific disasters but also by region. Fatalities, loss of livelihoods and displacement from natural disasters are most prominent in Asia Pacific. Threat levels are more pronounced in Asia Pacific regions due to resource constraints and lack of proper communications and adequate response measures to reduce impacts. This is also an extremely serious threat issue as two-third of the world population – an estimated 6.3 billion people – live in Asia and Africa. Asia, despite its relatively lower level of urbanisation, is home to 54% of the world's urban population. Therefore, it is recommended in this chapter that global collaborative efforts (including implementation of resilience measures) be undertaken to address natural disasters and the related threats in a timely and efficient manner, resulting in least negative economic and social impacts.

Keywords Natural disasters · Classifications · Threat levels · Economic costs and social costs

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1 Introduction

Natural disasters vary widely in predictability and impact. The threat levels associated with social and economic impacts of natural disasters can be significantly high where a large number of people are affected; and total economic losses can also vary between countries. There are different types of natural disasters including droughts, floods, extreme weather, extreme temperature, landslides, dry mass movements, wildfires, volcanic activity and earthquakes (Ritchie and Roxer 2019). Globally, the number of natural disasters worldwide has ranged close to 300, and the most prominent natural disasters have been flooding and extreme weather. Although the number of deaths from natural disasters has decreased substantially, economic losses range in hundreds of billions every year from the damages caused by natural disasters (Ritchie and Roxer 2019).

Furthermore, three in five cities worldwide with a population of at least half a million people are at high risk of natural disaster, either cyclones, floods, droughts, earthquakes, landslides or volcanic eruptions – or a combination of those. Collectively, these cities are home to 1.4 billion people which is around one-third of the world's urban population (United Nations (UN) Department of Economic and Social Affairs' (DESA) 2018). When urban areas produce around 80 per cent of the world's economic output and accommodate 55 per cent of the population, the high density of people and assets make these cities extremely vulnerable to imminent risk of disasters. It means that natural disasters are potentially costlier and more fatal if they hit the cities (UN 2018). This is further evident in the report by the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) – climate change can further complicate the unprecedented urbanisation challenges. By 2030, without substantial investments into making cities more resilient, climate change and natural disasters may cost cities worldwide US$314 billion each year, up from around US$250 billion today, and may push up to 77 million more urban residents into poverty (The World Bank Group 2018). In the following section, each of these types of natural disasters together with their threat level and examples of disaster are discussed in detail. This study is limited to providing a basic understanding of threat levels, with a risk management focus, without delving too much into the technical details of threat levels, being beyond the scope of this work.

2 Discussion: Natural Disasters

2.1 Definitions

There are numerous definitions of a disaster. Turner and Pidgeon (1997) pointed out that no definition of 'disaster' is universally accepted. Seeking or proposing definitions of disaster can be a complex task and may create considerable frustration and obscurity in scholars (Cutter 2005). However, disasters can be classified into three

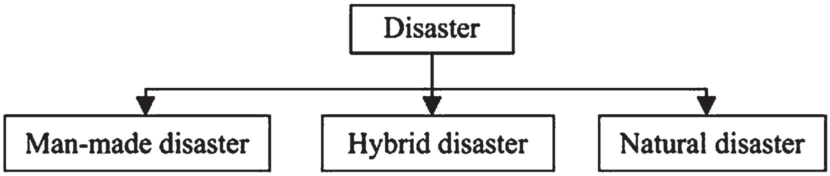


Fig. 2.1 Types of disaster

Fig. 2.2 Disaster risk components

types: man-made, hybrid and natural (Fig. 2.1) – it is believed that these three disaster types cover all disastrous events (Shaluf 2007).

The focus of this chapter is on the risk management aspect of natural disasters including pandemics which is the situation currently faced globally. Basic definitions of various types of natural disasters were covered, and broad considerations of their threat levels were provided, but the key contribution is the critical perspective on the current natural global disaster which is the COVID-19 pandemic.

The term disaster has been defined differently by various scholars – due to the systems by which they are explained and based on their causes and consequences (Al-Dahash et al. 2016). The United Nations Office for Disaster Risk Reduction (UNDRR – formerly known as UNISDR 2019) defines disaster as a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, involving human, material, economic and environmental losses and impacts which exceed the ability of the affected community to cope using its own resources. Similarly, disaster is defined as a dynamic mechanism that begins with the activation of a hazard and flows through the system as a series of events, in a logical sequence to produce a loss to life, property and livelihood. It negatively influences emergency systems (Iyer and Mastorakis 2006; Biswas and Choudhuri 2012) and acts as a burden on resources which are required for immediate (crisis) response and for long-term rebuilding and recovery efforts. A basic disaster model is presented in Fig. 2.2.

Various classifications of natural disasters have been identified, for example, by Lukić et al. (2013) (see Fig. 2.3).

Scheuer (2012) at the United Nations Development Programme (UNDP) commented that 'what we call natural disasters are not natural at all. A natural hazard only becomes a disaster when measures to mitigate its impact are lacking'. Disaster risk is widely recognised as the consequence of the interaction between a hazard

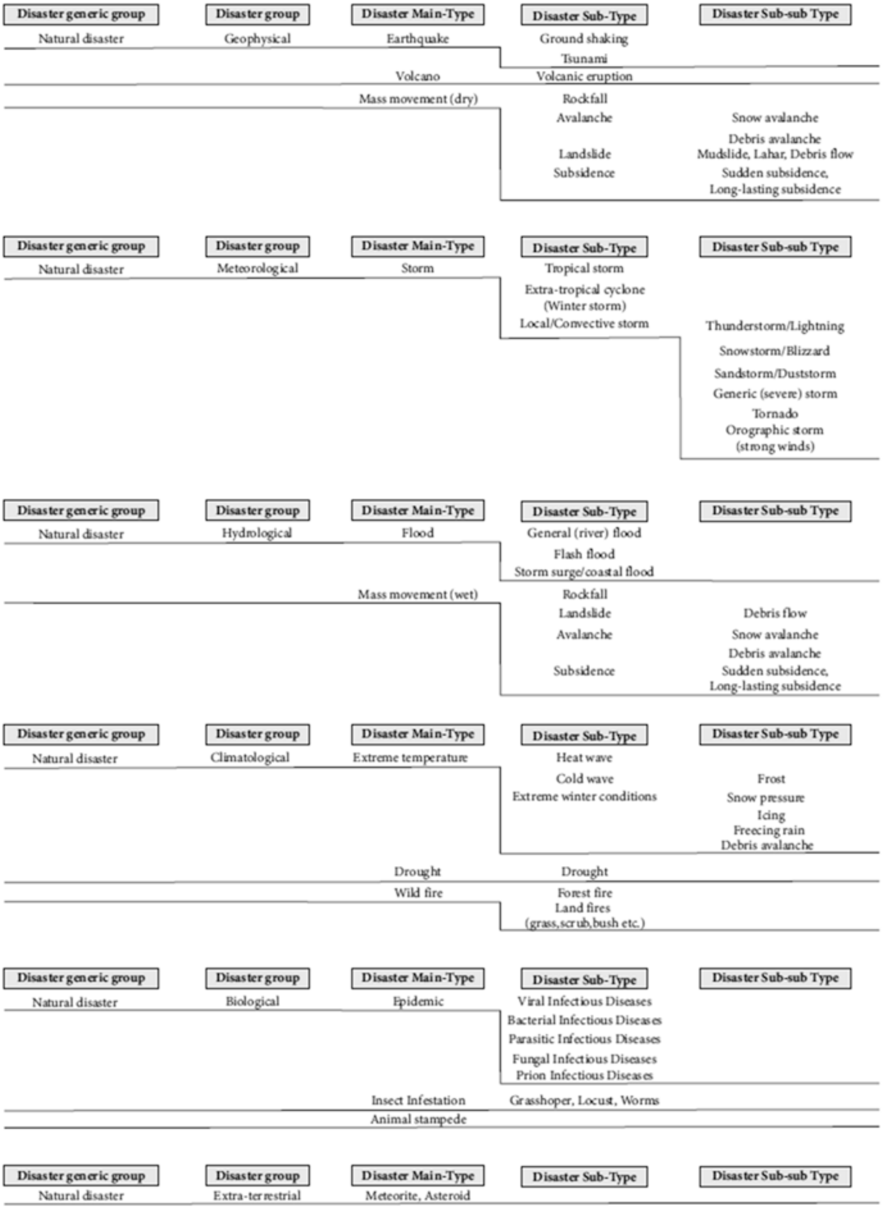


Fig. 2.3 Classification and various groups of natural disasters (adopted from Lukić et al. 2013)

and the characteristics that make people and places vulnerable and exposed. Hence, identifying, assessing and understanding of disaster risk in all dimensions (Fig. 2.2) are critical prior to the development of policies and practices for disaster risk management (UNDRR 2019). COVID-19 global pandemic is one such example of human vulnerability and exposure to a natural disaster. Its emergence and impact, as well as its spread, have been unexpected. There has been a lack of preparedness as there has been a lack of foreseeability, at least in political circles. This lack of seriousness assigned to a potentially serious threat as this current pandemic is a typical example of lack of effective risk management, which is causing continuous loss of lives on a global scale.

As far as threat levels are concerned, they are specific to specific disasters. They are specifically impacted by geographical, political and social factors. They require detailed pre-assessments, scenario analyses and continuous feedback loops and evaluations during crisis and post disaster recovery phases.

Risk assessments are produced to estimate possible economic, infrastructure and social impacts arising from a particular hazard or multiple hazards (Dalezios et al. 2017). Three components are usually considered when assessing risk and the associated probable loss: hazard, exposure and vulnerability (GFDRR 2014, p.5).

- *Hazard* is defined as the probability of experiencing a certain intensity of harm at a location and is usually determined by a historical or user-defined scenario, probabilistic hazard assessment or other methods. Some hazard modules can include secondary perils (such as soil liquefaction or fires caused by earthquakes or storm surge associated with a tropical cyclone or extratropical cyclone).
- *Exposure* represents the stock of human physiology and/or psychology, property and infrastructure exposed to a hazard, and it can include socio-economic factors.
- *Vulnerability* accounts for the susceptibility to damage of the assets exposed to the forces generated by the hazard. Fragility and vulnerability functions estimate the damage ratio and consequent mean loss, respectively, and/or the social costs (e.g. number of injured, homelessness and fatalities) generated by a hazard, given the specified exposure.

2.2 Disaster Criteria

The Centre for Research on the Epidemiology of Disasters (CRED) launched the Emergency Events Database (EM-DAT) which is an International Disaster Database in 1988. EM-DAT was created with the initial support of the World Health Organization (WHO) and the Belgian government. CRED requires that for a disaster to be entered into the database *at least one* of the following criteria must be met (Université catholique de Louvain (UCLouvain) 2009):

1. Ten (10) or more people reported killed
2. Hundred (100) or more people reported affected
3. Declaration of a state of emergency
4. A call for international assistance

2.3 Global Occurrence of Natural Disasters in 2018

In 2018, there were 315 climate-related and geophysical disaster events recorded in the EM-DAT with 11,804 deaths and over 68 million people affected across the world. Figure 2.4 shows the numbers of disasters by continent and top ten countries. Globally, Indonesia recorded nearly half the total deaths from disasters, while India recorded the highest number of individuals affected (CRED 2019).

As depicted in Fig. 2.5, floods have affected more people than any other type of disaster in the twenty-first century, in 2018 and between the period of 2008 and 2017 (CRED 2019). Floods have accounted for 127 events. Storm is the second largest disaster type where two major storms struck the USA, while in Asia, China, India, Japan and the Philippines faced extensive damage from multiple storms. As a result, storms were also the costliest type of disaster in 2018, particularly due to hurricanes Florence (US$ 14 billion) and Michael (US$16 billion) and typhoon Jebi (US$12.5 billion). It was similar for the period between 2008 and 2017. In terms of social and human impacts, the Philippines suffered from multiple deadly storms that took over 300 lives in total and affected over 10 million people. Third disaster is droughts and extreme temperatures (41 events) which affected 3 million people who have been experiencing an ongoing drought in Kenya, while Afghanistan suffered a major drought that impacted 2.2 million people, causing the internal displacement of hundreds of thousands (CRED 2019). Numerous drought events affected agricultural industries costing billions of dollars in damages across the world, while in South Asia, East Asia, Europe and North America, heatwaves cost hundreds of lives overall (ibid.). Data on the human impact of drought and extreme temperatures are difficult to capture; hence, they are likely to be underestimated. However, the reporting of these events should be improved, particularly in low- and lower-middle-income countries where the effects will be the most impactful (ibid.). The

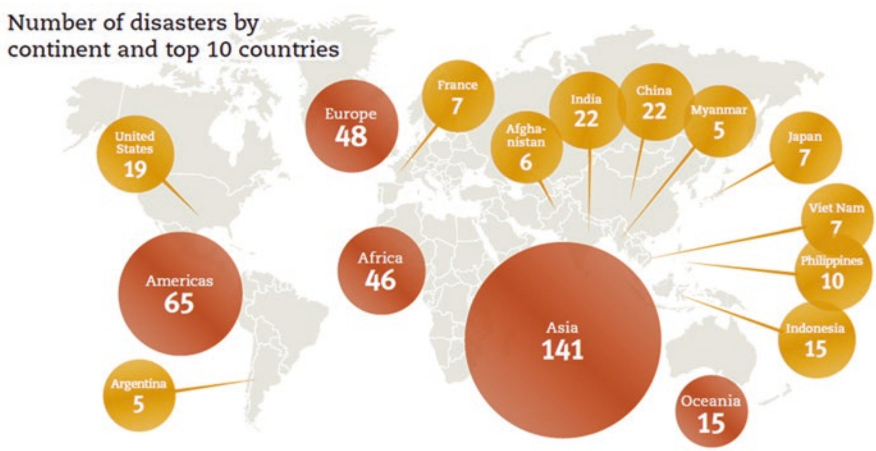


Fig. 2.4 Number of disasters by continent and top 10 countries (CRED 2019)

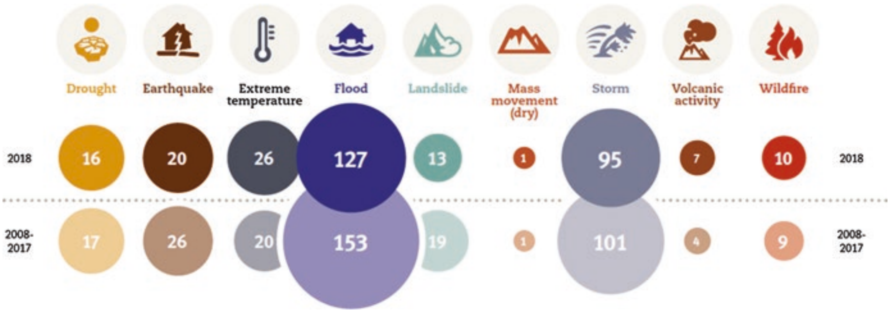


Fig. 2.5 Occurrence by disaster type: 2018 compared to 2008–2017 annual average (CRED 2019)

	Event	Country	Death Toll
1.	Earthquake/Tsunami, September	Indonesia	4,340
2.	Earthquake, August	Indonesia	564
3.	Flood, August	India	504
4.	Volcanic Activity/Tsunami, December	Indonesia	453
5.	Volcanic Activity, June	Guatemala	425
6.	Flood, June	Japan	246
7.	Flood, September	Nigeria	199
8.	Storm, December	Philippines	182
9.	Heatwave, May	Pakistan	180
10.	Flood, August	Korea DPR	146

Fig. 2.6 Total deadliest disaster events in 2018 (RED 2019)

Intergovernmental Panel on Climate Change (IPCC) (2018) suggests an increase in intensity or frequency of droughts and heatwaves in some regions, with global warming up to 1.5 °C compared to pre-industrial levels.

Figure 2.6 shows the total deadliest disaster events in 2018 and top ten countries by total disaster death toll in 2018. It was observed that earthquakes and subsequent tsunamis have been the deadliest type of disasters in the twenty-first century, and this trend continued in 2018. The concentration of the damage was in South East Asia and Melanesia, specifically in Indonesia and Papua New Guinea, respectively. A string of earthquakes in Papua New Guinea in early 2018 killed 181 and affected over half a million people, many of whom lived in remote highlands which were difficult to reach by aid and rescue operations. In Indonesia, multiple earthquakes caused extensive damage and loss of life. The island of Lombok suffered multiple earthquakes, the deadliest being on August 5, which killed 564 people. Another earthquake hit the island of Sulawesi on September 28 which triggered mudflows and a tsunami killing 4340 people, making it the deadliest disaster worldwide since 2015 (CRED 2019).

The last 20 years have seen a dramatic rise of 151% in direct economic losses from climate-related disasters, according to a report by UNDRR (Wallemacq and House 2018). In the period 1998–2017, disaster-hit countries reported direct economic losses of US$2908 billion of which climate-related disasters accounted for US$2245 billion or 77% of the total. The greatest economic losses have been experienced by the USA, US$944.8 billion; China, US$492.2 billion; Japan, US$376.3 billion; India, US$ 79.5 billion; and Puerto Rico, US$71.7 billion. Storms, floods and earthquakes place three European countries in the top ten for economic losses: France, US$48.3 billion; Germany, US$57.9 billion; Italy, US$56.6 billion; Thailand, US$52.4 billion; and Mexico, US$46.5 billion. In terms of occurrences, climate-related disasters also dominate the picture, accounting for 91% of all 7255 major recorded events between 1998 and 2017. Floods, 43.4%, and storms, 28.2%, are the two most frequently occurring disasters (Fig. 2.7) (ibid.).

During this period 1998–2017, the social impacts were that 1.3 million people lost their lives and 4.4 billion people were injured, rendered homeless, displaced or in need of emergency assistance; 563 earthquakes, including related tsunamis, accounted for 56% of total deaths or 747,234 lives lost (Wallemacq and House 2018). Comparatively to the previous decade (2008–2017), in 2018 there were fewer disasters compared to the annual average of 348 events, fewer deaths compared to the annual average of 67,572, fewer number of people affected compared to the annual average of 198.8 million people affected and lower economic losses compared to the annual average of US$166.7 billion (CRED 2019).

However, CRED (2019) noted that the burden was not shared equally as Asia suffered the highest impact and accounted for 45% of disaster events, 80% of deaths and 76% of people affected (Fig. 2.8). Globally, Indonesia recorded nearly half the total deaths (47%), while India recorded the highest number of people affected (35%). Earthquakes were the deadliest type of disaster accounting for 45% of deaths, followed by flooding at 24%. Flooding affected the highest number of

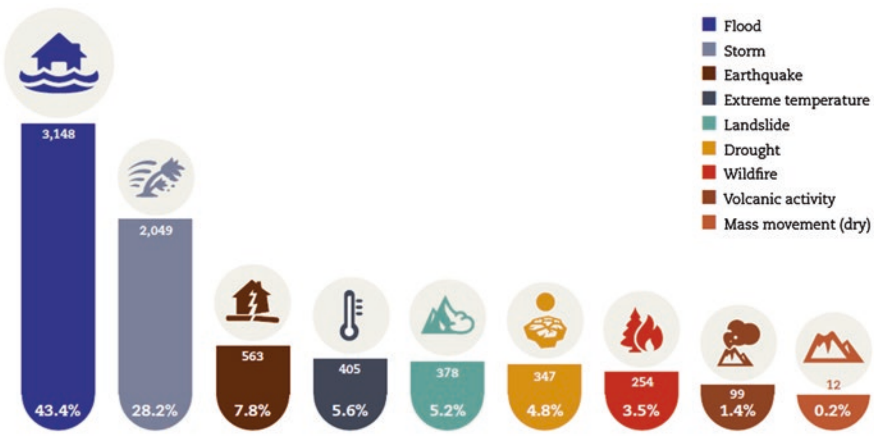


Fig. 2.7 Numbers of disasters per type (Wallemacq and House 2018)

	Country	Total Death Toll
1.	Indonesia	5,510
2.	India	1,396
3.	Japan	438
4.	Guatemala	427
5.	China	354
6.	USA	317
7.	Philippines	313
8.	Nigeria	300
9.	Pakistan	240
10.	D.P.R. Korea	232

Fig. 2.8 Top 10 countries by total disaster death toll in 2018 (CRED 2019)

people, accounting for 50% of the total affected, followed by storms which accounted for 28% (ibid.).

2.4 Geophysical Disasters

Geophysical disasters are destructive events that originate within or are caused by the processes of the solid earth. They include earthquakes, volcanoes and mass movement.

2.4.1 Earthquakes

Earthquakes are the vibrations caused by rocks breaking under stress. The underground surface along which the rock breaks and moves is called a fault (Geoscience Australia n.d.). Sudden motions along faults release the stored-up stress energy. The seismic energy released from these events travels through the Earth and propagates through the ground and over its surface, in the form of waves, and causes the tremors observed as earthquakes (ETH Zürich 2016).

According to Geoscience Australia (n.d.) and Swiss Seismological Service (SSS) (2016), the size or magnitude of earthquakes is determined by measuring the amplitude of the seismic waves recorded on a seismograph and the distance of the seismograph from the earthquake. These are then calculated and converted to a magnitude, which is a measure of the energy released by the earthquake. Earthquakes have naturally destructive effects of the planet's constantly changing surface (Geoscience Australia n.d.; Swiss Seismological Service 2016).

The levels of danger refer to the intensity of an earthquake in a specific warning area. The intensity is a measure of shaking at each location, and this varies from place to place, depending mostly on the distance from the fault rupture area (USGS n.d.). The effects of an earthquake are based on the extent of the destruction (buildings, landscape) and the subjective perception of an observer. Using a 12-point scale, it describes the consequences of an earthquake for people and buildings in a particular place (Swiss Seismological Service 2016).

The aftermath of an earthquake can create many implications socially and economically; it can cause many buildings to collapse which claim by far the majority of lives, but the destruction is often compounded by mudslides, fires, floods or tsunamis. It is also known that smaller temblors that usually occur after a large earthquake can further complicate rescue efforts and further cause death and destruction (National Geographic n.d.). Earthquakes can generate tsunamis (International Tsunami Information Center (ITIC) 2019a) and can also be linked to volcanic activity (ETH Zürich 2016), which will be covered in the next sections. The top ten deadliest earthquakes in recorded history with associated threat level – total casualties and total economic damage – are presented in Table 2.1.

The deadliest earthquake was on January 23, 1556, in the Shaanxi province of China (Table 2.1). An estimated 830,000 people died in one of the largest geophysical disasters ever recorded in human history.

One of the other largest earthquakes in terms of socio-economic losses is the massive and enormously devastating Great Sichuan earthquake (also called the Wenchuan earthquake) that happened on May 12, 2008. In a 7.9-magnitude earthquake, almost 90,000 people were counted as dead or missing and presumed dead in the final official Chinese government assessment; this included 5300 children. In

Table 2.1 Top ten deadliest earthquakes

	Earthquake location	Year	Magnitude	Deaths/ injuries	Financial loss[a]	Financial loss
1	Shaanxi, China	1556	8	830,000		>$25
2	Port-au-Prince, Haiti	2010	7	316,000		
3	Antakya, Turkey	115	7.5	260,000		>$25milion
4	Antakya, Turkey	525	7	250,000		>$25milion
5	Tangshan, China	1976	7.5	242,769		~$1 to $5 million
6	Gyandzha, Azerbaijan	1139	Unknown	230,000		>$25milion
7	Sumatra, Indonesia	2004	9.1	227,899	$10billion	
=8	Damghan, Iran	856	7.9	200,000		>$25milion
=8	Gansu, China	1920	8.3	200,000	$25milion	
9	Dvin, Armenia	893	Unknown	150,000		>$25milion
10	Tokyo, Japan	1923	7.9	142,807	$600milion	

Source: Ritchie (2018), National Geophysical Data Center /World Data Service (NGDC/WDS) (n.d.-a)

[a]In US$

addition, 375,000 people were injured and 4.8 million of people were made homeless. The economic loss was estimated at US$86 billion where four-fifth of the structures in the affected area were destroyed (Pletcher and Rafferty 2019). It was also estimated that it needed US$137.5 billion on rebuilding the affected areas (BBC 2013). Since then, there have been many other damaging earthquakes, such as L'Aquila in 2009, Haiti and Chile in 2010 and Japan and New Zealand in 2011. More recently, in 2019, a magnitude (M) 8 that struck Amazon jungle in Peru (Christian 2019); M 7.3 in Saumlaki, Indonesia; M 7.2 in L'Esperance Rock, New Zealand; M 6.7 earthquake struck Japan's north-western region (The Japanese Times 2019); M 6.4 in Ust'-Kamchatsk Staryy, Russia; M 6.2 in Aserrio de Gariche, Panama; and M 6.1 in the Philippines (United States Geological Survey (USGS) 2019a).

On April 23, 2019, a magnitude 6.3 earthquake hit the central Philippines, only a day after the 6.1 quake struck the country's north and killed at least 16 people. Bodies were found in the rubble of a supermarket that crashed down; buildings and an airport were damaged in the area. At least 24 people are missing (Associated Press 2019a). The Philippines is one of the world's most disaster-prone countries and has frequent earthquakes and volcanic eruptions because it lies on the Pacific 'Ring of Fire' – a seismically active arc of volcanoes and fault lines in the Pacific Basin. In 2013, a major tremor hit Cebu and Bohol provinces in the central Philippines, killing more than 200 people (Lopez and Calonzo 2019), and a magnitude 7.7 earthquake killed nearly 2000 people in the northern Philippines in 1990 (NBC 2019).

On June 18, 2019, China's Sichuan province was hit again, by another high-profile earthquake. A magnitude 6.0 earthquake struck the southern edge of the Sichuan basin near Yibin County which resulted in at least 12 deaths and 134 injuries. More than 4000 people were relocated as many structures were damaged or collapsed after the quake struck, according to the city government (Mediacorp 2019). This prompted the need for urgent scientific research and analysis to understand whether Sichuan is more prone to earthquakes and whether human activities have increased seismic activity (Wei 2019). Similarly, one notable incident is the Kaikōura earthquake in the South Island of New Zealand; its earthquake's complexity defies many conventional assumptions about the degree to which earthquake ruptures are controlled by fault segmentation and provides additional motivation to rethink these issues in seismic hazard models (Hamling et al. 2017). The earthquake was the most powerful seismic event in that area in more than 150 years in which shaking was widely felt throughout New Zealand.

2.4.2 Tsunami

Tsunami means 'wave in the port' in Japanese; the term originated in Japan as it has a significant record of earthquakes and tsunamis. Tsunamis have been documented as early as 684 AD (Karan and Suganuma 2016). Tsunami is a series of waves (with long wavelengths when traveling across the deep ocean) that are generated by a displacement of massive amounts of water through large underwater earthquakes, major submarine slides, volcanic eruptions or landslides. Tsunami waves travel at very high speed across the ocean, but as they begin to reach shallow water, they slow down, and the wave grows steeper (UCLouvain 2009; USGS 2019b).

Earthquake magnitude is one factor that affects tsunami generation, but there are other important factors to consider. Thrust earthquakes (as opposed to strike slip) are far more likely to generate tsunamis, but small tsunamis have occurred in a few cases from large (i.e. >M8) strike-slip earthquakes. Earthquakes of the size of magnitudes between 6.5 and 7.5 do not usually produce destructive tsunamis. However, small sea-level changes might be observed near the epicentre. Tsunamis capable of producing damage or casualties are rare in this magnitude range but have occurred due to secondary effects such as landslides or submarine slumps. On the other hand, earthquakes of the magnitudes between 7.6 and 7.8 can potentially produce destructive tsunamis, especially near the epicentre or fault line near or on the ocean floor (UCLouvain 2009; USGS 2019b). The general guidelines are based on historical observations and in accordance with procedures of the Pacific Tsunami Warning Center (PTWC) 2009). Destructive tsunamis usually occur in regions of the Earth characterised by tectonic subduction along tectonic plate boundaries. The high seismicity of such regions is caused by the collision of tectonic plates; and more than 80% of the world's tsunamis occur in the Pacific along its Ring of Fire subduction zones (ITIC 2019b).

Tsunamis were largely unknown to the wider public before the enormously destructive 2004 tsunami that shook Sumatra, Indonesia. The source of the tsunami was a huge earthquake, measuring 9.1 on the Richter scale, its epicentre in the Indian Ocean 250 km south-east of the Indonesian city of Banda Aceh. It was reported that the fault zone that caused the tsunami was roughly 1300 km long, vertically displacing the sea floor by several metres along that length. The ensuing tsunami was as tall as 50 m, reaching 5 km inland near Meubolah, Sumatra (Borrero et al. 2006; Phillips 2011; Penberthy 2014). These massive surges of water swept away buildings and people, especially on the coastlines of Indonesia, Sri Lanka, India, Thailand and the Maldives; and the effects were felt as far away as Somalia on the east coast of Africa, which was 4500 km west of the epicentre (Penberthy 2014).

The threat level was high as both social costs and economic damage of this event were significantly high – about a quarter of a million are dead, 5 million required immediate aid, 1.8 million citizens were rendered homeless, and the tsunami caused US$10 billion in damage. This natural disaster caused extreme devastation over huge areas and accompanying grief and anxiety, especially in Indonesia, Thailand and Sri Lanka, mainly due to the lack of planning, a warning system and a disaster management plan for the entire Indian Ocean region (Suppasri et al. 2015).

In Indonesia, there was a string of earthquakes which occurred in Lombok Island in August, 2018. One notable event was a 6.9-magnitude earthquake that ruptured the northern reaches of the Indonesian island of Lombok on August 5. The earthquake killed 560 people, injured 7733 people, displaced more than 160,000, destroyed 83,392 houses and caused US$509 million in damage. The disaster struck exactly 1 week after a foreshock clocked in with a strength of 6.4 magnitude which

Table 2.2 Top ten most destructive tsunamis

	Location	Year	Earthquake magnitude	Deaths/ injuries	Financial loss	Other damages
1	Sumatra, Indonesia	2004	9.1	227,899	$10billion	>1000 houses
2	North Pacific Coast, Japan	2011	9	18,434	$235billion	12,3661 houses
3	Lisbon, Portugal	1755	8.5	60,000	~$25 million or more*	>1000 houses
4	Krakatau, Indonesia	1883		40,000[a]		>1000 houses
5	Enshunada Sea, Japan	1498	8.3	31,000		>1000 houses
6	Nankaido, Japan	1707	8.4	30,000		30,000 buildings
7	Sanriku, Japan	1896	7.6	27,122		11,000 houses
8	Northern Chile	1868	8.5	25,000	$300 million	
9	Ryukyu Islands, Japan	1771	7.4	13,486	~$25 million or more*	3137 houses
10	Ise Bay, Japan	1586	8.2	8000	~>$5 to $24 million*	>1000 houses

Source: Phillips (2011), NGDC/WDS (n.d.-a)
[a]As many as 2000 deaths can be attributed directly to the volcanic eruptions, rather than the ensuing tsunami

left 20 people dead (NGDC/WDS n.d.-a; Solomon and Haynes 2018). Yet, another magnitude 6.9 quake hit Kota Ternate, North Maluku, Indonesia, on July 7, 2019. The quake was centred 185 kilometres (115 miles) south-east of Manado in the Molucca Sea at a depth of 24 kilometres (15 miles), according to USGS. The nation's geophysics agency predicted waves of half a metre (1.6 feet) for parts of central Indonesia, which triggered the issue of tsunami warning for North Sulawesi and North Maluku but was then cancelled just about 2 hours after the quake hit. Indonesia, a vast archipelago of 260 million people, is frequently struck by earthquakes, volcanic eruptions and tsunamis because of its location on the 'Ring of Fire', an arc of volcanoes and fault lines in the Pacific Basin (Associated Press 2019b). A list of the top ten most destructive tsunamis is presented in Table 2.2.

2.4.3 Volcano

A volcano is defined as a type of volcanic event near an opening or vent in the Earth's surface including volcanic eruptions of lava, ash, hot vapour, gas and pyroclastic material as defined by UCLouvain (2009) and Integrated Research on Disaster Risk (IRDR) (2014). Borgia et al. (2010, p.7) propose a more detailed definition of volcano, 'volcanoes are geologic environments where magma, generated at a source within the crust or mantle, flows upward and is subject to varying amounts of physicochemical evolution, intruding and reacting with the encasing ricks and other magma, and originating a geothermal system'. Once near the lithosphere top (i.e. of a major rigid-fluid, high-low-density zone of interface), the magma erupts, piercing the interface. Volcanic deposits are accumulated from eruptions giving rise to a volcanic edifice. In turn, these deposits may become intruded or modified by magna, eruptions, geothermal fluids, tectonics, erosion, landsliding and all other kinds of geologic processes. The boundaries of this environment (volcano) are frequently time dependent, transitional, ill-defined or unknown. However, working boundaries can be based on different arguments using factors such as geometry, morphology and structure.

There are various volcano types as listed by the Smithsonian Institution's Global Volcanism Program (GVP) (2013a), namely, stratovolcanoes, shield volcanoes, calderas, craters, fissure vents, pyroclastic cones and lava domes (for more information please see Smithsonian Institution 2013a). Each volcano is idiosyncratic. They have their own eruption styles and eruption frequencies (Andrews 2018). At the time of writing, 40 volcanoes are erupting, and at least 20 volcanoes are actively erupting on Earth at any given time (see Smithsonian Institution's (2013b) GVP Current Eruptions).

Measuring the size or strength of natural events has always been a challenge for natural scientists. Chris Newhall of the US Geological Survey and Stephen Self at the University of Hawaii developed the Volcanic Explosivity Index (VEI) in 1982. VEI is a relative measure of the explosiveness of volcanic eruptions of recent and historic eruptions, on a scale from 0 to 8 which is largely based principally on the erupted mass or volume of a deposit. The height of the ash column produced by the eruption and qualitative observations (using terms ranging from 'gentle' to 'mega-colossal') are also taken into consideration to determine the explosivity value (USGS 2017). In general, VEI value roughly correlates with an eruption's frequency. VEI 0 eruptions take place where trapped gas and magma can easily make it to the surface and the magma itself is not that viscous and gloopy – common Hawaiian or Icelandic lava flows where these eruption types are always happening somewhere in the world (Andrew 2018). A 'significant volcanic eruption' is often defined as an eruption with a VEI value of 6 or greater. Historic eruptions that were definitely explosive but carry no other descriptive information are assigned a default VEI of 2.

It is important to note that tsunami (see *Tsunami* section) can also be caused by volcanic sources (ITIC 2019c). The collapse of a coastal or underwater volcano can cause a landslide leading to a tsunami. Similarly, underwater eruptions where hot magma and cold seawater meet can create a steam explosion resulting in a tsunami (Geoscience Australia 2016). Table 2.3 shows the world's ten most devastating volcanic eruptions.

Table 2.3 Top ten most devastating volcanic eruption

	Volcanic eruption location	Year	VEI	Deaths/ injuries	Financial loss	Other damages
1	Mt Tambora, Indonesia	1815	7	11,000	~$25 million or more*	>1000 houses
2	Krakatau, Indonesia	1883	6	2000	~$5 to $25 million*	101 to 1000 houses
3	Laki, Iceland	1783	6	10,000	–	–
4	Mt Pelee, Caribbean	1902	4	28,000	~ $50 million	–
5	Ilopango, El Salvador	450 AD	6+	30,000	–	–
6	Mt Unzen, Japan	1792	2	15,000/707	~ $150 million	6200
7	Nevado del Ruiz, Columbia	1985	3	20,000	~ $1 billion	–
8	Mount Pinatubo, Philippines	1991	6	722	>$200 million	200,000 people homeless
9	Mt Vesuvius, Italy	79 AD	5	2100	–	–
10	Santa Maria, Guatemala	1902	6	2500	~$1 to $5 million	~51 to 100 houses

Source: Cassella (2017), NGDC/WDS (n.d.-b)

2.4.4 Mass Movement (Dry)

Mass movement is a term applied to bulk movements of soil and rock debris downslope in response to the pull of gravity (primary agent of soil movement) or the rapid or gradual displacement of large volumes of soil and surface material in a predominantly vertical direction (IRDR 2014). It is said that hydrological processes are usually a major contributing factor even though gravity is the primary agent of mass movement; however, it may also be triggered by earthquakes (ibid.).

The forms of mass movement include rockfall, avalanche, landslide and subsidence. They are defined as the following (IRDR 2014, p.12):

- *Avalanche* is a large mass of loosened earth material, snow or ice that slides, flows or falls rapidly down a mountainside under the force of gravity. Snow avalanche is a rapid downslope movement of a mix of snow and ice. Debris avalanche is the sudden and very rapid downslope movement of unsorted mass of rock and soil. There are two general types of debris avalanches – a cold debris avalanche usually results from an unstable slope suddenly collapsing whereas a hot debris avalanche results from volcanic activity leading to slope instability and collapse (p.12).
- *Landslide* can occur following an earthquake which is independent of the presence of water or when heavy rain or rapid snow/ice melt send large amounts of vegetation, mud or rock downslope by gravitational forces (p.16).
- *Subsidence* refers to the sinking of the ground due to groundwater removal, mining, dissolution of limestone (e.g. karst, sinkholes), extraction of natural gas and earthquakes (p.17).

The disastrous February 17, 2006, rockslide-debris avalanche (landslide) occurred in tropical mountain terrain, on Leyte Island, central Philippines. Over 1200 people perished and 19,000 displaced when the village of Guinsaugon was overwhelmed directly in the path of the landslide (Evans et al. 2007). The landslide originated on a steep 450-m-high rock slope within the damage zone of the Philippine Fault where the rock mass consisted of sheared and brecciated volcanic, sedimentary and volcaniclastic rocks. Geological factors were thus major contributors to this catastrophic failure. When it was analysed, 'tectonic weakening of the failed rock mass had resulted from active strike-slip movements along the Philippine Fault which have been estimated by other workers at 2.5 cm/year. The landslide involved a total volume of 15 Mm^3, including significant entrainment from its path, and ran out a horizontal distance of 3800 m over a vertical distance of 810 m. Run-out distance was enhanced by friction reduction due to undrained loading when the debris encountered flooded paddy fields in the valley bottom at a path distance of 2600 m' (Evans et al. 2007, p.89). There was no direct trigger for the Guinsaugon landslide. The rockslide-debris avalanche was preceded, however, by very heavy rainfall with a lag time of 4 days. The rockslide-debris avalanche is one of several disastrous landslides that occurred in the Philippines in the last 20 years. In terms of loss of life, the Guinsaugon event is the most devastating single-event landslide to have occurred worldwide since the Casita Volcano rock avalanche-debris flow which was triggered by Hurricane Mitch in Nicaragua in 1998 (ibid.). Table 2.4 shows the world's ten most devastating mass movements (dry).

Table 2.4 Top ten most devastating mass movement (dry)

	Location	Year	Disaster subtype	Deaths/ injuries	Total affected	Total damage[a]
1	Ranrahirca area, Peru	1962	Landslide	2000	–	$200 million
2	South Mindanao, Philippines (the)	1985	Landslide	300	–	–
3	Mt Sale (Dongxiang area, N.W. Gansu), China	1983	Landslide	277	–	–
4	Sirnak, Siirt, Elazig, Batman, Bingol, Diyarbakir, Hakkari, Tunceli provinces, Turkey	1992	Avalanche	261	1069	–
5	Gachala, Colombia	1983	Rockfall	160	–	–
6	Trisuli, Nepal	1963	Landslide	150	–	–
7	Padang Panjang (West Sumatra), Indonesia	1987	Landslide	131	701	$1 million
8	Minshat Nasir district (Cairo province), Egypt	2008	Rockfall	98	697	–
9	Frank, Alberta, Canada	1903	Rockfall	76	23	–
10	Kaiapit district (Morobe province), Papua New Guinea	1988	Landslide	76	1000	–

Source: CRED (2009)
[a]In US$

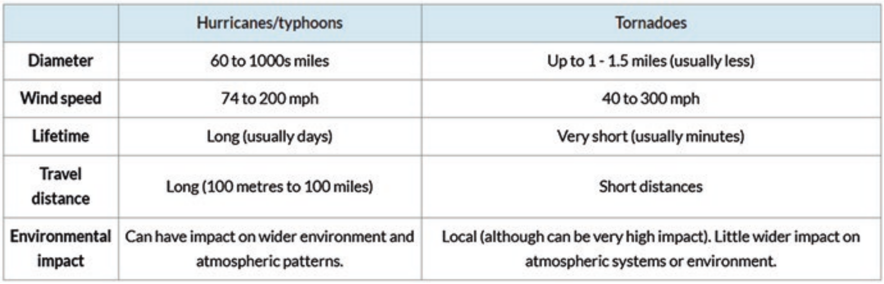
2.5 Meteorological Hazard

Meteorological hazard is defined as a hazard caused by short-lived, micro- to meso-scale extreme weather and atmospheric conditions that last from minutes to days (IRDR 2014). This hazard category includes various storms such as extratropical storms (winter storm), tropical storms/cyclones and local or convective storms; they are defined as the following (ibid.):

- *Extratropical storm* is a type of low-pressure cyclonic system in the middle and high latitudes (also called mid-latitude cyclone) that primarily gets its energy from the horizontal temperature contrasts (fronts) in the atmosphere. When associated with cold fronts, extratropical cyclones may be particularly damaging (e.g. European winter/windstorm, Nor'easter).
- *Tropical storm/cyclone* originates over tropical or subtropical waters. It is characterised by a warm-core, non-frontal synoptic-scale cyclone with a low-pressure centre, spiral rain bands and strong winds. The terms hurricane, cyclone and typhoon refer to the same thing; they can be used interchangeably. The choice of terminology is location-specific and depends on where the storm originates and their location; tropical cyclones are referred to as hurricanes (Atlantic, Northeast Pacific), typhoons (Northwest Pacific) or cyclones (South Pacific and Indian Ocean).
- *Convective storm* is generated by the heating of air and the availability of moist and unstable air masses. Convective storms range from localised thunderstorms (with heavy rain and/or hail, lightning, high winds, tornadoes) to meso-scale, multi-day events. One example of hail is the recent event that happened in Mexico, another event of tornadoes.

It is important to note that conventional (single phase) life cycles of extratropical and tropical cyclone development are completely cold core and completely warm core, respectively; there is no overlap in phase. They represent cyclones where the distinction between extratropical and tropical phases is clearly discernible. However, over the past several decades, it has become increasingly apparent that cyclone life cycles can involve many phases and can readily cross the artificial boundary between cold core and warm core (Hart 2003). The evolution of Hurricane Floyd in 1999 from intense tropical cyclone into an extratropical cyclone is a typical example of extratropical transition (see Lawrence et al. 2001).

The Saffir-Simpson Hurricane Wind Scale is the standard used to measure hurricane intensity; the scale of hurricane intensity classification is determined by wind speed alone (Simpson and Riehl 1981). This scale estimates potential property damage. Although the terms hurricane, cyclone and typhoon refer to the same thing, there are differences between hurricanes and tornadoes. While hurricanes and tornadoes have the same characteristic circulatory wind patterns, they are very different weather systems. The main difference between the systems is scale (tornadoes are small-scale circulatory systems; hurricanes are large-scale). These differences are highlighted in Fig. 2.9.



	Hurricanes/typhoons	Tornadoes
Diameter	60 to 1000s miles	Up to 1 - 1.5 miles (usually less)
Wind speed	74 to 200 mph	40 to 300 mph
Lifetime	Long (usually days)	Very short (usually minutes)
Travel distance	Long (100 metres to 100 miles)	Short distances
Environmental impact	Can have impact on wider environment and atmospheric patterns.	Local (although can be very high impact). Little wider impact on atmospheric systems or environment.

Fig. 2.9 Difference between hurricanes and tornadoes. (Adapted from Ritchie and Roser 2019)

In the USA, Hurricane Harvey hit Texas and Louisiana in late August 2017 as a category 4 storm. It lingered over land for days as a tropical storm, dumping feet of rain and causing catastrophic flooding in Houston and other areas. As a result, at least 82 people died with US$125 billion in damage, as estimated by the National Oceanic and Atmospheric Administration (NOAA). This made it the costliest natural disaster in US history (Ramsey 2018). The second costliest hurricanes were Hurricane Katrina (2005) and Sandy (2012), US$108 billion and US$71.4 billion, respectively. Hurricane Katrina made landfall as a category 5 near Miami before striking Louisiana as a category 3 storm which caused more than 1200 deaths (ibid.). Category 1 Hurricane (superstorm) Sandy caused deadly flooding to New York City's transportation systems, leaving 8.5 million people without power and destroying 650,000 homes, and was responsible for the deaths of at least 70 people in the Caribbean and almost 150 people in the USA (Gibbens 2019). The most devastating storms that killed the most people are listed in Table 2.5.

2.6 *Hydrological Disasters: Floods*

Hydrological disasters occur as a result of violent, sharp and harmful changes in the quality of Earth's water resulting in redistribution of water (OMICS 2019). A flood occurs because of overflow of water beyond its boundaries and impacts human settlements and infrastructure (ibid.). Floods are the most prominent type of hydrological disaster. Every year floods cause more than US$50 billion in damages, and fatalities from floods have been increasing over recent years (Nunez 2019). Floods are followed by serious contamination of water and land with hazardous materials including sharp debris, pesticides, fuel and untreated sewage (ibid.). Mould blooms become a serious hazard, and infrastructure damage can result in lack of access to electricity, clean drinking water as well as an increase in the risk of serious waterborne diseases including typhoid, hepatitis A and cholera (Nunez 2019). While immediate social impacts include loss of human life, property damage, damage to crops, loss of livestock, waterborne diseases, infrastructure damage resulting in lack of utilities availability and displacement, floods can also cause longer-term social

Table 2.5 Top ten most devastating storms

	Location	Year	Disaster name	Deaths/ injuries	Total affected	Total damage
1	Khulna, Chittagong, Bangladesh	1970		300,000	3,648,000	$86.4 million
2	Cox's Bazar, Chittagong, Patuakhali, Noakhali, Bhola, Barguna, Bangladesh	1991	Gorky or 02B	138,866	15,438,849	$1.78 billion
3	Labutta, Mawlamyinegyun areas (Myaungmya district, Ayeyarwady province), Ngapudaw area (Pathein district, Ayeyarwady province), Bogale, Dedaye, Kyaiklat areas (Pyapon district, Ayeyarwady province), Kungyangon, Kawhmu, Twantay, Kyauktan areas (Yangon (S) district, Yangon province), Bago (E), Bago (W), Kayin, Kayar, Mon provinces, Myanmar	2005	Cyclone Nargis	138,366	2,420,000	$4 billion
4	Swatow, China	1922		100,000		
5	West Sundarbans, Bangladesh	1942		61,000		
6	India	1935		60,000		
7	Wenzhou, China	1912		50,000		
8	Orissa, West Bengal, India	1942		40,000		
9	Barisal district, Bangladesh	1965		36,000	15,600,000	$57.7 million
10	Chittagong, Noakhali, Bangladesh	1963		22,000	1000,000	$50 million

Source: CRED (2009)

impacts (Queensland Government 2018). These include disruptions to supplies of clean water, wastewater treatment, disruptions to electricity, transport, communications, education and healthcare as well as loss of livelihoods, reduced purchasing power, loss of land value and creation of community economic vulnerability (Queensland Government 2018). Floods can also cause psychological impacts such as post-traumatic stress due to loss of family members, displacement from home, loss of property, disruption to business and social affairs (ibid.).

There are different types of floods including coastal and riverine floods.

2.6.1 Coastal Floods

Coastal floods are caused by storm surges which are sudden rises in sea levels caused by strong winds, hurricanes and cyclones, rising sea levels due to climate change, tsunamis which are very large waves caused by earthquakes, volcanic eruptions, meteor impacts as well as rising sea levels in reclaimed lands (Jackson 2014). Based on threat level, coastal flooding is categorised as minor which encompasses slight beach erosion and no major damages, moderate with fair amount of beach erosion as well as damage to homes and businesses and major which implies serious threat to life and property (Maddox 2014).

A recent example of a tsunami (see *Tsunami* section) which caused serious social, economic and environmental impacts was the 2011 Tohoku earthquake (see *Earthquakes* section) and tsunami in Japan. The threat levels of this tsunami were high as indicated in the following social, economic and environmental impacts:

- Social impacts. Close to 15,000 people were killed by the tsunami and thousands of people went missing. More than 100,000 children were forced out of their homes, and many of them were separated from their parents. Graves had to be dug for the large number of bodies, and traditional ceremonies could not be undertaken. Critical infrastructures including cultural sites were destroyed because of the tsunami. There was a nuclear meltdown at the Fukushima Daiichi power plant which forced additional evacuations, and the area surrounding the plant cannot be inhabited for a long time due to radioactive pollution (Jackson 2014).
- Economic impacts. The main economic impact was felt through the destruction of buildings resulting in tens of billions of dollars in damage and destruction. Hundreds of ports and fishing villages were impacted, and the fishing industry suffered from a ¥1.3 trillion loss. Many private dwellings were not covered by insurance, and households had to pay for reconstruction themselves or through government assistance. The tsunami caused high levels of salinity on thousands of hectares of farmland, rendering the land unfit for agriculture for many years (Jackson 2014).
- Environmental impacts. A large amount of debris was spread over land, and this is a usual occurrence from tsunamis. It poses a serious threat to marine biodiversity. The radioactive material from the nuclear plant has caused radioactive pollution in air and water as well as in food grown in the region. Radioactive pollution is not containable in the region; it has the potential for global impacts (Jackson 2014).

2.6.2 Riverine Floods

Riverine flooding takes place when water overflows the edges of a river or stream. Flash flooding can occur without much notice and poses serious threat due to hurling debris and the destructive force of the water (Maddox 2014). Pluvial or surface flooding can occur as a result of coastal and riverine flooding. The most relevant risk for pluvial or surface flooding is economic risk due to damage to infrastructure (ibid.). Urban areas are most at risk due to surface flooding as urban drainage systems may not be able to handle heavy rain or from hillsides which may not be able to absorb run-off or flowing water (ibid.).

It is possible to undertake adaptation strategies to avoid economic losses from floods which account for one-third of total economic losses from global natural hazards (Bosello et al. 2018). As a preventative strategy, adaptation costs need to be in the range of US$13–US$40 billion to create climate-proofing infrastructures (ibid.). Fifteen of the world's 20 megacities (with populations of over 10 million) are highly susceptible to sea-level rise and increased coastal storms (EPA 2017). A major flood in any of these megacities could result in the loss of a quarter of GDP of the city (ibid.).

2.7 Climatological Disasters

According to Below, Wirtz and Guha-Sapir (2009), climatological disasters include extreme temperatures (which include heatwaves, cold waves and extreme winter conditions), droughts and wildfires. Climatological disasters are defined as events which are caused by long-term meso- to macro-level processes and range from seasonal to multiple time periods and demonstrate climate variability (United Nations 2016).

El Niño occurred due to very warm Pacific Ocean water off the coast of Ecuador and Peru creating drought conditions in Australia, India, Indonesia, Japan and South Africa which resulted in negative economic impacts due to low crop yields and inflated prices (Rogoff 2016). Between 1998 and 2017, the economic costs of climate-related disasters have been around US$2.25 trillion with the USA suffering from worst economic losses, followed by China and Japan (McCarthy 2018).

Social impacts of climatological disasters have been captured as follows by the Environmental Protection Agency (EPA) in the USA (2017):

- Impacts on agriculture and food production. Heat and droughts reduce crop yields and livestock productivity as there is less water available for irrigation. Climate change also affects the fishing industry and food supplies of coastal communities.
- Impacts on water supply and quality. Semi-arid and arid parts of the world continue to experience reduced water resources, by as much as 50%.
- Impact on human health. Increased temperatures (heatwaves) cause frequent and severe heat stress. Heatwaves have a negative impact on air quality, and the impact of extreme temperatures on increased malnutrition and foodborne illnesses is a serious risk. Drought conditions have the potential to increase risk of meningococcal meningitis especially in sub-Sahara and West Africa.
- Mental health. Climatological disasters have a range of mental health consequences from stress and distress to clinical disorders such as suicidal thoughts.

Also, according to EPA (2017), climatological disasters have the potential to increase risk of conflicts (ethnic or resource), ecosystem degradation, lack of agricultural land and water for irrigation and displacement. It is important to note that according to the Intergovernmental Panel on Climate Change if global temperature increase is not kept under 1.5C, threat levels relating to climate-related disasters will increase dramatically in the near future (McCarthy 2018).

2.8 Biological Natural Disasters

According to the disaster classification provided by Lucic et al. (2013), biological natural disasters include epidemics and insect infestations. Epidemics occur because of wide-scale viral, bacterial, fungal, parasitic and prion (caused by a protein which can result in brain proteins to unfold abnormally) infectious diseases. The deadliest epidemic occurred in 1918 which was the Spanish influenza outbreak which took the lives of 50 million people. Nowadays, every month, the WHO receives 5000 early warning disease signals of which 300 require further investigation and 30 of which need in-depth field studies to determine their potential of becoming an epidemic (Candeias and Morhard 2018). According to the World Bank (2017), annual global cost of moderately severe to severe pandemics is comparable to other top priority global threats such as climate change and is approximately US $570 billion or 0.7% of the global income. Also, frequency and diversity of outbreaks have steadily increased over the last three decades (ibid.) (Fig. 2.10).

Although human fatalities have been decreasing from epidemics and pandemics, the economic costs have been on the rise (Candeias and Morhard 2018). For

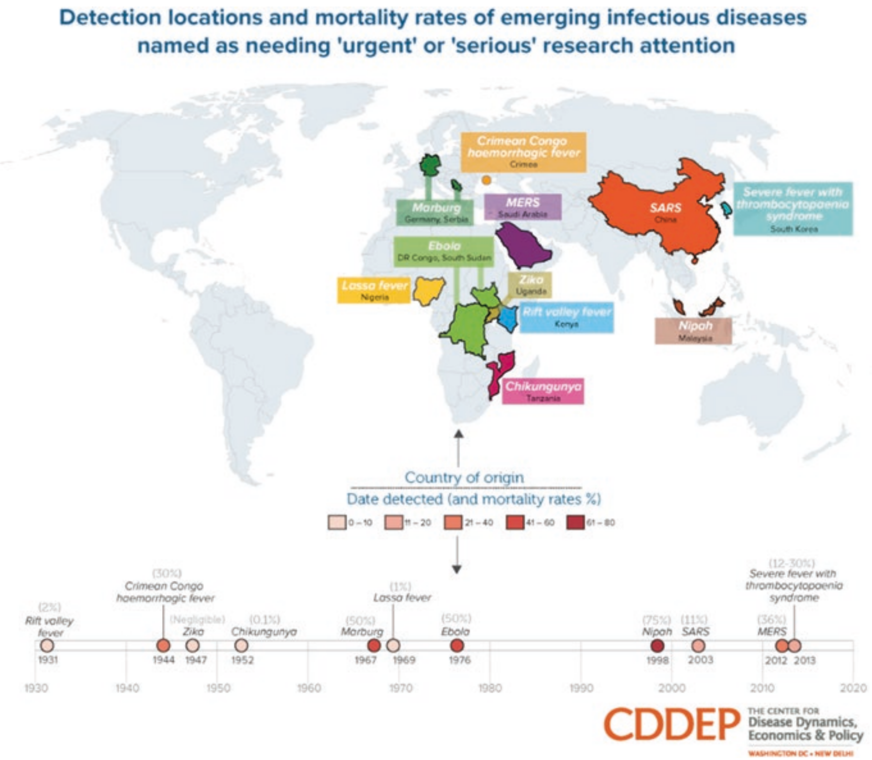


Fig. 2.10 Emerging infectious diseases marked as needing urgent attention (Source: Center for Disease Dynamics, Economics & Policy, in Candeias and Morhard 2018)

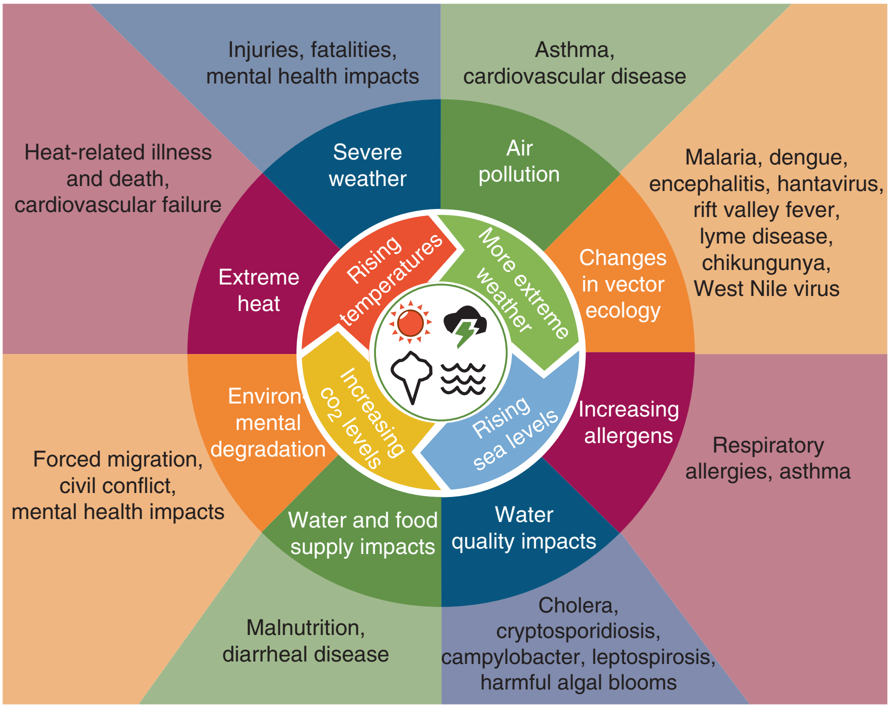


Fig. 2.11 Impacts of climate change on human health. (Source: Centre for Disease Control and Prevention 2014)

example, the 2015 South Korean Middle East respiratory syndrome (MERS) outbreak, which required 16,000 people to be quarantined and resulted in 38 deaths, led to substantial changes in consumer behaviour (ibid). There was a 41% reduction in the number of tourist visits to South Korea as well as people avoiding restaurants, theatres and shopping centres. The Bank of Korea had to cut its benchmark interest rate to a record low due to the social impacts of the epidemic (ibid.). It is important to note that climate change poses serious potential threat to human health as demonstrated in Fig. 2.11.

Vector-borne and waterborne diseases are particularly sensitive to global climate change, and as a result climate change has potentially increasing impact on vector-borne and waterborne epidemics (WHO 2019).

2.8.1 COVID-19 Pandemic

COVID-19 first cases were identified in December 2019 (WHO 2020). SARS-COV-2 (a novel virus) has been identified as the culprit for the globally disastrous political, social and economically dire situations currently faced, in 2020, in more than 200 countries worldwide. Countries such as the USA have now entered recession due to it. Millions of jobs have been lost. Social issues such as substance abuse, domestic violence and mental health problems have become more prominent since social distancing measures have been introduced (Taub 2020). There is social unrest, for example, in the form of the recent 'Black Lives Matter' protests which have been considered as physical distancing measures' violations in the USA and other countries. Governments have been accused of not taking enough measures to prevent the pandemic from spreading in their countries. China has been accused of lack of transparency in the initial stages of COVID-19 spread in Wuhan (Pedrero 2020).

At present, there are more than 7.5 million COVID-19 cases worldwide (Worldometer 2020). Fatalities from COVID-19 have been more prominent in economically developed countries, for now. The risk of further deaths in millions is high in economically developing regions such as Africa. From a risk management perspective, no one really saw this novel virus jumping from the bat to humans and evolving to become a very serious threat to human life. Multiple complications in addition to serious lung damage have been identified, including blood clots. People with pre-existing health conditions are deemed to be more susceptible to the potentially serious impacts of the novel coronavirus. Pre-existing ailments include diabetes.

From a risk management perspective, which were identified earlier, the basic elements are as follows:

- *Hazard* which is defined as the probability of experiencing a certain intensity of hazard at a location and is usually determined by an historical or user-defined scenario, probabilistic hazard assessment or other methods. From COVID-19 pandemic perspective, actual probability of such a pandemic occurring has been identified by the WHO and Bill Gates, much before the pandemic took its hold. But as WHO has pointed out, governments have not taken this threat seriously. Financial resources have not been allocated adequately to this serious hazard. In countries like the USA, which are meant to be at the forefront of public health response, including to a pandemic, response has poor. Medical professionals have had to make choices between individuals' lives to save, for example, in Italy and now in India.
- *Exposure* represents the stock of property and infrastructure exposed to a hazard, and it can include socio-economic factors. This is an extremely critical factor for all governments to consider. Something as basic as masks or ventilators have either been in short supply or have been defectives, rendering them useless. Political disagreements as now between China and the USA, for example, have cost lives. Egos of politicians have been more at the forefront than saving lives. Consider, for example, Brazil where there has been not only denial but mockery of the situation by the presidency. This has cost lives.
- *Vulnerability* accounts for the susceptibility to damage of the assets exposed to the forces generated by the hazard. Fragility and vulnerability functions estimate the damage ratio and consequent mean loss, respectively, and/or the social costs

(e.g. number of injured, homeless and dead) generated by a hazard, given the specified exposure. A vulnerability assessment, if undertaken, prior to COVID-19 taking its hold would have meant a good understanding of susceptibility and a well-informed assessment of vulnerability.

The critical point here is to emphasise the importance of strategic risk management; it is something that boards and directors of large corporations should delve into. Strategic risk management response to natural disasters including biological disasters is something which needs to be discussed, planned and taken extremely seriously by organisations of all sizes – large corporations, governments and small-medium enterprises. The main reason for this is that these risks and hazards pose very high threat levels as can be seen with the COVID-19 pandemic (WHO 2020).

3 Summary and Conclusions

This chapter covered and discussed various kinds of natural disasters, their classifications and threat levels. The threat levels associated with social and economic impacts of natural disasters can be significantly high where many people are affected; and total economic losses can also vary between countries. When natural disasters vary widely in predictability and impact, this makes it even more challenging to manage, respond and recover from the disaster. It is suggested that identifying, assessing and understanding of disaster risk in all dimensions are critical prior to the development of policies and practices for disaster risk management.

Based on a detailed literature review and discussion above, fatalities, loss of livelihoods and displacement from natural disasters have been found to be most prominent in Asia Pacific. Nevertheless, the COVID-19 pandemic is impacting a lot of regions in extremely negative ways such as in the form of recession in the USA. Threat levels become more pronounced when there are resource constraints and lack of proper communications and adequate response measures to reduce impacts. Globally, the most prominent natural disasters have been *flooding* and *extreme weather*, until the current COVID-19 pandemic. Kishore (2003) has pointed out that Asia and the Pacific are among the most disaster-prone regions in the world. Every year disasters of all kinds cause huge loss of life and property in the region, causing severe setbacks to the development process. The vulnerability posed in the Asia Pacific and African region is an extremely serious threat as two-third of the world population – an estimated 6.3 billion people – live in Asia and Africa. Asia, despite its relatively lower level of urbanisation, is home to 54% of the world's urban population (UN 2018).

Addressing natural disasters in Asia and Africa has required international involvement in recovery efforts. It is important to keep on developing initiatives to fund infrastructure improvements, to take measures for increased immunity to diseases and prevention of disease spreading as well as to create increased resilience to natural disasters.

It is believed that one of the most effective ways to address natural disaster reduction in Asia and Africa is through addressing global climate change and keeping temperature increase to below 1.5C; this is an urgent matter which must be considered and acted on by all countries around the world, as the UN (2016) report has found that 92 per cent of natural disasters are linked with climate and strong El Niño phenomenon. Hence, reducing greenhouse gases and proper climate change adaptation are critical to reducing disaster risks. This can be further strengthened with redesign of climate change policy responses and more robust and comprehensive strategic risk management. Future research will address the relationship with and impact of COVID-19 on achieving the SDGs.

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Chapter 3
Principles Regarding Urbanisation, Disaster Risks and Resilience

Richard Pagett

Abstract More than half of the world population now lives in urban areas, and virtually all countries of the world are becoming increasingly urbanised. With increasing urbanisation comes increasing disaster risk. For example, urbanisation spreading into earthquake-prone areas and building on unsuitable land is still a common practice. To a certain extent, the act of concentrating a large population in a small space (e.g. through urbanisation) inevitably increases the risk to populations when faced with high winds, heavy rains, heatwaves and so on. Resilience applies to both the industrialised and less-industrialised parts of the world and is associated with many aspects of human activity, often responding to the effects of climate change. Whenever and wherever there is threat of a hazard (such as flooding, drought, heatwave and so on), then there is an associated need to be resilient to "come back" after the effects of that hazard have been endured. This chapter describes the principles and planning necessary for urban resilience and offers a blueprint so that urbanising a population has the potential to deal with poverty, gender inequality, economic growth, sustainable livelihoods, land degradation, conflict and other priorities within the Sustainable Development Goals.

Keywords Disasters · Natural hazards · Governance · Resilience · Risk reduction · Urbanisation

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1 Introduction

Urbanisation refers to the increasing number of people that live in urban areas. Much of the world population now lives in urban areas, and virtually all countries of the world are becoming increasingly urbanised. Industrialised countries and those of Latin America and the Caribbean already have a large proportion of their population residing in urban areas, whereas Africa and Asia are still mostly rural and will urbanise faster than other regions during the rest of this century (UN Department of Economic and Social Affairs Population 2018). These trends are changing the landscape of human settlement, with significant implications for living conditions, the natural environment and development in different parts of the world.

Typically, migration from rural areas towards urbanised areas is related to business and employment opportunities. Traditional agriculture which typically forms the basis of the rural economy is unable to provide sufficient employment. In addition, agriculture may suffer increasingly from natural hazards such as drought, deluges and so on. Also, smaller land holdings find it increasingly difficult to compete with more commercialised farming.

Cities offer many attractions compared to rural areas. There are more employment opportunities in a wide variety of disciplines and for different skill sets. Social/cultural and recreational activities are also more easily accessible. Other benefits include improved education (better schools, colleges, etc.) and health care (better hospitals and a wider range of services), higher standards of living and so on.

With increasing urbanisation comes increasing *disaster risk* through, for example, urbanisation spreading into earthquake-prone areas or building on unsuitable land (e.g. hillsides, natural drainage courses and flood zones). It is worth pointing out that most of what we call natural disasters (tornadoes, droughts, hurricanes and so on) whilst the events are indeed natural, and although their increasing frequency may be due to humanity's activities, are not disasters *per se* – they are *natural hazards*. If a hurricane passes over land where no one lives, it is not a disaster; it is weather. A disaster is when a natural hazard interacts with a human population, adversely (Chmutina et al 2019).

To a certain extent, the act of concentrating a large population in a small space (e.g. through urbanisation) inevitably increases the risk to populations when faced with high winds, heavy rains, heatwaves and so on.

Resilience is the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential functions, identities and structure, whilst also maintaining the capacity for adaptation, learning and transformation (IPCC 2014).

Resilience applies to both the industrialised and less-industrialised parts of the world and is associated with many aspects of human activity, often responding to the effects of climate change. It could be related to food, water, land or energy scarcities. It could relate to living by the coast and the threat of sea-level rise and storm surges, in mountainous areas threatened by glacial deluge, in arid areas with erratic rainfall or on small or low-lying islands facing increasingly violent storms. It could also relate to living in rural areas or in urban situations. Whenever and wherever there is threat of a hazard (such as flooding, drought, heatwave and so on), then there is an associated need to be resilient to "come back" after the effects of that hazard have been endured.

Development gains can be quickly wiped out by a natural hazard directly, by a surge in prices (as a consequence of a disaster) or by conflict. Gains could also be undermined over time by the cumulative effects of stressors such as climate change; environmental degradation; water, food and energy scarcity; and economic uncertainty. Whilst humanitarian responses to crises have saved lives and helped to restore livelihoods, such efforts have not always addressed underlying vulnerabilities. A resilience-building approach helps to address the damaging effects of shocks and stressors before, during and after crises, thereby minimising future human suffering and economic loss.

From this, it is clear that when urbanising it is necessary to be aware of the prevailing natural hazards and the relative vulnerability of the contained population. To a certain extent, urbanising a population inherently increases the risk of a disaster. Yet urbanising a population also has the potential to assist in resilience-building through being able to, potentially, mobilise resources more efficiently and effectively.

Increasingly, the dimensions of gender and human rights need to feature in any resilience strategy. It is increasingly being understood that there is a causal relationship between women's empowerment and community or household-level resilience (Masson 2016). Human rights are the interlocking elements that build resilient and confident societies – societies able to withstand and surmount threats, peacefully resolve disputes and facilitate sustained progress in prosperity and well-being for all their members (UNHRC 2018).

Planning for urban resilience requires a framework for bringing together fragmented and diverse polices, capacities and finance to facilitate a system that is capable of planning and preparing for, absorbing, recovering from and adapting to any adverse events that may happen in the future. It could also be a cost-effective way to address water, food, energy and land insecurity. So, urbanising a population has the potential to deal with poverty, gender inequality, economic growth, sustainable livelihoods, land degradation, conflict and other priorities within the Sustainable Development Goals (SDGs).

UNDP (2020) noted that more than half of the Earth's population already live in cities. By 2050, two-thirds of all humanity – 6.5 billion people – will be urban. The rapid growth of cities – a result of rising populations and increasing migration – has led to a boom in megacities, especially in the developing world, and slums are becoming a more significant feature of that urban life. It is estimated that almost 900 million people live in slums, and the number is rising. Such places are inherently vulnerable to natural hazards. Between 2000 and 2014, the proportion of the global urban population living in slums dropped from 28.4 per cent to 22.8 per cent. However, the actual number of people living in slums increased from 807 million to 883 million.

Although cities occupy just 3 per cent of the Earth's land, they account for 60 to 80 per cent of energy consumption and at least 70 per cent of carbon emissions. In the coming decades, 90 per cent of urban expansion will be in the developing world.

The economic role of cities is significant, generating about 80 per cent of the global gross domestic product.

Yet many cities around the world are facing *acute challenges in managing rapid urbanisation* (ODI 2018a) – from ensuring adequate housing and infrastructure to support growing populations, to confronting the environmental impact of urban sprawl, to reducing vulnerability to natural hazards. Many cities have difficulty in providing even basic services.

The UN Development Programme (UNDP) estimates, based on data collected for 214 cities/municipalities, that only three-quarters of the municipal solid waste generated are collected. In 2016, 91 per cent of the urban population worldwide were breathing air that did not meet the World Health Organization air quality guidelines value for particulate matter (PM 2.5); more than half were exposed to air pollution levels at least 2.5 times higher than that safety standard. In 2016, an estimated 4.2 million people died as a result of high levels of ambient air pollution. From 1990 to 2013, almost 90 per cent of deaths attributed to internationally reported disasters occurred in low- and middle-income countries. Reported damage to housing attributed to natural hazards shows a statistically significant rise from 1990 onwards (UN 2018).

Even if human resilience is developed and sustained, there is, of course, considerable *uncertainty in knowing the planet-scale limits* (Meyer and Newman 2018) due to the intrinsic uncertainty of how these complex systems behave when faced with climate change, increasing population and consumption of resources. It is no longer possible to envisage the limits for Earth-scale processes to be independent of the preferences, values, political compromises or socio-economic justifications of humanity.

Work is clearly needed to *determine the future shape of human activities* in order to stay within limits at an Earth scale, if that is even possible. There is ample evidence from local to regional scale (Mumby and Anthony 2015) that ecosystems (such as lakes, forests and coral reefs) are experiencing gradual changes (through biodiversity harvesting, soil [mis-] management, freshwater abstraction, nutrient cycles and so on) that could trigger abrupt changes when critical limits have been breached. The latter could still occur despite enhanced human resilience (Pagett 2018).

It is known that in sub-Saharan Africa there are arid and semi-arid areas regularly affected by drought. Yet, these areas do not have the basic infrastructure in the first place. The basic requirements should be dealt with first as that is a fundamental of future resilience. For instance, barrages to retain seasonal water, well-constructed markets with the means to access them (roads that work during the rainy seasons) and early warning systems should be a priority. *Basic institutional strengthening at national and local level* is critical with, of course, treasury not project support (Anyonge et al. 2013). Such basic institutional development needs to be underpinned by a professional, career-structured civil service to retain skills, knowledge and experience. All this is essential to support the development of human resilience within an urban context.

The universal consensus through the adoption of the *2030 Agenda for Sustainable Development provides a unique opportunity* to build urban resilience by addressing the structural inequalities that perpetuate poverty, marginalisation and social exclusion and thus increase vulnerability to natural hazards. To be successful, resilience, disaster risk reduction and disaster management, social protection and adaptation strategies must all be part of a broader development framework which incrementally leads the way to the empowerment of disadvantaged groups, by improving their asset positions and access to input and product markets, by extending their access to quality basic services and by changing the norms that, currently, foster their social and political exclusion (UN 2016).

The high and increasing level of urbanisation is resulting in a serious review and discussion among countries around the world concerning the current state of urban policies and their effectiveness in bringing about resilient urban development. Two recent activities have been instrumental in reshaping the new policy framework. They include the universally adopted SDGs and recommendations from the New Urban Agenda (NUA) (Habitat III 2016).

All of the world's countries have formally committed to achieving the SDGs by 2030. For urban areas, this goal is expressed by SDG 11 and its components, which aim to "make cities inclusive, safe, resilient and sustainable".

The NUA, produced during Habitat III, also includes recommendations and measures that support the implementation of SDG 11. This renewed world focus on cities and their development also makes it a very good time for all governments to update their own *urban sector policy, strategy and operational guidelines* and establish a new set of objectives and actions that can recognise urban development as being an important sector in its own right.

Many cities in sub-Saharan Africa, the Caribbean, South Asia and the Pacific are undergoing major changes in their town centres and through the informal growth of housing in their peri-urban areas. A new urban policy framework needs to be developed to be able to facilitate adaptation to such changing circumstances and to stimulate improvement in urban decision-making. A set of clear and flexible guidelines are required to help implement urban policies and plans based on a more efficient use of available resources.

Experience has shown that the complex challenges facing cities today can no longer be solved by applying sectoral policies that do not take the broader spatial and economic impacts of their application into account. Urban policy has evolved from focusing on sectoral programmes, special initiatives and individual time-limited projects to a more collaborative, integrative and forward-looking approach that treats urban development in a more integrated manner.

This makes it *essential to mobilise and sustain active connectivity across government departments and agencies* with a stake in urban development. Gaining active support from these different parts of government will ensure a coordinated approach and the mobilisation of sufficient resources from different sources to make a difference. Urban sector policy implementation should include sustained efforts to build the necessary legal framework, institutional capabilities, administrative procedures and financial instruments necessary to implement integrated policies and programmes. This opportunity however is limited by the political landscape in any given country.

2 Principles

The following principles linking the SDGs and the NUA should guide urban resilience.

2.1 Accessibility

Accessibility is a cross-cutting issue aimed at enabling elderly and persons with disabilities to live independently and participate fully in all aspects of urban life. Serious consideration and promotion of accessibility as a collective good and key component in urban policy, design, planning and development are required to make urban resilience achievable. The advancement of accessibility with respect to the right to adequate housing, built environment, public spaces, transportation, community facilities and public services is particularly important for the growing elderly populations in cities.

2.2 Urban Adaptation

Urban areas need to be able to adapt to changes in their economy, population, demographics, technology and environment. This can be achieved most effectively through the use of strategic planning and an active process of consultation with both public and private stakeholders and with citizens. In addition, moving towards a development approach that includes green buildings, promotion of sustainable transportation, ecotourism development, environmental conservation and climate change resilience enables the management of urban economic growth in an equitable and sustainable manner (Bazrkar et al. 2015).

Urban settlements and the social and economic infrastructure and services that support them should be planned and managed to optimise their efficient use based on financially sound decision-making in the management of revenue sources and expenditures.

2.3 Civic Engagement

Planning, policies and programmes need to engage all sectors of the community. Civic engagement implies that living together in urban settlements is not just a passive exercise. People must actively contribute to the common good, with women and other vulnerable groups empowered to participate effectively in the decision-making process. This is all part of embedding resilience into the urban fabric.

2.4 Equity and Inclusion

Access to urban decision-making and distribution of opportunities by all segments of the population, especially women and other vulnerable groups, provide an important path to achieve the degree of equity and inclusion required for successful (resilient) urban societies. Inclusive cities provide everyone, including the poor, young or old, religious or ethnic minorities, indigenous people and those with disability, with equitable access to nutrition, education, employment and livelihood, health care, shelter, safe drinking water, sanitation and other basic services. It involves the development of social capital or the valuation of networks of social relations and associations – based on trust and reciprocity.

2.5 Gender Equality

The development and use of urban space, including its infrastructure and built environment, should respond to both male and female roles and responsibilities. Greater gender equality in the design, use and benefits of urban development is required. Among others, this involves reclaiming public space for daily life; creating inclusive neighbourhoods with a genuine mix of population in terms of their interests, needs and assets; localising economic and social development to support and enable community-based initiatives driven by women, youth and other disadvantaged groups; and promoting and supporting women participation and leadership in urban governance and community development.

2.6 Identity

Cities have specific identities that have been shaped to a large extent by their history and the role they have played as centres for trade. Local streets form part of both the tangible and intangible cultural heritage. They provide necessary support to cultural ecosystems based on traditional aesthetics, social practices and collective memory of the population. Implementation of this role makes it important that public policies and informal norms ensure that streets in historic areas maintain their continuing multicultural heritage when faced with disruption by natural hazards.

2.7 Innovation

The planning, design, construction and management of urban settlements require creative ideas and solutions to meet current and future challenges. A better understanding of the complex relationship between city growth and poverty will provide very useful tools for building resilience into an urban approach to sustainable development. New principles are required that address challenges such as the growth of informal housing, urban environmental degradation and resilience to climate change. A critical need exists to develop flexible and dynamic approaches to building urban resilience that go beyond risk mitigation and are embedded in virtually all urban development.

2.8 Integration

Policies and programmes need to be integrated across the different levels of government and portfolios, with private industry and with local communities. Rural-urban interdependence is particularly important due to the fact that rural areas are integrally linked to urban areas and part of the combined economic, social and cultural domains.

2.9 Partnerships

Resilient urban development requires working together in partnerships, whether formal or informal, which will give government agencies, private sector and civil society the opportunity to achieve greater effectiveness in terms of policy and programme implementation, more legitimacy and transparency in development decision-making and subsequent actions, mobilise a more diverse range of capital resources and improve institutional capacity across the board.

2.10 Security

A combination of security approaches should be pursued through partnership arrangements that include effective urban planning, design, governance and community-based initiatives aimed at increasing community ownership of various initiatives, a focus on groups likely to be perpetrators or victims of crime and violence and measures to strengthen social capital through initiatives to improve the ability of individuals and communities to respond to problems of crime and violence. All this embeds resilience.

2.11 Local Planning

Planning and services should be delivered by the most local level of government that has sufficient scale and capability to deliver, reasonably, in an efficient and cost-effective manner. This will also maximise the potential for including all levels of citizenry and population groups to participate in the process of urban resilience and governance.

Modern cities face increasingly complex challenges related to social, economic, physical and environmental issues. Many cities lack adequate capacity and resources to cope with these changes in a timely manner. Moreover, the variety of stakeholders involved in urban transformation often presents a serious challenge to effective programme/project implementation. Consequently, it is advisable that urban development policies and key identified programmes/projects should be included in national physical development plans (NPDPs), city-level urban development plans (UDPs) and any derived action plans so that impacts of their implementation at various levels can be addressed and integrated.

Whenever financing a multisectoral urban resilience programme/project, it is recommended that a facility be put in place with adequate resources to ensure:

- Full coordination among participating institutions
- Coordination with other projects
- Coordination with stakeholders, both public and private
- Timely project review and correction during all phases of project implementation
- Downstream support for sustainable operations and maintenance (O&M)

The most thoroughly developed policies for programme/project design will achieve little if they are ignored or not adequately understood as part of the development control process. Therefore, NPDPs and UDPs will need to be able to reinforce and guide the implementation of relevant urban design concepts or visions for urban centres.

A basic objective, central to NPDPs and UDPs, should be to promote resilient, sustainable development. Good design is essential if attractive, high-quality sustainable places are to be produced where people (both residents and visitors) will want to live, work and relax. Quality urban design is also fundamental to any sustainable strategy to redevelop and upgrade urban settlements.

As a result, UDPs and any required regulations should:

- Integrate participatory approaches that incorporate inputs from the public and private sectors and civil society organisations, ensuring that social welfare and protection, gender affairs, those with disability and the elderly and youth sectors are adequately represented
- Provide analysis of social and gender impacts to ensure that social and gender gaps and specific needs, capacities, constraints and opportunities are identified and accounted for, including citizen safety and crime prevention
- Provide analysis of climate change impacts to ensure that environmental resilience, food security, energy security and water security are fully addressed and that their specific needs, capacities, constraints and opportunities are identified and taken into account.

UN-Habitat stresses the adoption of national urban policies as a key step for reasserting urban space and territoriality (UN 2017):

> The development of a National Urban Policy is vital in providing the needed direction and course of action to support urban development. The policy provides an overarching coordinating framework to deal with the most pressing issues related to rapid urban development, including slum prevention and regularisation, access to land, basic services and infrastructure, urban legislation, delegation of authority to sub-national and local governments, financial flows, urban planning regulations, urban mobility and urban energy requirements as well as job creation.
>
> Approved at the highest level, a national urban policy should provide the general framework to orient public interventions in urban areas and be a reference for sectoral ministries and service providers. It should also be the key reference for legislative institutional reform. The Policy is also a good instrument for public and political awareness of the gains to be obtained from sustainable urban development, as well as an opportunity to promote consultation with urban stakeholders.

The preparation of a national physical development plan (NPDP) provides for a spatial framework for national development and subsequent formulation of urban development plans (UDPs) that includes the development and environmental control criteria necessary for effective monitoring of physical development, environmental and natural resource protection and resilience building.

Urban development plans (UDPs) should align with the NPDP, whilst providing specific planning and policy direction for local areas. These plans should provide the necessary framework for continued investment and development.

Contents of an UDP should incorporate, as a minimum, resilience measures within:

- Land-use planning
- Housing and building control
- Transport network
- Water, wastewater and drainage networks
- Landscaping and open spaces
- Employment areas and other economic activities
- Recreation and tourism asset development
- Community facilities (doubling for early warning refuges)

Action area plans (AAPs) are recommended to embed resilience measures in any urban development and regeneration of all sizes of cities, towns and urban areas, before any major new development is implemented. The designation of an action area plan implies a coordinated and comprehensive package of initiatives for the selected area. Such a package of initiatives generally is designed to revitalise the economic and social well-being of specific urban areas, which in many cases are suffering from various forms of urban and economic decline. Other bases for selecting such areas can include those primarily earmarked for urban regeneration, the conservation of heritage zones or where market development pressures are being felt and a balance between supporting the local economy and protecting the environment needs to be achieved. Within such packages of initiatives should be embedded the relevant resilience measures for each initiative.

Since AAPs lay down the first steps for future actions on the part of government and private sector stakeholders with a view, in many cases, to develop urban renewal and regeneration projects, it is obvious that such first steps should incorporate all the necessary resilience measures. This would ensure protection of street-scape and public realms, public open spaces and pedestrian networks, cultural and community facilities, heritage conservation and housing rehabilitation.

Resilience building measures should seek to unify and strengthen existing elements in the area. They should support and benefit from an integrated development framework that will enhance the value of future opportunities and discourage development from occurring in a piecemeal manner that is susceptible to future natural hazards.

2.12 Urban Legislation

Urban-related legislation involves a coordinated mix of policies, laws, regulations, codes and practices used to manage and control the development of urban areas and settlements. Many cities are now burdened by outdated laws and regulations, which prevent urban actors from achieving resilient urban transformation.

In the process of updating urban legislation, a specific focus should be addressed that encourages the achievement of SDG 11:

- Promotion of mixed use and higher- density development
- Promotion of design quality and sustainable development
- Full respect given to environmental and social concerns and potential hazard threats
- Promotion of gender equality

The urban design process should consider the resilience of a development in the character and setting of its surrounding environment. It should consider natural and human elements, including the form of the built environment and its open spaces, history, heritage, culture, location, patterns of movement and local community identity. An understanding of resilience should inform the design process and assist with the creation of resilient places that are distinct from, but also compatible with, existing built environments and communities.

Particular regard needs to be paid to:

Urban centres – their historical architecture, waterfront, shops in a reasonably compact setting, restaurants and bars – all of which have a significant role to play in ensuring resilience for residents and visitors. In urban centres, resilience programmes and projects should:

- Support developments that attract large numbers of people, including shops, commercial and public offices and entertainment and leisure uses, by enhancing urban centres as attractive places to live and work
- Protect and enhance the important environmental, historical qualities of the urban centre, its setting and the surrounding area
- Allow scope for, rather than constrain, continuing development within the urban centre

The conservation and promotion of cultural heritage is not only important for tourism development but also vital for the local community as it represents the country's structure and formation of society and cultural identity, which is a critical platform for resilience. In developing tourism resilience, particular attention should be paid to:

- Identifying, preserving and protecting places and practices of historical and cultural significance
- Increasing the awareness of and respect for heritage for both tourists and residents
- Preserving, celebrating and sharing traditional culture, life ways and traditions
- Supporting cross-cultural dialogue and social cohesion
- Developing and maintaining diverse cultural offerings
- Developing and supporting arts participation and the creative economy

2.13 Coastal Lands

Access around a coastline is becoming increasingly an issue as more of the coastline is developed. Policy support is needed to safeguard long-term community interests, whilst recognising specific natural hazards to which the coastline is exposed.

Waterfronts and coastlines represent key open space opportunities for active and passive recreation and green and blue economies. Safeguarding land and access for public usage is critical to future health and well-being. Coastal development should not be supported if it contributes to the creation of urban sprawl and where it would be harmful to the natural, landscaped and/or rural character of land areas that form belts of countryside around urban areas and particularly within flood plain and water catchment areas. Where coastlines are under clear threat, development needs to be prioritised elsewhere.

Open spaces play a significant role in protecting the environment and sustaining and improving the amenity of urban and coastal areas, attracting new investment, creating employment opportunities, improving the quality of life and providing refuges.

Where mitigating measures are insufficient to improve environmentally intrusive uses or compromise future resilience, development should be relocated. This approach will contribute to urban resilience and rehabilitation. The regeneration of *vacant land* and buildings will make an important contribution to accommodate additional growth where such ownership problems can be overcome.

2.14 Informal Settlements

There are informal housing settlements, worldwide, typified by inadequate potable water and sanitation provision, lack of formal power supply, lack of educational and health facilities and lack of local employment. Overcrowding conditions in these settlements also increase the exposure to and likelihood of disease, domestic violence, rape and incest.

Low wages and unemployment impede the ability of lower-income groups to take advantage of affordable housing options which are instead accessed by middle-income groups. Youth unemployment is in most cases higher than the national average, making access to housing difficult. Elderly persons are unable either to maintain homes that they own or to pay housing rents based on their fixed income pensions.

2.15 Social and Community Facilities

Sufficient land and sites should be set aside for social and community facilities. These will normally be centrally located in or adjacent to local communities. Provision for needed social and community facilities should be set out in UDPs and AAPs as part of the package of resilience measures.

Locating businesses in detached/isolated business parks on out-of-town sites should be discouraged. It is more desirable to create business environments that are active components of self-contained urban areas. Likewise, urban hotel accommodation should form part of the urban environment.

2.16 Urban and Peri-urban Agriculture

The growing of plants and the raising of animals within and around cities are increasingly recognised internationally and by more local authorities and civil society organisations as a form of available capacity to strengthen resilience in urban food systems.

Proposed urban and peri-urban agriculture (UPA) should be supported in areas:

- Where access to water is available without putting undue stress on the environment or existing water networks.
- That are identified in the NPDP and UDPs and land-use controls as suitable for urban agriculture.

2.17 Urban Resilience and Food Security

Urban food security is a complex, multidimensional problem related to food availability, access to affordable food, the effective use by people of the food that they consume and the stability of these elements over time (OECD 2016). There is a resilience dimension to each element of the food security issue. Fundamentally, most food insecurity is a result of poverty. Poverty is exacerbated by climate change since climate impacts will predominantly affect agriculture, typically a key sector in the poorest countries and a significant source of income, affecting livelihoods and therefore particularly the poor. By 2030, crop yield losses could mean that food prices would be 12 per cent higher on average in sub-Saharan Africa. The strain on poor households, who spend as much as 60 per cent of their income on food, could be acute (World Bank 2016).

Land is the most prized asset for food production, nutritional health and economic development. Yet, half a million square metres of land in Africa is being degraded due to soil erosion, salinisation, pollution and deforestation (UNEA 2018). This land degradation can damage agricultural productivity, nutrition and human health. A growing population and a rise in the demand for firewood will mean that forest cover in Africa is likely to continue shrinking, declining to less than 600 million hectares by 2050. Over-cultivation, inefficient irrigation practices, overgrazing, the over-exploitation of resources, uncontrolled mining activities and climate change will further degrade land in Africa. This will lead to reduced agricultural productivity; reduced food security, which can increase migration and spread disease; the destruction of infrastructure, such as roads and bridges; and high rates of poverty (Pagett 2018).

So, building resilience to urban food scarcity requires inclusive and climate-informed continuation and expansion of actions that reduce poverty, whilst increasing capacity to prepare for, and cope with, individual shocks. These efforts will need to be coupled with targeted climate adaptation measures. These measures could be protective infrastructure such as dykes and drainage systems or softer measures such as mangrove restoration to deal with flooding or changing land-use regulations to account for sea-level rise, disaster preparedness or the introduction of climate-resistant crops and livestock breeds.

A resilience-building approach starts with the way food policies, strategies and programmes are conceived and with resilience at the centre of the national development process. Enhancing capacities to absorb, adapt and transform in the face of shocks and stressors require a significant level of collaboration over a prolonged period, and it is essential that national governments align all their development activities and plans (agriculture, land-use, water resources and so on) within an overall resilience framework.

The global population is estimated to exceed 9 billion by 2050. New patterns of consumption threaten natural resources, food and energy security and cause pollution and climate change. To feed such a large population, global food systems will need to transform at an unprecedented speed and scale. This transformation will need to address healthy diets and nutrition; inclusion of smallholder farmers, women and youth; market efficiency; and climate change. In essence there will need to be a global agenda for the future of urban food, something that, currently, has little real traction.

The 2050 population will call for a greater global demand for agricultural products, perhaps by 50 per cent, and at the same time, greater numbers of people will be eating fewer cereals and larger amounts of meat, fruits, vegetables and processed food. This will further exacerbate pressures on natural resources, driving more deforestation, land degradation and greenhouse gas emissions. Interestingly, without serious additional efforts to promote pro-poor development, reduce inequality and protect vulnerable people, more than 600 million people could still be undernourished in 2030, contrary to the SDG 2 of zero hunger (FAO 2017).

2.18 Urban Resilience and Water Security

Population growth, competing for water resources and climate change are intertwined. Water security is a daily concern to those in peri-urban and urban situations where piped supply can be periodic and insufficient. Climate change and lack of opportunity are driving the traditional rural-to-urban migration, swelling towns and cities beyond their infrastructure and management capacity and exacerbating water scarcity.

The challenge of climate change resulting in changes in rainfall regimes, threatening surface water and the regularity of aquifer recharge and the contamination of aquifers in expanding urban areas are other factors that contribute to making water scarcity a reality, driving the need for urban resilience.

The way governments have mismanaged water for decades does not auger well for future management. Yet in almost every region, population growth, rapid urbanisation, rising levels of consumption, desertification, land degradation and climate change have combined to leave countries suffering from severe water scarcity.

So, building resilience to water security in urban areas requires improving efficiency of water supply and management and reducing climate change-related risks through integrated management of water, sewage, solid waste and storm water across household to city scales. Typically, current planning, legislation and management mechanisms would need to be transformed towards integrated management of water through collaborative management by multiple stakeholders. Decentralised water management should be emphasised by empowering and devolving the responsibilities to formal and informal institutions, especially in peri-urban areas (ACCCRN 2013). Given that some local governments have not been able to deal with the most basic of human needs such as clean water, sanitation, health and education, it is not safe to assume necessarily that they will be able to deal with one of the largest challenges to humanity.

So what of water security in the near future? By 2020 about 30–40% of the world will have water scarcity, and according to the researchers, climate change can make this even worse. Water is used around the world for the production of electricity, but new research results show that there will not be enough water in the world to meet demand by 2040 if the energy and power situation does not rapidly improve (Aarhus University 2014).

2.19 Urban Resilience and Land Security

Humanity may be reaching a point where further agricultural land expansion at a global scale may seriously threaten biodiversity and undermine regulatory capacities of the planet (by affecting the climate system and the hydrological cycle). Indigenous peoples and local communities are estimated to hold 65% of the world's land area under customary systems (Rights and Resources Initiative 2015). Yet, many governments formally recognise their rights to only a small fraction of those lands. This gap, between what is held by communities and what is recognised by governments, is a major driver of conflict, disrupted investments, environmental degradation, climate change impact and cultural extinction.

With secure land tenure, women and men in rural communities across Asia, Africa and Latin America could take action to adapt to a changing climate. Secure land rights, especially for women, could encourage farmers to make investments and adopt practices that conserve soil and water, improving short- and long-term food security. Most importantly, tenure security could provide a more enabling environment and access to resources for women, men and communities to make land-use decisions that are best for them, their families and successive generations (FAO 2018). Secure land rights assist rural resilience which lessens the migration potential to urban areas.

2.20 Urban Resilience and Energy Security

Urban energy security has many dimensions: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and sustainable environmental needs. Short-term energy security focuses on the ability of the energy system to react promptly to sudden changes within the supply-demand balance. Lack of energy security is thus linked to the negative economic and social impacts of either physical unavailability of energy or prices that are not competitive or are overly volatile. Between 60% and 80% of global energy is consumed in urban areas (UN HABITAT 2018), and given the projected increase in world's urban population, this share is expected to increase significantly in the future. Continuity of energy supply in cities is affected by climate change and a growing array of other threats such as cyberattacks, terrorism, technical deficiencies and market volatility. Determined efforts, acknowledging the interactions and interlinkages between energy and other sectors, are needed to ensure resilience by avoiding adverse consequences of disruption in energy supply (Ayyoob and Yamagata 2016).

In the past, geopolitics and the supply of oil and gas were the dominant factors determining energy security. Today, a broader and more complex spectrum of elements is interacting to both stabilise and threaten energy security in urban areas.

2.21 Urban Resilience and Governance

Resilience requires good governance at regional and national levels to ensure robustness, redundancy, recovery, conservation, sustainability and risk mitigation, all critical dimensions of resilience (Bedi et al. 2014). National and regional governance are essential for appropriate policy, infrastructure, finance and rule of law, again, all critical threads of resilience. Only national governance systems are capable of long-term planning for addressing recurring crises arising from climate-driven factors and resulting issues such as migration; food, water and energy insecurity; and ethnic conflict. At the same time, national systems must align with international protocols, since climate change does not recognise national boundaries.

Although resilience has become a central concept in government policy, local government is often used to managing complex shocks and stresses. For instance, it is generally agreed by practitioners that resilience requires decentralised, multi-stakeholder, adaptive and participatory governance (ODI 2018b). Yet to build a resilient future requires governance that is autonomous, accountable and flexible, and there is often a mismatch between devolved responsibilities and devolved resources and power.

Whilst the technical challenges to building resilience are understood and, to a certain extent, relatively straightforward to address, political challenges are typically less publically articulated, although they are clearly recognised. National governments are cautious about the activities of areas or cities that are not part of the ruling party because they recognise the threat that a resilience success locally could be a springboard for national office. Even when national and local governments share ambitions for a low-carbon, resilient future, there can be a marked difference between the effectiveness of more complex, national government and that of more nimble local government.

2.22 Future Development and Resilience

Table 3.1 proposes a set of screening questions designed to indicate whether or not a particular development project would add to, or subtract from, urban resilience. The questions are derived from those often used during environmental and social impact, and risk, assessment.

The screening table considers:

- Location and design of urban space projects
- Climate change and disaster risk vulnerability
- Materials and maintenance
- Performance of project outputs
- Energy security
- Water security
- Food security

Table 3.1 Urban resilience screening of new projects

Screening questions		**Score**	**Remarks**[a]
Location and design of urban space projects	Would siting and/or routing of the project (or its components) likely to be affected by climate conditions including extreme weather-related events such as floods, droughts, storms and landslides?		
	Would the project design (e.g. the clearance for bridges) need to consider any hydro-meteorological parameters (e.g. sea level, peak river flow, reliable water level, peak wind speed, etc.)?		
Materials and maintenance	Would weather, current and likely future climate conditions (e.g. prevailing humidity level, temperature contrast between hot summer days and cold winter days, exposure to wind and humidity, hydro-meteorological parameters) likely to affect the selection of project inputs over the life of project (e.g. construction material)?		
	Would weather, current and likely future climate conditions and related extreme events likely affect the maintenance (scheduling and cost) of project output(s)?		
Performance of project outputs	Would weather/climate conditions and related extreme events likely affect the performance (e.g. annual power production) of project output(s) (e.g. hydropower generation facilities) throughout their design lifetime?		
Energy security	Would the project or its components adversely affect energy security?		
Water security	Would the project or its components adversely affect water security?		
Food security	Would the project or its components adversely affect food security?		
Waste management	Would the project or its components adversely affect waste management capacity?		
Rural-urban linkages	Would the project or its components result in a weakening of rural-urban linkages?		
Blue economy	Would the project or its components result in a weakening of links with the blue economy?		
Green economy	Would the project or its components result in a weakening of links with the green economy?		
Options for answers and corresponding score are as follows:			
Response	**Score**		
Not likely	0		
Likely	1		
Very likely	2		

[a]Provide details on the sensitivity of project components to climate conditions, such as how climate parameters are considered in design standards for infrastructure components and how changes in key climate parameters and sea level might affect the siting/routing of the project, the selection of construction material and/or scheduling, performance and/or the maintenance cost/scheduling of project outputs or energy, food or water security

- Waste management
- Rural-urban linkages
- Blue economy
- Green economy

Responses, when summed, that provide a score of 0 would be considered low-risk projects that would not adversely affect existing urban resilience.

If adding all responses results in a score of 1–4 (and no score of 2 has been given to any single response), the project would be considered medium-risk category and may have some adverse effects on the existing urban resilience. These would need to be addressed.

A total score of 5 or more (in which there is a score of 1 in all responses or a 2 in any single response) would be categorised as high-risk project and would likely have adverse effects on the existing urban resilience. These would need to be addressed, the project relocated or abandoned.

3 Blueprint for Building Urban Resilience

A set of principles has been introduced to guide requirements for urban resilience incorporating key learning points from Habitat III and to align with targets set for SDG 11. From these principles has been derived a set of fundamentals which, in essence, provide a blueprint for building urban resilience.

- Strengthen urban governmental coordination and confront mediocre governance issues.
- Improve gathering, processing and sharing of data and information to inform decision-making.
- Enhance sustainable consumption and production to reduce environmental pressures by critically addressing drivers associated with manufacturing processes and consumer demand.
- Harness natural resources so that there is no further depletion of ecosystems.
- Implement measures to minimise and halt pollution and other environmental pressures.
- Invest in urban planning: infrastructure and clean transport.
- Insist national government to support urban government to decouple economic growth and resource consumption.
- Aggressively reduce dependency on fossil fuels and diversify energy sources.
- Establish greater foresight processes to identify, and plan for, possible future risks, opportunities and conflicts.
- Enhance meaningful international cooperation on population, climate, air quality and other planetary issues.
- Respond to planetary risk.
- Build urban resilience to natural hazards and extreme climate events.

4 Summary and Conclusions

Nearly all countries of the world are becoming increasingly urbanised with significant populations living in these urban settings. With increasing urbanisation comes increasing disaster risk. To a certain extent, the act of concentrating a large population in a small space (as in urbanisation) inevitably increases the risk to populations when faced with high winds, heavy rains, heatwaves and so on.

Resilience applies to both the industrialised and less-industrialised parts of the world and is associated with many aspects of human activity, often responding to the effects of climate change, food, water, land or energy scarcities. Whenever and wherever there is threat of a natural hazard (such as flooding, drought, heatwave and so on), then there is an associated need to be resilient to "come back" after the effects of that hazard have been endured.

Planning for urban resilience requires a framework for bringing together fragmented and diverse polices, capacities and finance to facilitate a system that is capable of planning and preparing for, absorbing, recovering from and adapting to any adverse events that may happen in the future. It could also be a cost-effective way to address water, food, energy and land insecurity. So, urbanising a population has the potential to deal with poverty, gender inequality, economic growth, sustainable livelihoods, land degradation, conflict and other priorities within the Sustainable Development Goals.

A framework has been proposed that provides a blueprint for building urban resilience which addresses several key requirements principally, governance, spatial planning, legislation, water, food and energy security and climate change. This blueprint can be tested through a set of screening questions designed to indicate whether or not a future development project would add to, or subtract from, urban resilience.

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Chapter 4
Learning from Past Disasters to Prepare for the Future

Julien Rebotier, Patrick Pigeon, and Michael H. Glantz

Abstract This chapter revisits a well-known paradox in disaster studies: why does humankind suffer more losses while knowing more and in spite of innumerable existing disaster risk reduction policies? This paradox questions the ability of societies to learn from disasters, which is the issue that this chapter investigates. The first part presents the gap existing between a logical requirement to learn from the past while trying to mitigate if not prevent disasters. The gap – between possessing more knowledge in the face of mounting losses – still exists in spite of the capacities to reconsider DRR policies and to promote new tools helping decision-making processes, as with knowledge management systems (KMSs). Such shortcomings in addition to certain aspects of human nature, such as a government's very short interest and attention span in any given crisis, seek to identify factors explaining why capacity to learn is limited today. The second part of this chapter draws attention to why, as well as how, to take into account local settings and local knowledge when framing risk-reducing policies. The latter are still highly compartmentalized for a variety of challenging reasons. However, opportunities and challenges demand immediate consideration. Societies must bridge, blend or mainstream their policy concerns about planning for future climate change adaptation (CCA) with attempts at policy development for disaster risk reduction (DRR) today, especially because hydrological and meteorological extremes that were expected by 2050 are beginning to confront societies now.

Keywords Capacity to learn · Disaster prevention policies · Climate change adaptation · Disaster databases · Contextualization · Disaster preparation

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1 Introduction

Those Who Fail to Learn From The Past Are Doomed To Repeat It. –George Santana

One of the biggest challenges concerning disaster risk reduction (DRR) policies, which aim at reducing losses, is to understand why they still meet numerous obstacles, when it comes to implementation or enforcement. This issue has been stressed numerous times for ethical as well as economic reasons and is considered key by international institutions such as the United Nations Office for Disaster Risk Reduction (UNDRR) or the World Bank. First (Sects. 2, 3, and 4), in spite of obvious logical and ethical requirements, databases on disaster clearly prove the capacity to learn but also expose numerous limitations. Reconsidering existing DRR policies and using new tools as with knowledge management systems (KMSs), which help decision-making, do not change the global assessment in any major way. Then (Sects. 5, 6, and 7) epistemological and institutional reasons explain why information and knowledge about losses are still very fragmented today. Contextualizing and territorializing disaster prevention to a greater extent should help to reduce the gap between what is expected from DRR policies and what statistics show. In spite of the numerous biases they have and the study limitation, there are pitfalls and opportunities of a deeper integration between DRR and climate change adaptation (CCA) policies.

2 Learning from the Past Disasters Should Be a Logical Requirement, Despite Notable Limitation

2.1 Learning from Past Disaster: A Logical Requirement Difficult to Represent

To learn from the past supposes integrating the build-up of knowledge of past events as a basis for decision-making processes about building back better following the occurrence of a new disaster (Weichselgartner and Pigeon 2015). As such, lessons identified (often referred to as lessons learned) are usually taken for granted as a key consideration for DRR in terms of awareness-raising, understanding and managing. Indeed, when it comes to prevent a disaster, it makes sense and seems logical to reconsider the situation existing before the event. In line with the so-called radical view about the societal and environmental risks (García-Acosta 2005; Wisner et al. 2004), damages depend first of all on how human societies of concern were structured long before the foreseeable hazard occurs. Various types of political decisions contribute to frame risk-prone situations in the long term, especially when the question arises about where and how to build structures. Disaster prevention and preparedness are, therefore, related to a wide array of decisions which take into consideration the functioning of societies on a day-to-day basis. This is often perceived to be the normal period, which fortunately is the prevalent situation.

This understanding strongly reduces the role hazards might play to explain the extent of damages experienced, which also determines what a disaster is. EM-DAT, the well-known database which is managed by CRED (2019), defined a disaster as an event exceeding the threshold of 10 people dead and/or 100 people affected and/or needing external help. Consequently, when it comes to disaster prevention after the occurrence of an event, it makes sense to reconsider the structure of societies existing before the disaster and to reconsider the related political choices. Therefore, learning from the past should be a first logical requirement to prevent a disaster.

Moreover, the widely used disaster cycle model, depicted as a "pragmatic concept" and has existed since 1975 (UNISDR 2015: 30–31), integrates learning from the past into the reconstruction process as a major obvious contribution to disaster prevention. The representation of a cycle seems to be consistent with the logical need to reconsider the existing socio-economic and political situation, which the disaster's occurrence exposed as problematic when the hazard occurred.

However, the cycle implies that following a disaster it might be possible to return to similar conditions that existed before its occurrence. In light of the so-called radical view mentioned above, the cycle representation becomes illogical. A solution would be to use spirals (Morin 2005; Michellier et al. 2020). They propose the idea of a cycle, while clearly depicting the difficulties to turn back to a previous situation once the disaster ended, especially when it comes to disaster prevention. However, spirals are harder to present and to read.

The general understanding of disaster prevention looks very ambiguous and balanced. A similar message arises from disaster databases. They indicate at the same time prevention shortcomings (Sect. 2.2) and achievements (Sect. 2.3).

2.2 Disaster Prevention Limitations and Increased Losses: Not Learning Enough, or Correctly, from the Past?

In spite of the obviousness of integrating learning from past disaster prevention policies, academics as well as managers admit that they collect, absorb or apply lessons identified and/or lesson learned (often represented as recommendations or findings) much less than is expected by the public, by researchers or by international institutions devoted to risk prevention. Evidence of such shortcomings is numerous. Disaster databases address first the limitations that confront disaster prevention policies. An analysis of disaster databases proves that "experience return" is less directly taken into consideration by disaster prevention policies than one might reasonably expect. Assessing the results, disaster prevention policies deliver more balanced outcomes. A closer reading of those databases reveals the contribution of disaster prevention policies toward reducing damages, as might be expected. Such assessments should include the ambiguous contributions that past experiences play, when it comes to prevent disasters. The assessments reveal that there is no direct relationship between information or knowledge about past events and disaster prevention policies. A similar mismatch exists between disaster prevention and preparedness policies and their implementation. Some disaster prevention policies try to integrate both aspects, while explicitly addressing "experience return" about the limitations encountered by previous disaster prevention policies. This process is very close to the principle of reflexivity that Beck (2001: 16) promoted. It justifies the rise of new tools to help decision-making processes and inspire the evolution of disaster prevention and preparedness policies, as well as new knowledge types, as is the case with KMSs.

The most striking evidence of limitations to learn from the past is exposed by statistical trends concerning disasters. This paradox has been stressed by the famous observation by American geographer Gilbert White (White et al. 2001): "The more we know, the more we manage, and yet the more we lose". This concern has also been investigated now and again during such international, multidisciplinary gatherings as, for example, the one that took place in Antalya, Turkey, a few years ago on "Lessons Learned About Lessons Learned" (Glantz 2015). The same paradox appears in the trends identified in disaster databases such as displayed in EM-DAT (Emergency Database, CRED 2019).

In spite of the various methodological limitations of those databases, the upward trend for disasters is clearly exponential on a centennial timescale. This trend is not related on a specific database, which would reflect methodological choices only. It is also displayed by databases such as DesInventar (D'Ercole et al. 2009; Pigeon and Rebotier 2016). Even more, the 2015 Global Assessment Report (GAR) stressed the relevance of taking into account events not identified by databases at the world scale, such as EM-DAT. Those "small" or "extensive" disasters (UNISDR 2015) are identified at local scales, as is the case in Medellin, Colombia (López-Peláez and Pigeon 2011). Their identification by databases such as DesInventar helped us to understand how local disasters are "set up" by urbanization dynamics. One of the main goals of DesInventar is to list and to map those disasters, helping local managers and households to prevent them in the future. Numerous studies investigated the limitations of using similar databases (Menoni and Margottini 2011; Mitchell et al. 2014), yet the general trend is always the same: an increase of disaster frequencies, in spite of existing prevention and preparedness policies and in spite of the call to integrate "experience return" into decision-making to a greater extent.

However, a closer and more critical reading of databases draws attention on the relevance of learning from the past to disaster prevention.

2.3 In Spite of Increased Losses, Disaster Statistics Also Show the Relevance of Learning from the Past

When delving into the details of statistics related to disasters, a striking difference between human losses and economic losses is found. Human loss trends show a much lower increase than economic losses and, in some cases, even a decrease. In both cases, trend assessments stress the various difficulties researchers meet when working on economic losses or even on mortality. According to Mitchell et al. (2014), "it is not possible to establish a true statistical average for mortality or economic losses from only a few decades of national data". This shortcoming results from a limited time series but also from the poor quality of the data and information concerning losses. A unified methodology does not exist, even in case of the relevance of framing one for major stakeholders, as exemplified by data on losses that states or insurance companies collect (André 2013; Cazaux et al. 2019). However, at least as concerns mortality related with floods, numerous studies discussing a decreasing trend are found, for example, in Southern France (Boissier 2013), in Portugal (Pereira et al. 2015) or in Spain (Olcina et al. 2016). Such results may reflect limitations due to short time series, to difficulties linking mortality to a specific hazard or to methodological choices related to definitions, among others. However, those results deliver several orders of value, proving that learning from the past and integrating such knowledge in disaster prevention policies likely contribute to reduce losses.

In the face of existing trend toward more people living in flood-prone areas, which is one of the major findings of the previously mentioned research, it is not possible to explain declining mortality trends without integrating the contribution coming from policies of prevention. The understanding of the situation cannot reflect a European exception or cannot arise from a specific hazard-type only. Analysis of the 2010 disaster related to the eruption of Merapi volcano in Indonesia exhibits similar results (Picquout 2013). For example, 350 people were reported dead during the various phases of the volcanic eruption, compared to the evacuation of more than 1 million people from the exposed area. What would have been the casualties in the absence of prevention policies and the use of existing information and knowledge about previous disasters? For the Merapi volcano, no less than nine eruptions occurred since 1872, with information also available on casualties and displaced people. In spite of numerous limitations – related to a wide range of uncertainties about the geodynamics of the eruption or about the timing and conditions of the evacuation of people from the exposed slopes of the volcano – learning from the past contributed to preventing a major disaster. Existing information was transformed into usable knowledge to justify risk maps and evacuation plans, in spite of limitations.

Thus, disaster databases simultaneously embed obvious limitations of disaster prevention policies as well as their hidden capacity to prevent. Such an ambiguous statement mirrors both the limitations and relevance of learning from the past.

3 Learning from the Past Explains the Evolution of DRR Policies and Tools

3.1 Reconsidering Existing Disaster Prevention Policies

As the integration of information into knowledge concerning past disasters in disaster prevention policies is found relevant and limited, it makes sense to reconsider how those policies were framed and to what extent they integrated "experience return". This issue does not only concern risk prevention but also a wide array of policies on land-use management.

During the last decades, numerous European-funded research programmes tried to investigate relationships between land-use management and disaster prevention such as ARMONIA (Menoni and Margottini 2011) and CapHaz-Net (Kuhlicke and Steinfuhrer 2010). They attempted to identify the means (1) to integrate both aspects, disaster prevention and land-use management, and (2) to bridge the gap between hazard-centred research on risk and research coming from the social sciences.

To illustrate those links, policies dedicated to what the French state named dike risk are presented. The issue of dike risk was identified many decades ago by American engineers and by Gilbert White (Macdonald et al. 2012). They found that dikes, as other protective and corrective works, tend to procure a delusive sense of security. They called it the "levee effect". The latter may induce local stakeholders to consider that dikes could be a means to eradicate flood risk. Consequently, it could be possible to build on flood-prone areas, without taking under consideration this type of risk. Indeed, dikes contribute to reduce flood frequencies. However, dikes, as corrective works, transform the physical parameters of rivers as well. In some cases, those transformations escape human control and contribute to increase river erosion, therefore, limiting the protection the dikes were meant to provide. Meanwhile, numerous "experience returns" proved that dikes contribute to reduce flood frequencies but do not allow the so-called protected areas to cope with flood events with higher energy and lower frequency of occurrence. Basically, human-built dikes, as elements of wider hydro-systems, unwittingly tend to produce conditions that create their own limitations. The latter trend has been specifically demonstrated in mountainous areas, where diking tends to increase mountainous river-specific power and also their destructive potential (Pigeon 2017).

Consequently, not taking dikes limitations into account while building on areas that are technically still flood-prone sets off preconditions for an eventual disaster. Taking stock of such disasters that happened during the previous decades (Le Grand-Bornand 1987; Vaison-La-Romaine 1992; Aramon 2002; La Faute-sur-Mer 2010), the French state decided to promote the integration of a specific zoning into a land-use tool dedicated to disaster prevention: the risk prevention plan (RPP). The new zoning type has been named dike risk which recognized at the very same time the relevance of diking, as dikes contribute to reduce flood frequencies, and the limitations that those corrective works meet. The zoning justifies forbearing buildings on areas where dikes increase flood risks, with the *RPP red zone* dike risk, and to adapt buildings in case of local decisions to still use flood-prone areas, with *RPP blue zones*. The French state local representatives use information on past floods and on dikes limitations to defend this solution. Indeed, the latter looks strange, as it reconsiders the traditional role dikes play: they are still currently presented as a protective work.

Basically, the evolution fits larger trends, which reconsider structural measures in the face of sustainable development principles, and also aims at "implementing room for the river" or "more space to the rivers" (Pigeon 2013). The latter expressions have been promoted by academic studies coming from the Netherlands (Warner and Van Buuren 2011).

In spite of such justifications, the implementation of those prevention policies integrating dike risk zonings still meets considerable opposition coming from various stakeholders, mainly local. They challenge the relevance of the structuring of information on "experience return", this time not only about previous disasters but also about previous existing disaster prevention policies, into a new form of knowledge suggesting to strongly reduce building initiatives. Those limitations, in turn, call for the development of new tools, hoping to increasingly strengthen the position the French state defends, in line with other main stakeholder implied, as is the case here with insurance companies. The evolution is dialectic and fits the understanding of policies that Beck (2001) and also Revault D'Allonnes (1999), among others, promoted.

3.2 Knowledge Management Systems (KMSs): Tools that Help to Learn More from the Past

A KMS integrates several existing databases, favouring information sharing and, therefore, the creation of knowledge (Weichselgartner and Pigeon 2015: 109). Basically, it can be understood as a tool helping to manage "experience return" and to structure information which is highly segmented and heterogeneous. This tool should help us to learn more from the past. In particular, KMSs try to compensate for the increasing segmentation (compartmentalization) amid multiple institutions and stakeholders that are imbedded in disaster prevention and which provide information. As such, the tool is not new: similar experiments were tried during the 1970s and applied at least in North America, in order to help find solutions to environment-related conflicts. KMSs are consistent with the understanding of disasters that the resilience alliance group seeks to promote (Berkes and Folke 2002). A KMS defends the relevance of systemic and socioecological approaches when addressing issues related to disaster prevention and tries to provide a more applied aspect to this type of very abstract thinking.

Since 2012, one of these KMSs, the "National Observatory of Natural Hazards" (ONRN), has been developed. Managed by the "mission des risques naturels", it incorporates several major databases that were previously separated. In particular, it integrates databases concerning damages recorded by insurance companies in France. The ONRN helps to display the results and limitations related to the implementation of the French major disaster prevention policy, launched in 1982. The scale of assessment is not only national but also local. The French municipality, as a local data cell, allows one to cross-check data on the number of disasters officially recognized by the French government since 1982, existing risk prevention plans, and claims data from insurance companies (Nussbaum and Pigeon 2015). The ONRN thus provides a stronger, shared database helping to assess elements that contribute to disaster prevention and management. This KMS also can be used to assess how the situation is for municipalities as regards disaster risk reduction policies and their outcomes within the national framework.

Furthermore, KMSs are used as tools to aid in decision-making processes: they may display the limits of policies and justify research as well as political decisions on how to integrate them into decision-making processes at the local level. Many examples of feedback on the use of KMSs are found: in the USA (Renaud et al. 2013: 140–162) and in South Africa (Renaud et al. 2013: 164–189). In all cases, these tools are presented as particularly useful, especially when the limits of research and disaster prevention policies are recognized: "planning for hazard mitigation and adaptation can be challenging when there is much uncertainty and disagreement about the best management practices to minimize risks" (Renaud et al. 2013: 155). Also, the use of KMSs has tended to increase and is now supported by UNDRR.

3.3 The Use of Knowledge Management Systems Also Has Limitations

The ONRN is basically a tool coming from two major stakeholders imbedded in disaster prevention in France: the French state and insurance companies. Therefore, the use of KMSs to help local decision-making, while integrating information and knowledge of local actors in the process, is much more difficult to achieve. Assessments and decisions made while using the ONRN tool can also pose many problems of acceptance. Above all, one cannot expect from the RPP (risk prevention plan) requirements to eliminate entirely future damages, as well as one cannot expect a dike to totally eliminate the risk of flood. Integrating other types of information and knowledge coming from local stakeholders into the decision-making process must be a key requirement. Another major question concerns the poorest households, for whom the issue of adaptation and its limits is secondary, if not even improper, compared to other types of risks they face that are more immediate.

In so doing, the limits of KMSs are identified and even denounced. This is certainly the tool that allows fighting against one of the elements that acts in the favour of disasters, namely, institutional segmentation as well as the fragmentation of information, which together reduce the capacities to learn more from the past. But it is also a tool that, though certainly not alone, fails to reconsider the key underlying drivers associated with the social construction of disasters.

4 How to Increase the Capacity to Learn from the Past?

Consequently, ambiguous statements on the capacities to learn from the past in spite of evolving disaster prevention policies and tools are found. Some questions would be as follows:

(i) Why does not humankind learn more from past disasters in spite of existing information?
(ii) Who learns for what reason, and what type of information is used to learn from the past?
(iii) Why experiences *identified* from previous disasters (often referred to as lessons *learned*) are often untested or not applied in plans to cope with similar future hazards?
(iv) What can be done in order to assure that societies *retain what they learn* from "experience return" and to enhance the recall of societal knowledge, use and management?

A first choice could be to avoid presenting disasters from the viewpoint of losses only, which in fact does not fully acknowledge the "creeping" increases in value of assets that can be affected at some point in time in the future (e.g. as identified for Atlantic hurricanes by Pielke Jr and Landsea 1998). Indeed, the assessment of mortality should take under consideration the demographic growth of population in exposed areas and the same for economic assets such as livelihoods and the built environment. In spite of methodological problems previously mentioned, the comparison of losses with assets and mortality potential should draw attention to the capacity to prevent and to learn from the past, in spite of the limitations of this capacity. In addition, presenting losses only tends to draw attention to one albeit motivating aspect of disaster understanding and managing limitations, the "dread factor". An overfocus on losses can overshadow prevention and preparedness approaches in the same way that focusing on climate change adaptation or mitigation fails to draw needed attention to climate change prevention.

Those drawbacks highlight the difficulties to display the positive contribution of prevention policies to disaster reduction. Indeed, disaster databases register failures and not the capacity to prevent, as the latter is by far more difficult to prove, less spectacular and less disruptive. If effective, disaster prevention is hardly seen and needs to be proven, as, by definition, nothing happens or damages experienced are lower in intensity and can be managed by using only local resources. Proving the effectiveness of disaster prevention policies requires turning to a "what if" reasoning type. On the contrary, the occurrence of a disaster immediately calls forward the limitations of disaster prevention and of learning from the past.

What would disaster assessments be like at the global scale in the absence of prevention policies? One solution would be to draw attention to the importance and relevance of having a more balanced overview of trends concerning losses, while including assets. It makes sense to call for a way to highlight disaster prevention, as a part of "experience return". This shortcoming draws attention to major constraints, helping to explain why the capacity to learn from the past exists but remains so much limited.

5 Eluding Three Main Pitfalls of Fragmented Risk Research by Contextualizing

Numerous approaches advocate situating risk in social contexts (Wisner et al. 2004; Lewis and Kelman 2012) as well as drawing "timescapes" of risk (Fra.Paleo 2019) or trajectories of vulnerability (Magnan et al. 2012). Critics of resilience also stress the need to involve contextual effects in the analysis, whether institutional or social (Reghezza and Rufat 2015) or, again, related with time and rhythms (Nobert et al. 2017). The way of considering risk or resilience also depends on underlying social, political, cultural or technical frameworks that stand for particular ideologies (O'Brien et al. 2007; Walker and Cooper 2011; Cote and Nightingale 2011). It is important to convey underlying ideological frameworks openly, as they can shape the production of knowledge, as well as the kind of solutions that can be explored. Underlying frameworks and drivers also influence risk conditions (García-Acosta 2005).

It is one thing to identify underlying mechanisms as root causes involved in the fabric of risk, but implementing consequent responses always faces multiple difficulties (Pigeon and Rebotier 2016). In spite of always being limited, knowledge for reducing risk and improving resilience makes sense in specific circumstances. It requires an effort of contextualization, for enlightening both the production of knowledge as well as the fabric of risk situations.

Thus, drawing on "experience return", attention must be paid to causality, complexity and standardization in producing knowledge as well as in considering frameworks of action in managing risk and strengthening resilience. On this basis, a situated approach of disaster risks and prevention policies is suggested to embed contextual effects in assessing and managing risk as well. It should help to identify and reduce pitfalls related to knowledge and management, as well as limitations that DRR policies encounter.

5.1 Main Pitfalls of Fragmented Risk Research: Causal Links

In spite of so many feedbacks, risk research is often framed by classical rationality, at the basis of modern science. Descartes' systematic approach applies when addressing risk in a fragmented way, separating its components into isolated subparts (second principle of the method); when linear or direct causal links are looked for, from the simplest relations to the more complicated ones (third principle of the method); or when generalization – if no universalization – of the analysis of the social world is at stake (fourth principle of the method). Each one of those principles of classical rationality is echoed in most risk research and management.

A classical definition of risk consists in combining hazard and vulnerability (Dalezios et al. 2017). It roughly separates society and the environment and suggests that knowing better any of those elements improves risk knowledge. In that view, a prior and almost self-evident element comes from the environment. As an – apparently – obvious triggering driver of a disaster, the natural event stands as a starting point of the analysis, shaping consequent research on risk and reducing the study area to the impacted area. Risk prevention plans in France rely on different kinds of hazard. Flood risk prevention plans (PPRI) or technological risk prevention plan (PPRT) identifies – often isolated – potential events as starting points of the problem to be addressed. The analytical and functional efficiency of such regulatory plans is counterbalanced by their inability to account for multi-hazard situations and the diversity of stakeholders concerned (Pigeon et al. 2018).

In a classical perspective, understanding simple causal links supposedly offers a method to grasp complicated risk situations. Yet, experience shows that simple causal relations do not exist in risk situations, except when risk situations are fragmented in isolated subparts that lose its actual interactions. On the one hand, there is no way to establish a cause and effect relationship between hazard and losses (part 1). On the other hand, two very similar hazards do not have similar consequences when they occur at different time or in different places. In La Faute-sur-Mer, in western France, many similar storm surges already happened in the past, even in recent years, without causing losses and deaths like in 2010, in the opportunity of the one called Xynthia (Feuillet et al. 2012). Territorial characteristics like the growing number of assets at stake do not explain such a dramatic balance by their own. A possible understanding lies in complex mechanisms that support interactions or positive feedbacks, which are hard to disentangle at first sight (Pigeon 2012).

Finally, when focusing on a trigger event, often outside of the social world, hazard-polarized research loses critical and political criteria when analysing risk situations. It also classifies the world according to potential trigger events. In an illusory way, it might even pretend to account for any kind of possible causes of disasters to be addressed on a systematic base. Universalization of causal processes organizes EM-DAT database of disasters, and an inventory of triggering events organizes part of the *At Risk* book (Wisner et al. 2004). In view of benefits and limitations, how can it be explained that such a classical and fragmented way of understanding risk remains that significant? The importance given to rather neutral conceptual frameworks can be mentioned; the need to broadly communicate knowledge on risk by engaging in broadly shared categories, even at the price of later deconstruction; but also the difficulty to address complexity, to account for ambiguities and slight differences between specific cases and broader contexts, to give sense to the diversity of interests, power and economic relations at stake in a radical understanding of risk situations.

5.2 Main Pitfalls of Fragmented Risk Research: Complexity

Complexity disrupts causal and stable conceptions and introduces the need to think about systemic relations. Experiences show how important it is to consider the fluctuation of social and territorial systems when understanding risks and trying to reduce them. Complexity is defined as "a quantitative phenomenon, the extreme quantity of interactions and intrusions between a very large number of units". "However, the complexity does not only consist of quantities of units and interactions which defy our possibilities for calculation: complexity also consists of uncertainties, vagueness and random phenomena" (Morin 2005: 48). This way, it is possible to give sense to the diversity (sometimes the contradiction) of the links that make a system exist or to account for provisional and constantly adjusting mechanisms involved in the fabric of risks.

Chanaz and Culoz are two neighbouring municipalities in France, on each side of the Rhône river. They face very similar flood conditions. But more than flood hazard, urbanization, territorial dynamics, competing interests in each municipality and differentiated interests converging with the ones of important institutional, private and public actors at other scales allow understanding the opposite management of risk shown in one place and the other. On fragmented and isolated basis, it is hardly possible to explain why different risk management is different that much in apparently similar risk conditions. An integrated and situated analysis of risk conditions and its contexts gives room to complexity and contextualization over time, between places and among a particular set of actors (Pigeon et al. 2018).

A more complex reading of risk situations is appropriate to embed risks in broader contexts. Accounting for spatial and temporal scales broadens the scope far beyond a sole kind of actors or the area of impacts only. It addresses mechanisms of the fabric of risks far beyond triggering events and allows identifying underlying drivers as well as socially or politically rooted mechanisms (Lewis and Kelman 2012). In line with the radicals, the complexity and embeddedness of the elements involved in the fabric of risks can be addressed on different basis, like through the study of "trajectories of vulnerability" (Magnan et al. 2012). Up to a certain point, resilience offers possible answer to the fluctuation of social and territorial systems as it is an advocate for the ability of a system to absorb a perturbation and to mitigate potential damage without questioning its original structure. Yet, on the ground, the will to return to the normal stance as soon as possible is often the rule, in spite of so many returns of experience concerning build back better processes. Key issues are displaced more than solved, as the normal stance is a convention constantly updated (Kelman et al. 2016; Fra.Paleo 2019). In front of such a volatile basis for assessing and managing risks and considering the promises of resilience, which are criticized both in general (Cote and Nightingale 2011) and particular terms (Nobert et al. 2017), giving room to complexity may be a condition to account for significant aspects of the fabric of risks and to learn more and better from past experiences.

5.3 Main Pitfalls of Fragmented Risk Research: "One-Size-Fits-All" Viewpoints

Finally, standardization of best practices and kind of homogenization of research perspective pretend to learn from different experiences and be valuable for reducing risk in more general terms. Yet such a generalization faces two pitfalls at least: it tends to overlook contextual specificities, and it carries specificities of past experiences that do not make sense necessarily at present, anywhere or for future situations. Generalization of standard assessment and responses comes from the need to broadly address risk issues, for instance, through a framework of actions. Yet, neither risk assessment nor risk reduction can be considered out of any territorial context. Even if it may be accepted that science relies on universal principles, knowledge (and action) remains highly context-sensitive.

Literature and lessons from past experiences show how important it is to embed risk situations in historical structures, in scales of time and space (Kelman et al. 2016; Lewis and Kelman 2012; Wisner et al. 2004). Elements of interpretation and risk drivers must be found necessarily out of the moment of the disaster and out of the area of impacts. Such an idea is at the base of the territorial vulnerability approach (D'Ercole and Metzger 2009). It states that knowing well the territory at stake gives significant elements to understand risk situations and potentially to manage them. Stressed by the need to act, ticking boxes of frameworks' expectations or in guidelines' steps of action looks like a goal by itself. It disregards local conditions and contextual specificities that appear so meaningful in understanding risk situations and managing them. Instead of standing as an ideal (almost metaphorical) future of lower risk or a desirable goal to achieve thanks to an accurate risk assessment and management (Alexander 2013), good practices (in absolute terms) turn to be the rule and disregard specific conditions. Contexts are not a limitation to disaster risk prevention policies. They are conditions for action and stand as a starting point for knowledge and management. This is the meaning of the approach exposed in the following subsection.

6 Territorializing Risk: A Means to Fight Against Fragmentation

6.1 What Does Territorial Approach of Risk Mean?

Territorializing risks consists of an integrative framework that accounts for physical aspects of risks as well as for its representations, conceptions and discourses, be they related with scientific work, prevention policies or social perceptions. Territories are not only areas under control, but they also correspond to social constructions. They concern a piece of space whose fuzzy frontiers depend on social meanings and identification, on appropriation and symbolic dimensions. They also realize competing interests between actors, or institutions, by making them tangible either materially or on a more speculative basis in the social world. Inspired of French social geography (Antonsich 2011; Jean and Calenge 2002), a territorial approach defines a way to address social issues as they are rooted in space, over time (in a sequence of historical events, Pred 1984) and within society (accounting for uneven relations among social actors).

Risk situations show spatial dimensions that can be assessed through the lens of a territorial approach. Territorializing risk allows setting a dynamical framework to assess risk situations. It articulates them to a contextualized sequence of events proper to a place, a set of actors and their interests (Simon and Dooling 2013). The uneven distribution of territorial characteristics (in terms of space, time and social stratification or competing interests) is reflected in the endless combination and diversity of risk drivers. Thus, not to multiply the analysis of singular case studies, territorializing risks allows shedding light on recurring causal mechanisms of risk fabric that involve territories and its necessary situation in time, over space and among the complexity of the social world (Rebotier 2012).

Two main directions can be considered to set the ground to a territorializing approach that contextualizes risk situations, knowledge on risks as well as the way it is produced (Jasanoff 1998; Pestre 2006).

6.2 How to Territorialize Risks?

A two-step approach can be defined. The first step is twofold and considers risk situations. The second step implies accounting for the conditions of knowledge production about risks.

As for the first step, it is important to draw a comprehensive network of the actors who interact on the territory at stake (even from different scales), and how meaningful are what kind of territorial characteristics and for whom. Such a broad reading of a territory might look misleading for risk research, but there is no doubt that many of the significant risk drivers, the ones that shape not only risk situations but also disasters, are rooted in territorial characteristics (D'Ercole and Metzger 2009) and can be found outside of the reductionist perimeters defined by the area of potential impacts (Lewis and Kelman 2012). Once the main criteria are identified (depending on the specificities of each territory at stake), it is possible to address interactions and mechanisms at work between them. How do such significant territorial criteria turn concrete? How important are they in defining risk situations? In concerning uneven pieces of space or social sectors? Main concerns ask for what makes people or places vulnerable, regarding territorial characteristics and its interactions. It embeds risk situations in the contextualized understanding of territories.

But as for the second step, even if scientific principles might be considered as universal, there is no such thing as universally valid knowledge in social sciences, as the social world is sensitive to space, time and social context. Such a distinctive preliminary view brings epistemological consequences, as the status of the scientific proof (potentially falsifiable) is different for non-empirical sciences (Pigeon and Rebotier 2016: 143–147). The knowledge produced differs from experimental science mechanisms. It does not correspond to any kind of truth made visible or understandable through a positive scientific process. It is rather a set of interpretative meanings, making sense according to a specific context, that potentially echo main structures (or recurring dynamics) accounted for in other experiences. Producing knowledge in social sciences on territories goes through an iterative process of consolidation, by multiplying the observations in front of a continuously evolving framework of a broader explanation of the phenomena at stake (Passeron 1995). And, as with any social activity, production of knowledge is sensitive to social, political, institutional and economic conditions in which it is produced (Bourdieu 2001).

That is why territorializing risks concerns not only risk situations and its contexts but also the way knowledge on risks is produced, by who, fulfilling which interests, on the basis of which conception of risks, etc.

6.3 *Territorializing Risks: The Example of Esmeraldas, Ecuador*

A research experience in Esmeraldas provides an example of the importance of contextualizing risk situations (Pigeon and Rebotier 2019), following the two-step approach.

The city of Esmeraldas, in northern Ecuador, on the Pacific coast, hosts strategic oil assets for the country. At the same time, the site is very exposed to high-intensity earthquakes associated with potential tsunamis, and the local government shows very low capacities for dealing with such risk conditions, in spite of being the municipal level at the forefront of the national strategy for managing risks (Rebotier 2016). The risk situation in Esmeraldas is worsened by a deeply fragmented governance of risks and planning. Yet, such a paradoxical situation can be better understood by shedding light on significant contextual characteristics, as political history of Esmeraldas province in Ecuador; the cultural and symbolical status of Afro-Ecuadorian population of the province; the conflictive relationship between Quito and Guayaquil, being Esmeraldas at the crossroad of the competition; the late territorial integration of the province to the rest of the country; the strongly centralized management of oil sector in spite of a budding process of decentralization; etc. A good understanding of territorial dynamics gives insights to enlighten influential mechanisms that give rise to particular risk situations in one place, at one moment, in a particular social context. These risks can shift over time.

The same research experience in Esmeraldas shows the importance of acknowledging contextual conditions of the production of knowledge on risks (Rebotier et al. 2019). When studying earthquakes in pre-instrumentation periods, seismologists are bound to consider different kinds of proxies to shape important physical characteristics as magnitude or location of past events. Such reconstructions for pre-instrumentation periods are important for knowing better regional characteristics of seismicity (Nocquet et al. 2017). Seismologists use proxies coming from geomorphology or paleoseismology, but they also use historical archives giving information on damage intensities (Beauval et al. 2013). Historical archives on damage description (mainly writings by diplomats, merchants or clergymen) must be reliable enough to be considered in the shaping of past earthquakes. The more historical archives that are found, the more consistent the information looks, and the more robust can results be considered for geoscientists. Yet, as for a marginal region like Esmeraldas province, historical archives are not offering the same contextual conditions than the ones in the early occupied Sierra region. On the one hand, the fact that no (or a few) expression of damage is found in the northern Ecuadorian coast does not mean that no earthquake happened. On the other hand, the status of historical archives describing past damage in Esmeraldas is different from the one of the archives found in the Sierra, close to long-standing places of secular and religious powers. Not even considering the social conditions of producing knowledge (Haraway 1988), historical data considered in seismology requires being duly contextualized in order to make full sense and not to mislead the analysis. Contextualization and the fight against fragmentation can be applied to another thematic scope.

7 Fighting Against Fragmentation: Opportunities and Challenges Related with DRR-CCA Integration

7.1 Why Reconsider the DRR-CCA Divide?

"Best practices" represent a popular concept used for planning to prepare for and respond to hydro-meteorological and geohazards in the future, based on assessments of lessons drawn from previous disasters. This is a useful approach, if all socio-economic, political and demographic conditions as well as behaviour of hazards stay the same over time. "Best practices" work in theory. However, everything noted above changes sometimes in predictable ways and sometimes in surprising ways. Because of increasing human-induced greenhouse gas emissions, the global climate is heating up. The warming of the atmosphere is increasingly generating – over a long term and in a low-grade, incremental and cumulative way – more frequent, more extreme hazards in new locations as well as in historical ones. Existing "best practices" will be short-lived and may even fail under a warmer atmosphere. At the least, they must be monitored and re-evaluated for appropriateness under a warmer climate. Although many people may not see it, societies are "at war with their changing climate".

The natural hazards research community has a proverbial elephant in the room: the elephant is the warming global climate. The warming is a result of increasing greenhouse gas emissions as a result of human activities. For decades the natural hazards research community has worked on disaster risk reduction (DRR) separately from the climate change adaptation (CCA) research community. This was in large measure because the IPCC, since the early 1990s, focused mainly on the science of climate change (e.g. the IPCC's working group I) at the relative expense of research on its societal and environmental impacts (working group II) and policy implications (working group III). WG II belatedly received the attention it deserved and at first heavily focused on environmental concerns and later on societal implications of environmental changes that would likely accompany a warmer atmosphere many decades in the future. However, climate researchers are seeing now some of those climate change-related impacts expected decades in the future, such as the rapid melting of Arctic sea ice, the melting of Greenland ice, record-setting flooding and heatwaves. Scientific estimates of expected adverse environmental changes affecting societies by, say, 2050 are beginning to appear now. This suggests that many of the adverse impacts of a changing climate expected in the 2050s are beginning to occur: the climate impacts of the 2020s are perhaps becoming the climate impacts expected of the 2050s. Thus, it is time for the natural hazards and the climate change research communities to join forces and resources *where their concerns overlap*.

The following pages present a brief overview of the possibilities for and problems encountered in efforts to bridge, blend or integrate DRR and CCA (See Glantz et al. 2014; EFDRR 2016; Ramasamy 2016). These two communities would each benefit from identifying *how to blend their common (overlapping) activities*.

7.2 Similarities Between CCA and DRR Should Help Merging Both Issues

Even though their missions focus on very different time frames and have different tasks, different sources of funding and even different vocabularies, the following concerns among others are shared by both DRR and CCA.

DRR and CCA both:

- Seek to reduce if not avoid risk to hydromet and geohazards
- Seek to foster adaptive capacity
- Seek to foster societal resilience
- Face an uncertain climate future (e.g. climate water and weather variability, change and extremes)
- Have (share) overlapping but different time frames (short to midterm; midterm to longer term)
- Focus on hydro-meteorological hazards
- Could benefit from each other's knowledge
- Seek to reduce vulnerability of at-risk populations
- Are concerned about rural development
- Are concerned about hazard risk management (but on different timescales)

It is important to note that all DRR activities have a CCA component and all CCA activities have a DRR component. Commonalities between the two fields include concern with improving disaster response, reducing societal vulnerability and increasing resilience. Both the DRR and the CCA communities are focused on climate-, water- and weather-related disasters: the DRR community because it is its core concern; the CCA community because planning for future disasters has become a primary concern for policymakers. The DRR community has traditionally placed greater emphasis and resources into anticipating and preparing for educating the public about how communities could more effectively cope with the hydro-meteorological hazards that they currently face.

Communities armed with knowledge about preparedness and DRR can be expected to better fend for themselves in a direct threat from a known hydro-meteorological hazard. In a way, humanitarian organizations are forced by circumstances to undergo "mission creep" toward CCA issues in order to effectively fulfil their mission of protecting life, livelihoods and property under a changing climate and the extremes it might bring. For its part, the longer-term climate change (CCA) and sustainable development community's activities have been greatly influenced by today's news headlines about the growing threat of hazards becoming societal disasters in addition to its focus on wide-ranging impacts of global climate change.

Although there is a fuzzy boundary between CCA and DRR research missions, the first decade of the twenty-first century witnessed an increasing number of CCA projects dealing with contemporary hazards, which was the beginning an *overlapping of activities* that traditionally had been undertaken by DRR researchers. Preparing society for future climate change and preparing it to reduce weather-related hazard risks are quite similar. Both communities involve ongoing processes that include information generation, awareness raising, planning and monitoring (Klein et al. 2003). Adaptive capacities have to be considered in both approaches; however, CCA by definition focuses on longer-term issues such as sustainable development much more so than does DRR. As such, adaptation, originally promoted with regard to future climate change impacts, has slowly moved toward undertakings that also manage present climate hazard impacts. This transition by

CCA to focus attention and resources on present-day hazards has been justified by the growing awareness of global warming's association with current climate extremes.

7.3 Challenges Raised by Differences Between CCA and DRR

CCA is concerned about identifying ways for societies to adapt sustainably to an increasingly warmer climate over decades. However, coping with disasters is only one of several key concerns of the CCA community: reducing carbon emissions (mitigation), adapting to changing environmental conditions, developing non-polluting energy sources, protecting tropical forests, modelling and monitoring atmospheric changes and so forth. Its direct involvement in disaster preparedness is an example of the CCA community's "mission creep" into today's DRR's mission of disaster preparedness planning for regional and local climate, water and weather extremes.

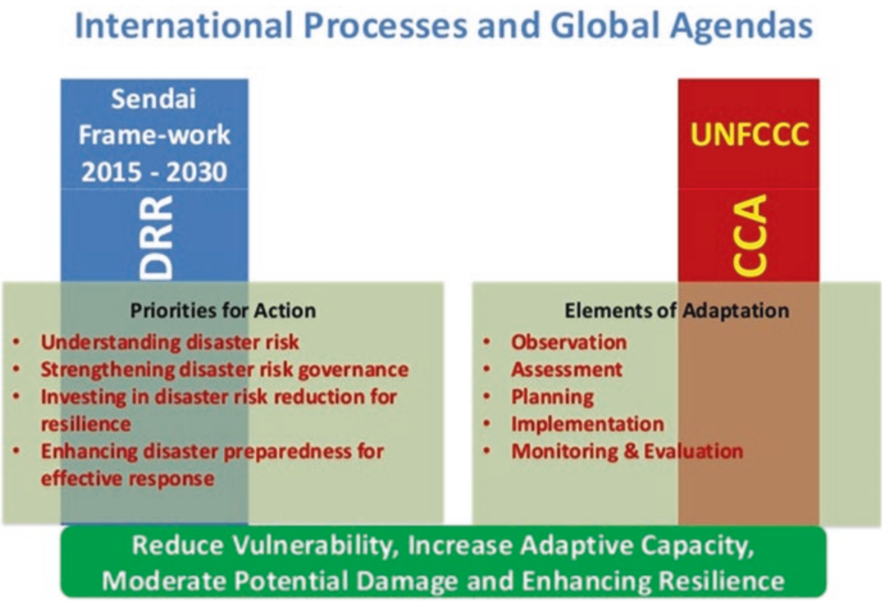
Several researchers (Mitchell and van Aalst 2008; O'Brien et al. 2008; Shaw et al. 2010) argued that CCA's more future-looking perspective will be essential to ensure that DRR activities remain viable in the face of climate change. In this way, CCA researchers may also consider slow-onset (creeping) environmental changes such as the incremental rising sea level, loss of biodiversity and changing water resources (Shaw et al. 2010) as well as consider the end result of such accumulating incremental environmental changes.

There are also significant differences in the tools and approaches both CCA and DRR use in addressing hazards. DRR has a history of interventions and specific tools such as case studies that have yet to be well-developed in CCA (Mitchell and van Aalst 2008; O'Brien et al. 2008). DRR also has a tradition of including local actors and local knowledge, whereas CCA has largely been dictated by global policy processes and scientific guesstimates about impacts throughout the rest of the twenty-first century.

CCA proponents sometimes suggest that DRR programmes that seek to "get life back to normal" to "build back better" or to "bounce back" are short-sighted in that their tendency is to rebuild communities by getting life back to normal as soon as possible but still poverty-stricken and in the same risky locations: they raise tents where houses were and place trailers where schools or other municipal buildings were in pre-disaster days. CCA proponents often critique such DRR actions as examples of "unsustainable development" or even as maladaptation to a changing climate. Yet disaster victims often want to return to a semblance of normalcy, risky conditions notwithstanding, at least for the immediate and short- to midterm future. Doing so may be a viable tactical objective, as it provides more time for the CCA community to identify ways to move settlements out of harm's way or to protect them from the foreseeable hazards they will face if they remain in harm's way.

7.4 What Might Be Gained by Integrating DRR and CCA

Potential synergies between the fields of DRR and CCA provide compelling reasons for greater communication between the two fields as well as for each to adopt elements of the other in the name of both efficiency and effectiveness. For example, CCA might benefit from tools already established by DRR, including methods for engaging local communities, while keeping its focus on long-term vulnerability reduction. Conversely, DRR could benefit from CCA's proactive approach toward sustainable development, which might better ensure that both risk reduction and disaster relief programmes incorporate changing climate scenarios into their programmes and actions. Assuming a longer-term perspective within the field of DRR could increase the societal resilience of projects that will eventually be affected by climate change.



Ramasamy, S. (2016). Disaster risk reduction (DRR) and climate change adaptation (CCA)

7.5 What Might Be Lost in a Merger of CCA and DRR

Disasters and DRR are usually conceptualized in terms of human losses not environmental losses (i.e. biodiversity, coral reefs, etc.). Climate change adaptation emphasizes loss of resilience in biological systems more so than DRR, which tends to be strictly anthropocentric in its focus. Merging the two, however, runs the risk that climate change would become the primary focus to the detriment of other hazard-related sources of vulnerability. Also, how climate change will affect specific locations might lead to greater paralysis of action, given scientific uncertainties. There is also a risk that political support for funding DRR might be undermined in areas where the climate change issue is still politically contested, as in the USA today.

It would be interesting to explore how political support for CCA and DRR is mobilized in order to see if integration might inadvertently undermine support for one community or the other. To be sure, the values underlying each separate approach are certainly worth considering before a merger or *blending of overlapping concerns* is carried out. One might argue, for example, that CCA, being situated within environmental ministries because it is largely being framed as an environmental issue, draws strength from "ecocentric" values and its strong support from the environmental community. In contrast, with its roots in humanitarian relief, DRR is more oriented toward disaster prevention, preparedness and relief of human suffering.

7.6 Targeting Institutional Fragmentation

Several researchers argue that integration would open space for each field to learn from the strengths and weaknesses of the other and contribute to more efficient use of resources (Shaw et al. 2010; Tear Fund 2008). One of the primary challenges facing humanitarian and development organizations is redefining the relationship between disaster risk reduction (DRR), climate change adaptation (CCA) and other kinds of development frameworks. There has been a growing recognition in the areas of complementarity (Red Cross and Red Crescent 2013) and in tensions between these fields, as well as calls for greater integration between them (Shaw et al. 2010; Tear Fund 2008). Calls for "mainstreaming" DRR and CCA within development more generally have often been made (O'Brien et al. 2008; Schipper 2009; Schipper and Pelling 2006; Mitchell et al. 2006).

A complete integration of institutions governing DRR and CCA research and policy is unlikely because of power disputes between various entrenched research organizations or among various units within them. Other principle challenges to integration include fragmentation of funding and implementation of resources, entrenched interests, different spatial and temporal scales, differing systems of norms and different kinds and sources of knowledge (Birkmann and von Teichman 2010). In particular, reconciling the top-down CCA agenda, which is driven by multilateral organizations, and bottom-up with the local approach common to DRR may be especially difficult.

Currently, agencies, funding sources and approaches are largely separate. Much DRR funding comes from humanitarian budgets, whereas most funding for CCA comes from environmental ministries. Such separation has also meant the development of different terminologies, which further complicates cooperation and communication between the two fields. For example, "mitigation" in the context of climate change refers to a reduction in CO_2 emissions, whereas in DDR it is taken much more broadly, referring to efforts to reduce potential damages from known natural hazards (Schipper 2009).

Bridging requires changes in the way these groups meaningfully interact; they can no longer remain as autonomous sub-fields of operation sometimes even within the same agency. Resistance to bridging results primarily from the following factors: the two communities have different mandates, they are focused on different aspects of development, they have differing missions, they have different time frames of concern, they employ different approaches to fulfilling their missions, they require different resource streams and amounts, they have different ways to access funds, and they have different time frames for evaluating success or failure. Bridging these two communities will be easier said than done, even though *they have shared overlapping interests in addressing disasters today and in the future*.

This shift in mindset and approach to make humanitarian and longer-term development activities more beneficial to donors and recipients alike will take some time to implement to the fullest extent. Only time will really tell, as sustainable outcomes are seldom identified overnight. Discussion continues about how to link, complement, bridge, blend or integrate DRR and CCA, the two autonomous development-related mandates. One possible example to foster their interactions would be to establish a common pool of funds that is solely to support those activities in which the DRR and CCA communities truly overlap and on which they truly collaborate.

Boxed Inset

As an example, it can be suggested that there are "gateway" concepts that enhance DRR activities designed to cope with present-day climate-, water- and weather-related impacts, while keeping future CCA needs in mind. El Niño-ready nations is such a gateway concept that not only bridges DRR and CCA but also allows for the blending of their overlapping activities. It is not possible to avoid addressing the changing climate factor, when it comes to making countries El Niño ready.

The history and contemporary monitoring of El Niño in the tropical Pacific are more useful than just preparing for an impending episode itself and its teleconnected environmental and socio-economic impacts. It is what it is called a gateway (bridging) concept because it links the past and present to the future. Our reasoning is as follows: because El Niño events have an average return period of 4½ years, societies affected by it can prepare for it both tactically and strategically, as a nation's funds permit. It can be shown that El Niño events serve as lab experiments quasi-periodically where favourable preparations and responses to previous events can be evaluated and strengthened and weaknesses identified and addressed. It serves as a "canary in the mine" for societal institutions' and communities' prevention and preparedness for coping with a changing climate.

As the global to local climates change, a society's best practices will also be changing. As climate change so far has been incremental, a creeping environmental change, monitoring El Niño can glimpse such changes and, hopefully, spark and test societal adjustments (acclimatizations) as early as possible. The study of El Niño and its impacts is one example of other potential gateway concepts and notions that must not be divorced from studies of the earth's changing climate. Focusing on the El Niño phenomenon as a bridge can blend mutual concerns about present-day hazards (DRR) with those for sustainable development (SD) and, more specifically, about climate change adaptations (CCA) that will be needed in future generations.

8 Summary and Conclusions: What to Do to Improve the Existing Situation?

Learning from the past is a key aspect for the well-being of humankind in the future. Learning is key for societal improvement to avoid natural and human-generated disasters. Learning alone, however, cannot lead us to the perfect one and forever solution, because natural, environmental and societal processes are each dynamic and their combined interactions often yield unanticipated concerns.

It is common sense to assess existing as well as past disaster-related situations, as it concerns disaster risk reduction prevention and preparedness policies with an eye on possible changes in the future. There is a collective societal hope and expectation that it really is possible to be better prepared for future hazards and the disasters they generate. This is generally acknowledged through the gateway concept of the "learning curve". But difficulties in assessing results from prevention and preparedness measure gains are reflected by the numerous shortcomings of various tools such as databases, models or knowledge management systems. They enlighten, but at the very same time, their relevance and usefulness for decision-making have inherent challenges.

Two main pitfalls are epistemological and institutional. Basically, they arise from the basic need to understand and then to manage complexity, while reducing analytical and institutional fragmentation where possible. It requires taking into consideration more types of risk and bringing local stakeholders into hazard-related decision-making processes. Limitations are not a dead-end for managing risk because they are part of risk management. They should be acknowledged through "gateway" concepts and approaches, like territorialization. Hazard and disaster institutions as well as political decision-makers must rise to the challenge.

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Chapter 5
New Frameworks for Building Resilience in Hazard Management

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Abstract Over the last 50 years, the human, environmental and economic cost of natural and climate-induced disasters has increased globally. Such disasters are expected to increase in frequency and magnitude, bringing increased risk of loss. Systematic efforts to reduce disaster risks are vitally needed and should be increasingly founded on risk and resilience assessments. In this chapter, it is argued that the public scrutiny of recent disasters stimulated changes in the legal framework of civil protection and governance policies related to natural hazards and associated vulnerabilities. It is shown how the new institutional and legal framework was strategically integrated by local populations in their mitigation practices, appealing to past practices and memories but also to the new challenges posed by the building up of official emergency plans, hazard zoning and new technical instruments and practices. In this confrontation between the national laws, the municipalities' technicians and rulings and the mundane practices of hazard preparedness and mitigation, a new public awareness emerged that allowed for a discussion of priorities, inclusion dynamics, effectiveness of the alert messages and the production of new ways of participating in the public sphere and new dimensions to define citizenship and political belonging. This chapter analyses the conceptual, technical and practical dimension of such processes by highlighting the different components and dynamics of relevant frameworks.

Keywords Building resilience · Disaster · Framework · Natural hazards · Risk management · Risk reduction

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1 Introduction

Climate change is increasingly acknowledged to be one of the most important current global challenges. Climate-induced risks and disasters are expected to increase in frequency and magnitude, bringing increased risk of loss (IPCC 2012). Thus, societies and communities vulnerable to climate change urgently need approaches and methods to assess and design strategies for building resilience (Eslamian et al. 2019). Indeed, disaster risk reduction strategies will not be efficient unless they are founded on risk and resilience assessment. This kind of assessment sits between the theoretical domain of resilience as a way of understanding changing and uncertain environments and the practical domain of resilience as a decision support tool for managing how societies live within changing and uncertain environments (Parsons et al. 2016). The practice of disaster resilience assessment is entering what will be a multi-decadal phase of diverse and reflective advancement. Assessment of disaster resilience summarizes the status of resilience within a community.

More precisely, risk and disaster resilience assessment consists in the evaluation of threats, hazards, vulnerabilities, consequences, needs and resources through algorithms or other methods to define and prioritize risks so community members, decision-makers and responders can make informed decisions and take the appropriate action. Such an assessment directly connects threat and hazard data and information in order to analyse and understand the potential effects on a community. A robust risk and disaster resilience assessment capability allow a comparison and prioritization of risks from disparate threats and hazards across a variety of communities and jurisdictions. Outcomes from risk and disaster resilience assessments, such as analysis and data, can be leveraged in planning efforts and resource allocation across the other mission areas.

Assessment of disaster resilience using an index is often a key element of natural hazard management and planning. Many assessments have been undertaken worldwide from which a set of common properties that should be considered in the design of any disaster resilience assessment has emerged. It consists of assessment purpose, top-down or bottom-up assessment, assessment scale, conceptual framework, structural design, indicator selection, data analysis and index computation and reporting and interpretation. Indicators are collected to determine the status of each theme. As assessments of disaster resilience develop worldwide, reporting of their design as standard practice has the potential to track knowledge generation in the field and enhance the relationship between applied disaster resilience assessment and foundational principles of disaster resilience.

Against this background, this chapter aims at analysing the frameworks for resilience by presenting the different properties for the design of disaster resilience assessments (2), reviewing the various definitions and operational frameworks (3), analysing the differences and commonalities between disaster risk management and disaster risk reduction (4) and presenting an integrated approach to manage health risks and build resilience (5).

2 Frameworks for Resilience

Disaster resilience assessments are designed based on many properties. In this section, focus will be made on the determination of the assessment purpose, the choice between bottom-up and top-down approaches, the concerned scale, the scope, the structural design, the indicator selection, data analysis and index computation and reporting and interpretation.

2.1 Properties for the Design of Disaster Resilience Assessments

Common properties set the scope of any disaster resilience assessment and are influenced by conceptual, technical and practical considerations. In this section, we outline the common properties that should be considered when designing an assessment of disaster resilience and its component index and indicators. These properties are derived largely from Eric Tate's stages and options for social vulnerability index construction (Tate 2012). Assessment purpose (Cutter 2016), top-down versus bottom-up assessment (Cutter 2016) and index reporting (Beccari 2016) are our additions.

2.1.1 Assessment Purpose

In broad terms, assessment refers to a qualitative or quantitative process of evaluating the status of some phenomenon of interest. Assessment can be driven by different concerns and conducted for different purposes including (1) to gauge or audit the state of a system at one point in time or over time, (2) to assess whether regulated performance criteria have been exceeded, (3) to detect and assess the impacts of human-generated disturbance and (4) to assess the responses to mitigation, restoration or policy implementation efforts (Downes et al. 2002).

Assessment can also be undertaken to predict or forecast future trends in a phenomenon of interest in response to the application of treatments.

Information arising from the assessment is usually fed back into decision- or policymaking processes to highlight potential problem areas, approve regulation conditions, reform policy, prioritize support, guide research and development, establish programmes and set organizational goals. Thus, the purpose of any resilience assessment needs to be defined at the outset because purpose influences the design, content and computation of an index.

2.1.2 Top-Down or Bottom-Up Assessment

A key distinction is made between bottom-up and top-down assessment approaches. Bottom-up approaches (Arbon 2014; Pfefferbaum et al. 2013) use community surveys and stakeholder interviews to directly derive indicators and assess resilience (NAS 2015). Top-down approaches (Cutter et al. 2003; UNU 2014) use existing secondary data, such as census or economic data, to indirectly derive proxy indicators and assess resilience (NAS 2015). A bottom-up resilience assessment can theoretically be undertaken at a national scale and a top-down resilience assessment at a local scale. However, there is generally an inverse relationship between scale and the logistics of community involvement, so that bottom-up assessments tend to be undertaken at a local level and top-down assessments at a state, national or international level (NAS 2015). Bottom-up and top-down assessments may also be hazard specific or general to all hazards (NAS 2015).

The choice of top-down or bottom-up assessment is an important consideration because it determines the degree of community involvement in the assessment process and influences the cost and spatial extent of the assessment (NAS 2015) and the ability to compare across units of analysis using standardized data (Cutter 2016). It is also important to understand the boundaries of each approach, because both have a level of spatial or conceptual limitation beyond which conclusions about resilience are no longer valid. For instance, top-down approaches, which are based on analogous systems with well-documented performance records, are usually good at highlighting the challenges in a historical context, but the results need to be adjusted when applied to a new design with no or little real flight history. On the other hand, while bottom-up approaches are good at capturing the risk of a system that is comprised of at least some components with demonstrated reliabilities and has a specific design, environment and operational concept, the method is heavily dependent on the analyst to define the failure modes and capture the failures caused by component interaction or by environment hazards. This difficulty often challenges the completeness of a bottom-up model and makes it difficult to produce bounding risk estimates. In all cases, the relationship between the outputs of top-down and bottom-up resilience assessments has not yet been well researched and, therefore, needs further investigations (Parsons et al. 2016).

2.1.3 Assessment Scale

Extent is the overall area encompassed by a study and grain is the size of the sampling units used in a study (Wiens 1989). Larger spatial scales are assessed by increasing the extent of the study, and smaller spatial scales are assessed by making the study fine grained. Despite the apparent simplicity of this concept, trade-offs need to be made in the design of an assessment. If the spatial extent of a study is large, the sampling will be prohibitively expensive unless the grain is relatively coarse, and any study with a fine grain must of necessity have a narrow extent (Allen and Hoekstra 1991). This is why bottom-up assessments of disaster resilience tend to be local in extent, with data derived from fine-grained survey instruments (Arbon 2014), whereas top-down approaches tend to be large in extent, using secondary data with a predetermined grain (Cutter et al. 2003). Consideration of the spatial grain and extent of a resilience assessment ensures that the processes influencing the selected dimensions of resilience are captured in the assessment at an appropriate spatial scale.

Dimensions of resilience are also dynamic through time (Cutter and Finch 2008). Assessment design thus needs to consider the temporal scale of the assessment in relation to the purpose of the assessment. The assessment will be an audit at one point in time or conducted repeatedly to determine trends in resilience in relation to a baseline condition (Cutter and Finch 2008; Cutter et al. 2010). The temporal domain within which an assessment is conducted should be reported to ensure that interpretations of resilience are not taken outside their temporal boundary.

2.1.4 Conceptual Framework

The underlying conceptual framework is the philosophical justification of the resilience assessment approach. In short, the conceptual framework justifies the dimensions of what the index is intended to measure (OECD 2008; Tate 2012; Winderl 2014). For example, the disaster resilience of place (DROP) model (Cutter et al. 2003) underpins the Index of Social Vulnerability. A conceptual framework can be created or extended from an existing framework. Regardless of its origin, the conceptual framework is an important step in constructing a resilience assessment because it positions the assessment in the context of the field of disaster resilience and guides the scope and treatment of assessment elements. The conceptual framework should be published before, or in conjunction with, the assessment results (Birkmann et al. 2013; Cutter and Finch 2008; Orencio and Fujii 2013) although some assessments of disaster resilience are conducted and reported without reference to a guiding conceptual framework.

2.1.5 Structural Design

Structural design is the arrangement of indicators within an index-based assessment of disaster resilience (Beccari 2016). The structural design of a resilience assessment index can be deductive, hierarchical or inductive (Tate 2012). Deductive designs contain fewer than ten indicators, which are normalized and aggregated to an index. Hierarchical designs employ around 20 indicators that are separated into themes sharing the same underlying dimension. A sub-index is generated for each theme and the sub-indices aggregated to an index. Inductive designs begin with a large set of indicators which undergo dimensional reduction, either with principal component analysis or factor analysis. The factors are aggregated to form the index. Consideration of structural design is important because different structural designs are sensitive to data computation elements. Deductive designs are sensitive to data transformation, hierarchical designs to indicator weighting and inductive designs to the indicator set and scale of analysis (Tate 2012). Deductive and hierarchical designs also report data directly, whereas inductive designs transform data into components which may not be readily interpretable.

2.1.6 Indicator Selection

An indicator is a quantitative measure 'intended to represent a characteristic of a system of interest' (Tate 2012). An indicator can be composed of one variable or many. In the latter case, it is known as a composite indicator or index (OECD 2008; Tate 2012). An index responds directionally according to the behaviour of the system (Burton 2015) and can be arrayed along a continuum of good to poor status. Indicators are based on normative understandings of relationships between a variable and a broader thematic concept, with varying degrees of empirical support (Birkmann 2013; Maggino and Zumbo 2012). The evidence supporting these relationships can be literature-based logical plausibility (Cutter et al. 2003) or causal validation (direct observation or indirect structural equation modelling) of the relationship between an indicator and the thematic dimension it represents (Burton 2015; Paton 2007). The use of logical plausibility is presently most common in disaster resilience assessment because causal validation specifying the association between an indicator and disaster resilience or vulnerability is only recently attracting research focus.

Selecting indicators, and the variables that makeup indicators, is both an art and a science. An indicator always implies that a relationship exists between the indicator and a latent construct representing some aspect of resilience. Thus, the process of indicator selection is also coupled with the purpose, framework, design and interpretation of the index. While there will always be trade-offs between indicator specificity, data availability, cost-effectiveness and sensitivity (Birkmann 2013; Winderl 2014), the selection of indicators can be guided by criteria that help bound large sets of potential indicators (Table 5.1). The use of indicator selection criteria minimizes potential sources of uncertainty in the interpretation of disaster resilience arising from the types of indicators included in the computation.

2.1.7 Data Analysis and Index Computation

There are many data analysis and computation elements to consider in the construction of a resilience index, including measurement error, transformation, normalization, data reduction, factor retention, weighting and indicator aggregation (Tate 2012). Index construction also involves geographical adjustments (e.g. spatial aggregation or disaggregation) and indicator adjustments (e.g. imputation of missing values and indicator reversal to align with resilience), many of which are directed towards reducing the undesirable effects of the skewness and kurtosis (types of departure from normality) of indicators on composite indices (OECD 2008).

Table 5.1 Generalized criteria for indicator selection

Criteria for indictor selection	Requirements
1. The indicator reflects a justifiable element of natural hazard resilience	The relationship between the indicator and natural hazard resilience has been verified in the academic/professional literature
2. The indicator can track change and variability in natural hazard resilience	Change in the indicator can be determined and associated with change in resilience spatially and temporally
3. The indicator is relevant to the scale(s) of assessment	The indicator aligns with the scale at which the assessment is undertaken. There may be a requirement for an indicator to remain valid across scales (e.g. local to national)
4. The indicator is measurable and readily interpretable	The indicator is specific and precisely defined
	The indicator is quantifiable and spatially referenced
	The indicator is easy to define, understand and communicate
5. The measurement method for the indicator is robust	Measurement is reliable (and verifiable) and representative of reality
	Measurement occurs regularly enough for the purpose
	Measurement is methodologically sound
6. The indicator is achievable - data are available, accessible and cost effective	Data are available at the required scales across most of the study area
	Data are readily available from secondary sources
	Data can be accessed within the cost and resource framework

Compiled from Bene (2013), Birkmann (2013), Brown (2009), Maggino and Zumbo (2012), and Winderl (2014)

Analysis and computation choices ultimately influence the relative rankings of entities (Tate 2012). Thus, sensitivity and uncertainty analysis must be built into index construction to evaluate and report the reliability of index-based assessments of resilience under different computational choices. Sensitivity analysis examines how each source of computation choice contributes to the output variance, and uncertainty analysis examines how the computation of the input factors propagates through an index structure (Saisana et al. 2005). Methods for undertaking sensitivity and uncertainty analyses are well developed (see reviews by OECD 2008, and Saisana et al. 2005).

2.1.8 Reporting and Interpretation

Reporting is a key property of resilience assessment because it interprets and communicates findings in relation to the purpose of the assessment. Reporting of a resilience index generally involves a spatially explicit depiction of the value of an index or component themes (Cutter et al. 2003; UNU 2014) and may be accompanied by tools that allow spatial interrogation of the index or sophisticated graphical representation of index outputs (Beccari 2016). Resilience assessments are also used to support policy- and decision-making, and thus, reporting should help to construct narratives for lay and literate audiences (OECD 2008).

3 A Review of Definitions and Operational Frameworks

A number of reviews of the resilience concept and its applicability in reducing disaster risks and uncertain impacts arising from climate change exist. This section aims to contribute to the understanding of resilience through the systematic review and analysis of existing resilience definitions and frameworks and the documentation of 'on-the-ground' experiences from resilience building initiatives in the context of natural hazards (Djalante and Thomalla 2011).

A comprehensive and effective disaster resilience framework needs to incorporate fundamental elements of sustainable development, disaster risk reduction and community engagement and climate change adaptation. In addition, it needs to go beyond the specification of concrete outcomes to describing the process by which the initial resilience status can be identified and the goals for each element can be established. Conceptualizing resilience building as a process is important to enable the monitoring and evaluation of progress towards desired goals (Djalante and Thomalla 2011).

3.1 Vulnerability Due to Disaster and Climate Change

The Asia Pacific disaster report states 'in Asia Pacific the population of the region has increased from 2.2 billion to 4.2 billion people between 1970 and 2010, but the average number of people exposed to annual flooding has more than doubled from 29.5 to 63.8 million; the number of people residing in cyclone-prone areas has grown from 71.8 million to 120.7 million' (Djalante and Thomalla 2011). Within South Asia is Bangladesh, where various geo-specific communities are prone to natural shocks and climatic disasters. Alarmingly, considering mortality risk distribution of selected hydro-meteorological hazards (tropical cyclones, floods and rain-triggered landslides) in South and South-West Asia, Bangladesh has been identified as 'extreme' risk area.

The recently released sixth annual Climate Change Vulnerability Index (Djalante and Thomalla 2011) revealed that Bangladesh would feel the economic impacts of climate change most intensely. In Bangladesh, the significant threat is posed by natural as well as human-induced hazards into multiple geographic areas through floods, cyclones, droughts, tidal surges, tornadoes, earthquakes, river erosion, high arsenic contents of groundwater, waterlogging, water and soil salinity, etc. The National Alliance for Risk Reduction and Response Initiatives (NARRI), however, will concentrate on natural hazard-related issues when it comes to building resilient communities.

Other than natural disasters, climate change adds a new dimension to community risk and vulnerability. Indicators are that not only will floods and cyclones become more severe but they will also start to occur outside of their 'established seasons'. Events, such as drought, may not have previously occurred in some areas, but they may now be more evident. Therefore, both rural and urban communities dispersed in various geographic areas remain ecologically as well as economically vulnerable.

3.2 The Key Elements of the Framework

The framework for community safety and resilience in the face of disaster risk is constructed from several interrelated components. The essential end result, a safe and resilient community, emerges as an outcome of the achievement of a number of interrelated development goals. This is reinforced by increasingly reduced loss of life, livelihoods and assets following a disaster and the ability to build back stronger afterwards. Reduced loss of life, livelihoods and assets is enabled by a greater awareness of hazards and risks, a greater capacity for disaster response and the establishment and maintenance of safe environments. The ability to build back stronger is enabled by having access to essential services; resolving the provision of basic needs, particularly among the most vulnerable; and the creation of an enabling environment. The elements that identify the Red Cross and Red Crescent contribution to disaster risk reduction (DRR) as a key action in building community safety and resilience are as follows (Ainuddin and Routray 2012):

(a) *Risk-informed humanitarian response.* The provision of relief and the satisfaction of immediate needs following a disaster, as well as follow-on recovery activities aimed at getting communities back on their feet, are undertaken in a way that works towards meeting longer-term risk reduction objectives. It is understood that humanitarian response to disaster and recovery following a disaster is the absolute imperative of National Societies. However, this is not an end in itself but a means to an end, with increased safety and resilience and decreased vulnerability as a consequence, implying a diminishing need to respond to disasters in the future.
(b) *Country-specific mitigation, prevention and adaptation activities.* National Societies will be working with their country-specific hazard profile and within their national socio-economic, environmental and political contexts and with communities in both rural and urban situations. They will also be working within a mandate agreed to and supported by national governments and civil society generally. Support to community safety and resilience will include mitigation, prevention and adaptation projects targeted towards the reduction of risks from specific hazards.
(c) *Sector-based programming to build across the disaster management spectrum.* National Societies may have ongoing sector-based programmes in, for example, health and care, water and sanitation and shelter. These sectors are important elements of effective community-based DRR programmes. With good coordination these sector-based contributions should work towards DRR objectives and the building of community safety and resilience. It is intended that each of the Red Cross and Red Crescent sector-based programmes will offer

guidance in supporting programming from response through to DRR and the building of community safety and resilience.

3.3 Resilience as an Outcome Versus a Process

Cutter et al. (2008) and Manyena (2006) emphasized the significance of considering resilience as an outcome versus a process. Resilience is considered an *outcome* when it is defined as the ability to bounce back or cope after a disaster, the ability to survive and cope with a disaster with minimum impact and damage and the capacity to avoid, reduce and minimize impacts of disaster and recover quickly and effectively (Bruneau et al. 2003; Cutter et al. 2008). Resilience is considered a *process* when it is defined to be the ability to learn to mitigate future disasters (Tierney and Bruneau 2007; Cutter et al. 2008). The frameworks either suggest activities or processes aimed at building resilience or specify important elements of resilience or both.

3.3.1 Resilience as an Outcome

In this section, we closely examine elements and indicators of resilience described by the 12 frameworks. We identify 14 elements of resilience and group them into 3 categories: sustainable development, disaster risk reduction and community engagement. Table 5.2 presents a detailed analysis of the 14 resilience elements and indicators for each framework and the elements within the 3 categories.

3.3.2 Resilience as a Process

Five of the 12 frameworks included concrete activities to build resilience. The Climate Resilient Cities (CRC[1]) framework of the World Bank, the Hyogo Framework for Action (HFA[2]) and the Coastal Community Resilience (CCR[3]) framework all suggest similar activities to build resilience. The other two frameworks, the Community Safety and Resilience in the Face of Disaster Risk (CSR[4]) of the International Federation of Red Cross and Red Crescent Societies (IFRC) and Disaster Resilient Cities (DRC[5]) of Infrastructure Canada, prescribed attributes or characteristics of a resilient community. They are as follows:

[1] Climate Resilient Cities

[2] Hyogo Framework for Action

[3] Coastal Community Resilience

[4] Coastal Community Resilience

[5] Disaster Resilient Cities

Table 5.2 Fundamental elements of a resilience framework (Djalante and Thomalla 2011)

	1. HFA	2. CDRC	3. CCR	4. CSR	5. CRC	6. CDRI	7. 4R	8. CRD	9.CDRF	10. CDR·CBA	11. CRF	12. DRC
A. Sustainable development												
1. Governance & institutions	Institutions and legal frameworks	Governance	Governance	Governance	Governance and institutions	Departments and institutions	Institutions	Organi-sationall dimension	–	–	–	Insti-tutions
2. Training & education	Training, education	Knowledge, education	–	Advocacy, education and awareness	Education	–	Education; knowledge and awareness	–	–	Human capital	Human capital	–
3. Social development	Social development	–	Society and economy	–	Social development	Community development	Social develop-ment	Social dimension	Social and economic development	Social capital	Social capital	Social
4. Economic development	Economic and financial policies	–	–	–	Economic and financial resources	Economy and financial resources	–	Economic dimension	–	Economic capital	Economic capital	–
5. Built environment / physical infrastructure	Infrastructure and built environment	–	Land use, structural design	–	Infra-structure and built environment	Infrastructure and built environment	–	Technical dimension	–	Physical capital	Physical capital	Built environ-ment
6. Natural environment / ecosystem	Environmental plans include DRR	–	Coastal resource management	–	–	(Hydro-meteorological) disasters	–	–	–	–	Natural capital	Natural system
B. Disaster Risk Reduction												
7. Disaster prevention / mitigation	Risk assessment and VCA	Risk assessment and VCA	–	Risk assessment and identification	Risk assessment and VCA	–	–	–	–	–	–	–
8. Disaster preparedness	Disaster preparedness	Disaster preparedness and response	Warning and evacuation	–	Disaster preparedness	–	–	–	–	–	–	–

	1. HFA	2. CDRC	3. CCR	4. CSR	5. CRC	6. CDRI	7. 4R	8. CRD	9.CDRF	10. CDR·CBA	11. CRF	12. DRC
9. Emergency management	Response and emergency management	–	Emergency response	–	–	–	–	–	–	–	–	–
10. Disaster recovery & reconstruction	Disaster recovery and reconstruction	Disaster preparedness and response	Disaster recovery	–	–	–	–	–	–	–	–	–
C. Community engagement												
11. Values / goals / aspiration	Resources to implement DRR	–	–	Partnerships Community-based	–	–	–	–	Community of interest; Aspirations; goal	–	–	–
12. Partnerships/ collaboration	Community participation and decentralisation	–	–	disaster preparedness;	–	–	–	–	Shared values; partner-ships; network	–	–	–
13. Participation/ networks	Public awareness and	–	–	Early warning and prediction	–	–	–	–	Resources and skills	–	–	–
14. Knowledge/ capacity	outreach	–	–	–	–		–	–	–	–	–	–

- *HFA/five priorities for actions:*

    1. To ensure that DRR is a local and national priority with a strong institutional basis for implementation
    2. To use knowledge, innovation and education to build a culture of safety and resilience at all levels
    3. To reduce the underlying risk factors
    4. To identify, assess and monitor disaster risks and enhance early warning
    5. To strengthen disaster preparedness for effective response at all levels

- *CDRC/guidance note for CDRC:*

    1. Section A: Introduction and background/key concepts
    2. Section B: Tables (components of resilience; characteristics of a resilient community; characteristics of an enabling environment)
    3. Section C: Thematic areas (governance, risk assessment, knowledge and education, risk management and vulnerability reduction, disaster preparedness and response)

- *CCR/steps to assess CCR:*

    1. Define purpose, scope and participants of the assessment.
    2. Review CCR benchmarks.
    3. Prepare for the assessment.
    4. Collect information and data.
    5. Compile and analyse results.
    6. Validate and communicate results.
    7. Provide recommendations to adapt plans and programmes for enhanced resilience.

- *CSR/characteristics of a safe and resilient community:*

    1. Community understand, can assess and monitor risks so that they can protect themselves when disaster strike
    2. Community able to sustain their basic community functions and structures due to disaster impacts
    3. Community continue to build back after disasters and keep reducing vulnerabilities for future disasters
    4. Community understand that building safety and resilience is a long-term and continuous process
    5. Community appreciate that building resilience can help achieve sustainable development

- *CRC/a primer for reducing vulnerabilities to disasters:*

    1. Understanding the impacts of climate change and disaster risk management (DRM)
    2. Explaining climate change impacts and DRM
    3. Assessment exercise: discovering a ‘hotspot’ and create city typology and risk characterization matrix as well as local resilience action plan (LRAP)

4. Information exercise: creating a city information base compiled in climate change impacts and disaster risk management workbook and eventually framework
5. Examining sound practice of adaptation and mitigation to climate change for lessons learnt

- *DCR/core concepts of DRC:*

1. Cultural attitudes must accommodate resilience.
2. Disaster resilience is a philosophy, a process and a condition.
3. Resilience requires an all-hazard approach.
4. Resilience requires an all-vulnerabilities approach.
5. Community requires greater resistance to hazard stresses.
6. Community systems must be flexible.
7. Recovery capacity must be enhanced.
8. Community must develop an adaptive capacity.

3.4 Important Elements of Resilience to Natural Hazards

Three aspects are considered fundamentally important across all frameworks, namely, sustainable development, disaster risk reduction and community development. Resilience is complex and multifaceted, and, therefore, different characteristics of resilience are needed to cope with different kinds and severities of stresses. A multifaceted approach for resilience building is also proposed which states that promoting resilience in various elements is essential to reduce risks, accelerate recovery and adapt to changing conditions. However, resilience building needs to be undertaken in line with community goals.

3.5 A Framework to Evaluate Community Resilience to Urban Floods

Preparing people, property, critical infrastructure resources and the economy to withstand or absorb the impact of an incident and rebound in a manner that sustains their way of life in the aftermath makes their communities and the nation more resilient. Individuals, communities, NGOs, all levels of government and the private sector should consider the long-term economic, health, social and environmental dimensions of their choices and ensure resilience is maintained and improved. Sustainability employs a longer-term approach through plans, policies and actions that reflect a comprehensive understanding of the economic, environmental, social and cultural systems within a community.

A study investigated the differences in community resilience to urban flooding in three types of communities, which can be applied to group decision-making methods in urban flood management. The Fuzzy Delphi and ANP methods were applied to quantitatively identify the interdependence relationships among community resilience indicators and flood-relief strategies. Some major conclusions can be drawn as follows (Zhong et al. 2020):

1. With reference to the investigation results from the study area and experts' suggestions, public facilities (BE1), the spatial structure of land use (BE2), relative management organizations (OI2), vulnerable population (SE1), individual capability (SE2), rescue capability (ST1) and accuracy of weather forecasts (ST2) were identified as indicators of community resilience to urban floods, and the combined effects of resilience indicators were measured. The results support the definition of community resilience to urban floods. Communities are expected to strengthen the public facilities and land structure to defend against urban flood hazards; relative management organization at the local level is required in response to urban floods; scientifically and quickly, neighbours in the community are suggested to improve their self-ability to reduce hazard losses; and the demographic characteristics of the community also influence the recovery from urban floods. All of the indicators affect the enhancement of community resilience to urban floods.
2. In this study, three typical communities were selected, which included a newly built neighbourhood, an ancient college and a flood-prone village in Nanning, China. The neighbourhood (with a total average score of 2.13) had the largest community resilience to urban flood, followed by the college (1.8) and, finally, the village (0.91). The findings of this analysis shed light on the relationship between the type of community and resilience to urban floods. For example, the strength of the built environment and the organization and institute dimension in the neighbourhood community, with a high level of resilience in the science and technology dimension and social-economic status dimension for residents in the neighbourhood, are strong predictors of community resilience. In other words, examining the types of the community could enhance community resilience effectively. Flood management organizations play a leading role in the urban flooding resilience of the neighbourhood and college, while the vulnerable population has a great impact on the community resilience of the village.
3. Results of the strategy analysis indicate that science and technology improvement (0.543) is more important than social-economic status improvement (0.325) and built-environment improvement (0.132) for mitigating urban hazards in Nanning. Science and technology improvement is related to self-rescue ability and the accuracy of weather forecasts, which could ultimately drive the enhancement of the residents' perception of risks and responses to hazards when urban floods occur.

The differences in the three communities demonstrate the different access to resources and variations in the situations when urban flooding occurs. These proposals and ideas may point to future directions for flood risk management at the community scale and indicate effective measures in the various communities to enhance the resilience to urban floods.

3.6 The Hyogo Framework for Action 2005–2015: 'Building the Resilience of Nations and Communities' to Disasters

As mentioned, resilience is defined as a system's ability to absorb change, to self-organize and to bounce back, learn and adapt (Carpenter and Walker 2001). The concept of resilience has been studied, reviewed and adopted in various fields since its early development (Djalante and Thomalla 2011). It is closely associated with concepts of adaptation, vulnerability and adaptive capacity (Gallopı ́n 2006; Smit and Wandel 2006; Miller and Osbahr 2010; Nathan 2011). Its strong relationships with vulnerability and adaptive capacity make the resilience concept very relevant in the field of DRR. Reducing disaster risk is about reducing the underlying causes of risks which are closely related to vulnerability. However, increasing resilience also means looking at what is available and accessible to individuals, households and communities and building on those existing capacities. For this reason, the concept of resilience has been examined and implemented extensively in advancing understandings in the field of humanitarian aid and livelihood improvement (Buckle et al. 2000; Paton and Johnston 2001; IFRC 2004). The concept of resilience received worldwide attention in the DRR field through the adoption of the HFA at the World Conference on Disaster Reduction in 2005 in Japan (IDNDR 1994). The HFA is a 10-year global strategy to make the world safer from natural hazards and provides the first systematic and comprehensive approach to reducing disaster risks and losses. The following text summarizes the strategic goals, priorities for action, indicator of progress, reporting process, key documents and supporting mechanisms of the HFA (Djalante et al. 2012).

- *3 strategic goals*

  More effective integration of disaster risk consideration into sustainable development policies, planning and programming at all levels, with a special emphasis on disaster prevention, mitigation, preparedness and vulnerability reductions

  The development and strengthening of institutions, mechanisms and capacities at all levels, in particular at the community level that can systematically contribute to building resilience to hazards

  The systematic incorporation of risk reduction approaches into the design and implementation of emergency preparedness, response and recovery programme in the reconstruction of affected communities

- *5 priorities for action*

  HFA 1: Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation.

  HFA 2: Identity, assess and monitor disaster risks and enhance early warning.

  HFA 3: Use knowledge, innovation and education to build a culture of safety and resilience at all levels.

  HFA 4: Reduce the underlying risk factors.

HFA 5: Strengthen disaster preparedness for effective response at all levels.

- *22 indicators of progress*

HFA 1: Four indicators (existence of institutional and legal frameworks for DRR; availability of resources; community participation; functioning national platform)
HFA 2: Four indicators (risk assessment and vulnerability information; hazard and vulnerability information system; early warning system; national, regional/transboundary and local risk assessments)
HFA 3: Four indicators (disaster information sharing and dissemination systems; school curricula and educational materials on DRR; research, tools and analysis for risk assessments; public awareness strategy)
HFA 4: Six indicators (DRR as part of development policies and plans; social policies to reduce vulnerabilities; policies that reduce economic vulnerability; inclusion of DRR into built-environment planning; DRR consideration into recovery and reconstructions; risk screening for major development projects)
HFA 5: Four indicators (policy and mechanisms for disaster management; disaster preparedness and contingency plans with training and drills; financial reserves and contingency mechanisms; procedure for information exchange during response and recovery)

- *5 levels of progress*

Level 5: Comprehensive achievement has been attained, with the commitment and capacities to sustain efforts at all levels.
Level 4: Substantial achievement has been attained, but with some recognized deficiencies in commitment, financial resources or operational capacity.
Level 3: There are some commitment and capacities to achieving DRR but progress is not substantial.
Level 2: Achievements have been made but are relatively small or incomplete, and while improvements are planned, the commitment and capacity are limited.
Level 1: Achievements are minor, and there are few signs of planning or forward action to improve the situation.

- *Reporting process*

Progress reports: regional, national and thematic reports and global assessment reports
Monitoring and review: regional HFA monitor, national HFA monitor, local HFA monitor and HFA midterm review

- *Selected key documents*

Words into action: a guide to implementing the HFA (UNISDR 2011)
Indicators of progress: guidance on measuring the reduction of disaster risks and the implementation of the HFA (UNISDR 2008)
Guidelines: national platforms for disaster risk reduction (UNISDR 2007)

- *Supporting UNISDR systems*

  Partners: governments, United Nations system, regional bodies, international financial institutions and non-governmental actors

  Mechanisms: global platform for disaster risk reduction, national platforms, regional platforms, thematic platforms, ISDR support group, ISDR system, management oversight board, inter-agency group, scientific and technical committee and secretariat

4 Disaster Risk Management and Disaster Risk Reduction

The United Nations Office for Disaster Risk Reduction (UNISDR) states that the term ‘disaster management’ encompasses several activities of organization, planning and application that address measures for preparing, responding to and recovering from disasters (UNISDR 2016). Disaster management focuses on implementing strategies that may not lead to eliminating the risk of disasters.

This topic was debated as early as 1961, as cited by Kroll-Smith and Couch, identifying the physical factors of disaster. On the contrary, they suggested the social norms of disasters in relation to the demand of action and capability of response beyond geophysical terms (Kroll-Smith and Couch 1991). The UNISDR defined disaster as ‘a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts’. Disasters’ social and physical scopes are considered, with focus on the scale of impact. This is recognized in the differentiation between emergency response and recovery actions (UNISDR 2016).

Emergency management was first initiated during the First World War in 1935, following the bombing of civilian areas, and the establishment of the Civil Defence Service by the Home Office of the United Kingdom. With focus on protecting the population against nuclear destruction, a shift towards protection against natural hazards such as floods, storms and earthquakes arose by the end of the Cold War.

In the early 1960s, the United Nations General Assembly (GA) started adopting measures regarding severe disasters, to inform the secretary-general of the type of emergency they are in the position to offer. This came into effect following the Buyin-Zara earthquake which struck Iran and killed more than 12,000 people. This is followed by the creation of the United Nations Disaster Relief Office (UNDRO), to promote the study, prevention, control and prediction of natural disasters and assist in providing advice to governments on pre-disaster planning. The period 1990–1999 is considered ‘the International Decade for Natural Disaster Reduction’, where the GA recognizes the importance of reducing the impact of natural disasters for all people with a focus on developing countries. This was endorsed by the Yokohama Strategy and Plan of Action at the World Conference on Disaster Reduction, which was held at Yokohama, Japan, from 23 to 27 May 1994 (UNISDR 2016).

The third millennium witnessed the international community movement towards early warning to take timely actions in advance of hazardous events. This was triggered with El Niño phenomenon's acute impact, and climatic changes affecting the equatorial Pacific region and beyond, aimed to review the Yokohama Strategy, identify gaps and challenges. The early warning system movement was consolidated with the establishment of the International Strategy for Disaster Reduction (ISDR) and emphasis on shift from disaster risk management (DRM, to disaster risk reduction (DRR), with efforts to integrate the Johannesburg Plan of Action agreed at the World Summit on Sustainable Development (WSSD).

The ISDR endorsed the Hyogo Framework for Action (HFA) 2005–2015: *building the resilience of nations and communities to disasters*, adopted by the World Conference on Disaster Reduction held at Kobe, Hyogo, Japan, to facilitate disaster reduction strategy into national plans. Focusing on the reduction of disaster losses, Priority for Action 4 of the HFA calls to 'reduce the underlying risk factors' (UNISDR 2015a).

Since 2007, 146 governments have participated in at least 1 cycle of the HFA review using the online HFA monitor.

In 2011–2013, 136 countries submitted reports, and governments have reported growing levels of HFA implementation over time. Nevertheless, HFA monitoring mechanism focused on reporting data losses from large-scale intensive disaster (e.g. earthquakes and cyclones) and overlooked the underlying risks of mortality, physical damage and economic losses from small-scale extensive disasters (e.g. floods, landslides) derived by poor urban governance and planning (Fig. 5.1). These notions have been elaborated by Dodman et al. (2009), in the light of scale, frequency and impact, divided into biological, chemical and physical hazards. Thus, the notion of risk is identified here, to understand the impact of reporting mechanisms on global targets and risk measuring mechanisms for disaster risk management.

Recognized in two settings, acceptable risk and residual risk, for DRM, acceptable risk is associated with single risk 'used to assess and define the structural and non-structural measures that are needed in order to reduce possible harm to people, property, services and systems' (UNISDR 2016). On the contrary, residual risk is

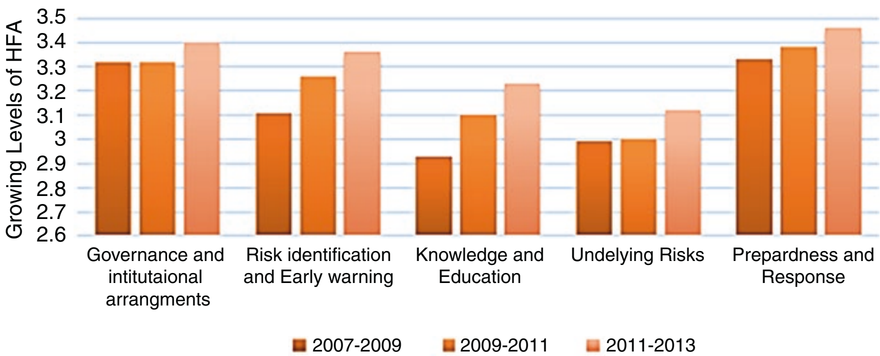

Fig. 5.1 Progress in implementing the HFA 2007–2013 (Etinay et al. 2018)

associated with DRR sequential risks ‘that remains even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained’ (UNISDR 2016).

An evolution from managing disasters to managing risks was affiliated with the launch of the Sendai Framework for Disaster Risk Reduction (SFDRR). Evidence from the 2015 Global Assessment Report on Disaster Risk Reduction recognizes that ‘most resources continue to be invested in strengthening capacities for disaster management, and there has been limited success in applying policies, norms, standards and regulations to manage and reduce risk across development sectors’ (UNISDR 2015a, b). This articulates the importance of differentiation between DRR and DRM tools and mechanisms to address the underlying risk drivers, not tendencies to mitigate challenges in post-disaster recovery only.

5 An Integrated Approach to Manage Health Risks and Build Resilience

Strengthening health systems, implementing the and developing multi-hazard disaster risk management strategies – together with increased attention to climate change adaptation – are good examples of progress made to improve management of the health risks associated with hazardous events. Nevertheless, many communities, subpopulations and countries remain highly vulnerable to emergencies and disasters. The ability to achieve optimal health outcomes related to emergencies has been hindered by fragmented approaches to different types of hazards, by overemphasis on reacting to rather than preventing and preparing for events and by gaps in coordination across the entire health system and between health and other sectors. In view of current and emerging risks to public health and the need for more effective coordination, utilization and management of resources, there is a need to consolidate contemporary approaches and practice through the conceptual framework or paradigm of ‘health emergency and disaster risk management’ (WHO 2019).

6 Summary and Conclusions

Natural hazards are expected to increase in frequency and magnitude, bringing increased risk of loss. As depicted in the above analysis, assessment of disaster resilience summarizes the status of resilience within a community. However, resilience assessment is only one part of a wider field of disaster resilience, and further research is needed in many areas, including the empirical relationships between the potential resilience of a community derived from indexes and actual resilience measured following a natural hazard event. Given the complexity of social interactions with natural hazards (Wisner et al. 2004), policymakers, emergency management agencies, researchers and the public will need to work together as a community of practice in many aspects of operationalizing ideas of disaster resilience, including in the area of assessing disaster resilience.

As assessments of disaster resilience continue to develop worldwide, reporting of their design as standard practice will track knowledge generation in the field and enhance the relationship between applied disaster resilience assessment and foundational principles of disaster resilience.

For example, the indicators listed in Fig. 5.2 under vulnerability, risk perception and resilience have been tested in an earthquake-prone area of Balochistan that

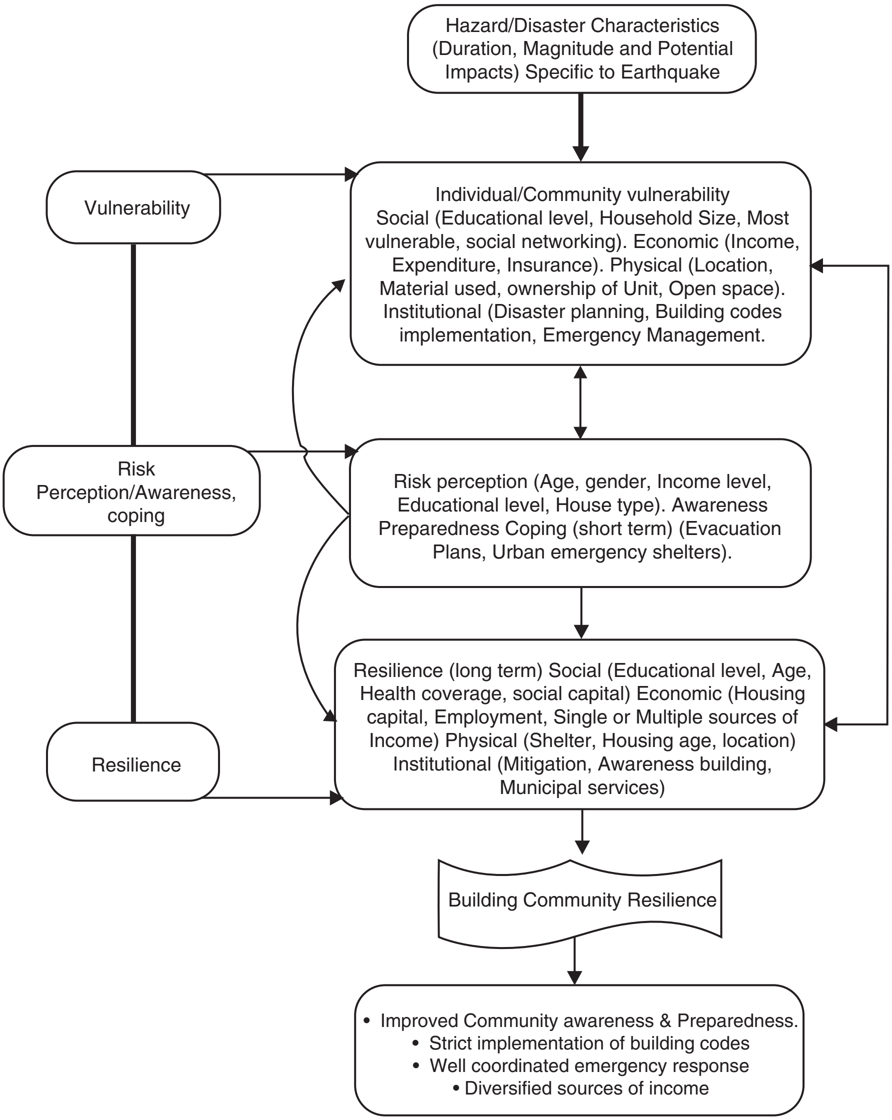

Fig. 5.2 Proposed community resilience framework (Ainuddin and Kumar Routray 2012)

revealed the community is extremely vulnerable to the future impacts of earthquakes. This form was proposed by Ainuddin and Kumar Routray (2012).

It was reflected that poor awareness and preparedness and poor resilience may exacerbate the community vulnerability to a considerable level. Based on the above analysis on vulnerability, risk perception and resilience, the paper proposes a community resilience framework for Balochistan in order to upgrade community preparedness and awareness to earthquake hazards and disasters.

The framework also recommends improved awareness and preparedness, diversified sources of income, implementation of building codes and well-coordinated emergency response to minimize disaster impacts and enhance the community coping and quick recovery from earthquake hazards in the future. This particular framework can also be applied in communities with identical situations and prone to disaster and hazards.

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Chapter 6
A New Framework for a Resilience-Based Disaster Risk Management

Adriana Galderisi and Deniz Altay-Kaya

Abstract This chapter aims at providing hints to improve existing frameworks for disaster risk management based on a review of the main documents framing disaster management within the last two and a half decades and with reference to the potential contribution of resilience thinking. The evolution path of disaster risk management shows that, although some progresses have been made, there are still numerous gaps to be filled. On the opposite, focusing on the increasing convergence of resilience and disaster studies, it emerges that a resilience-based approach could still provide significant theoretical and operational inputs towards an improved disaster risk management. In particular, this chapter emphasizes the potential contribution of resilience thinking in developing a new framework for guiding disaster risk management capable of (1) taking into consideration the rapidly changing risk landscapes due to the interplay between climate change and the consequent increase of hazardous events, urbanization patterns and the complex interrelationships among them; (2) shifting from sectoral approaches to disaster risk reduction (DRR) towards integrated approaches and cross-sectoral strategies and tools; (3) embracing transformational perspectives to significantly reduce disaster losses and achieve sustainability goals; (4) improving learning capacity through the setting up of continual learning processes; (5) emphasizing the role of spatial and land use planning for DRR; and (6) developing more innovative governance models based on collaboration, shared responsibility and active engagement of the stakeholders.

Keywords Disaster cycle · Disaster risk management · Risk reduction · Policies · Strategies · Resilience

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1 Introduction: Disaster and Disaster Risk

The definition of the term disaster has gained new meanings since the late 1990s, with reference to the amount of occurred losses (referring either to the loss of human lives or to economic losses), to their geographical extension, or, even, to the capacity of the affected communities to cope with their consequences without external assistance (Al Dahash et al. 2016). The UN Office for Disaster Risk Reduction (UNDRR), previously known as UNISDR, has significantly widened the definition of the term disaster in the last decade. In 2009, indeed, this term was intended as "a serious disruption of the functioning of a community or a society involving widespread human, material, or environmental losses and impacts which exceeds the ability of the affected community to cope using only its own resources" (UNISDR 2009). Then, in the 2016 update of the terminology related to disaster risk reduction (DRR), disaster has been defined as a "serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts" (UN 2016).

According to this update, the term is referred to different geographical and temporal scales (from small to large and from slow to sudden onset), as well as to different frequencies of occurrence (frequent and rare events), and no thresholds in terms of relevance of impacts and losses or of resources needed to face the event are currently established. Moreover, the provided definition of disaster sheds light on its dependency on the interactions among hazardous events, exposure and vulnerability features of the hit area, as well as on the response capacity of the affected communities to cope with the event and its negative consequences.

However, this contribution will mostly refer to the concept of disaster risk; but, what is the difference between disaster and disaster risk? The main, and probably the most relevant one, is that the term disaster refers, indeed, to the outcomes of an occurred hazardous event, that is, to something that has already occurred; while disaster risk refers to the potential, to what could occur in the future, and it is defined as "the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity" (UN 2016). Based on this definition, disaster risk management is here interpreted as the whole set of actions and measures – to be performed before and after the impact of a given hazard – that characterize the so-called disaster cycle (Alexander 2002). These activities are generally addressed to preventively reduce risks and to ensure a prompt response and an effective recovery and reconstruction following a hazardous event. However, it is worth underlining that the different phases of the disaster cycle are closely connected to each other, since post-event activities are more and more oriented both to cope with and recover from the impact of the occurred hazardous event, and to lay the foundations to reduce the impacts of future events (Dalezios et al. 2017).

Furthermore, despite the common usage of the notion of natural disasters since the 1990s both in literature (see Alexander 1993; Davis 2008; Hallegatte 2016) and in international documents (see, e.g. the outcome document of the World Conference on Natural Disaster Reduction held in 1994 in Yokohama), here the term "natural" is exclusively related to hazards. The latter can be, indeed, correctly defined as natural or human-made, although this distinction can be sometimes blurred; whereas disasters or risks, being interpreted as a result of hazardous events, exposure, vulnerability and response capacity, should be always defined as human-made, even in case the triggering hazard is a natural event, like an earthquake or a volcanic event. According to numerous scholars (Burton 2005; Peduzzi 2019), indeed, the term "natural disasters" reflects the historical and nowadays largely outdated idea that these events represent acts of nature.

Once the basic concepts have been clarified, it seems useful to remind some data on disasters occurred all over the world in the past two decades. Based on the data provided by the International Disaster Data (EMDAT-CRED), the total number of disasters[1] due to natural and climate-related hazards that occurred in the last two decades has increased overall, experiencing significant peaks in the first half of the 2000s and a fluctuating trend over the last decade (see Fig. 6.1). In particular, floods and storms show the highest values in terms of number of events, with a peak of flood events in the mid-2000s. Unfortunately, available disasters data do not consider other climate-related phenomena, like drought, so far largely neglected due to their creeping nature, even though they are already inducing in some areas relevant economic, social and environmental impacts (Dalezios et al. 2017).

In respect to the relationship between geophysical events and climate-related ones, available data for the temporal span 1998–2017 highlight the prevailing number of climate-related events, being the number of geophysical ones more or less constant along the considered temporal span. In detail, they confirm that floods and storms correspond to more than the 70% of the total amount of disasters, whereas earthquakes represent only the 7.8% (Guha-Sapir 2018). This relationship is reversed when shifting from the number of events to their consequences in terms of human lives: in the period 1998–2017, total deaths due to earthquakes correspond to 56% of the total. On the opposite, reported damage due to storms (46%), in terms of economic losses, is double in comparison to those due both to floods and earthquakes, which together represent the 23% of the total amount (Guha-Sapir 2018).

It is worth emphasizing the unequal geographical distribution of induced damage too: while in respect to geophysical disasters Asia accounts for the majority of all recorded impacts, indeed, the impacts of climate-related disasters show a more balanced distribution, with a significant percentage of fatalities and economic losses also in Europe. Moreover, reminding the idea that disasters depend on hazardous events interacting with exposure, vulnerability and response capacity of the hit

[1] The EM-DAT International database classifies a disaster according to the following criteria: number of deaths (10 or more people); number of affected people (100 or more people affected/injured/homeless); and declaration by the country of a state of emergency and/or an appeal for international assistance.

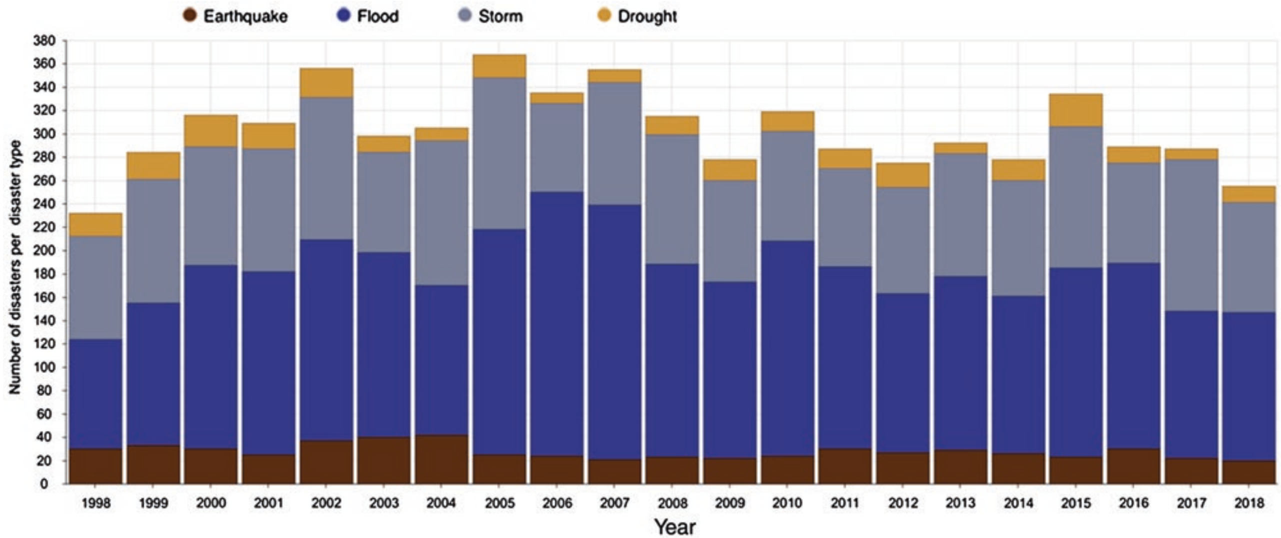

Fig. 6.1 Total number of disasters due to natural and climate-related hazards in the period 1998–2018. (Source: EM-DAT – The Emergency Events Data Base, https://www.emdat.be/emdat_db/)

communities, it is also useful to highlight that damage shows a very different distribution in respect to socio-economic features of countries' population. In particular, available data show that low and lower-middle income countries experienced the 43% of all major recorded disasters in the past 20 years but the greatest proportion (69%) of fatalities. On the opposite, high and upper-middle income countries, although experiencing an even higher number of events, show a limited number of fatalities (31%) while recording the highest percentage of economic losses (Guha-Sapir 2018).

Based on the provided definitions and on the brief overview on disasters that occurred in the last two decades all over the world, in the following paragraphs, the evolution path of policies and strategies addressing disaster risk management during the last two decades will be described based on an overview of three major international frameworks: the Yokohama Strategy, the Hyogo Framework for Action and the Sendai Framework for Disaster Risk Reduction. In detail, the contribution aims at shedding light on the main steps forward that have been made so far as well as on the still open issues; then, based on the key role played by the resilience thinking, some hints for outlining a new framework for guiding disaster risk management will be provided. However, this study shows also some limitations, related to the prevailing focus on the principles outlined by the major international frameworks for DRR, with a limited attention to the numerous problems arising from their implementation, as well as to the lack of an in-depth analysis of the obstacles and barriers that could be encountered in translating into practice the suggested key principles for a resilience-based disaster risk management.

2 Disaster Risk Management: The Evolution Path

The evolution path of policies and strategies aimed at improving disaster risk management at international level can be traced back to the 1970s, with the establishment of a permanent office in the United Nations focused on disaster relief (United Nations Disaster Relief Office – UNDRO) and the provision of advices to national governments on pre-disaster planning. A significant change of pace in this field occurred in the 1990s, following the decision adopted by the General Assembly to designate the 1990s as the International Decade for Natural Disaster Reduction, in order to foster international cooperation in the field of natural disaster reduction.

Hence, starting from the 1990s and aiming at better understanding how disaster risk management policies and strategies have been so far improved, three milestones will be in-depth analysed:

– The Yokohama Strategy for a safer world, established in 1994 within the framework of the International Decade for Natural Disaster Reduction
– The Hyogo Framework for Action (HFA) 2005–2015: Building the Resilience of Nations and Communities to Disasters
– The Sendai Framework for Disaster Risk Reduction 2015–2030

Referring to policies as sets of key principles that guide decision-making at different scales according to a long-term perspective, and to strategies as sets of actions, which address specific goals within a given time horizon; the three mentioned documents have to be interpreted as key references for disaster risk management both in terms of policies and of strategies, since all of them include key principles, goals, priority areas for intervention and sets of actions. In detail, the Yokohama Strategy, following the declaration of the 1990s as International Decade for Natural Disaster Reduction, represented a key step to bring the issue of DRR to international attention; it provided both the key principles for achieving DRR goals and a plan aimed at translating these principles into actions. The Hyogo Framework, building on the outcomes of the International Decade for Natural Disaster Reduction, recalled and extended the principles set by the Yokohama Document; it emphasized the need for a more effective DRR strategy in order to achieve a significant reduction in disaster losses and established five priority areas and related key activities to be undertaken at different levels. The latest document, the Sendai Framework, being aware of the increasing complexity and interdependency of global challenges (from demographic change to rapid urbanization, from climate change to the decay of natural ecosystems, etc.) and looking at DRR as a cross-cutting issue for sustainable development, enlarges both the guiding principles and the scope of the HFA and underlines the need for implementation and follow-up of the defined actions.

The in-depth analysis of the three mentioned documents clearly reveals the progress that has been made in different matters over the last three decades but also the still open issues in the field of DRR. Based on the vast literature that provides general or thematic reviews of the three mentioned documents (see Tiernan et al. 2019; Tozier de la Poterie and Baudoin 2015; Aitsi-Selmi et al. 2015), some key issues will be here investigated, shedding light both on the steps forward and on the increasing complexity that disaster risk management policies and strategies have to cope with.

First of all, the scope of disaster risk management policies has been progressively widened along the last three decades: while the Yokohama Strategy was mostly focused, indeed, on the need of promoting a widespread culture of prevention, clearly stating that the mere improvement of disaster response policies was insufficient, the Hyogo Framework showed a more ambitious scope, aiming at a substantial reduction of disaster losses, both in terms of human lives and in terms of social, economic and environmental assets of communities and countries. Finally, the Sendai Framework has further enlarged its scope, putting emphasis on the implementation phase: it provides, in fact, seven global targets to be measured through adequate indicators, in order to evaluate the progresses towards the expected goals.

Another important issue is related to the considered types of risks: the Yokohama Strategy was mostly focused on natural hazards, although mentioning the need for enlarging the focus of DRR from natural to environmental and technological hazards and their relationships (Na-Techs); 10 years later, the Hyogo Framework broadened the focus to climate-related risks, underlining the need of a better integration between DRR and climate change adaptation (CCA). This need has been further emphasized by the Sendai Framework, which focuses on “small-scale and large-scale, frequent and infrequent, sudden and slow-onset disasters caused by natural or human-made hazards, as well as related environmental, technological and biological hazards and risks” (UN 2015). It is worth noting that while the Yokohama Strategy clearly referred to the importance of taking into account the interdependencies among different hazards, with a particular reference to Na-Tech events, this issue disappeared in the most recent documents, with the exception of a limited reference to the possible sequential effects of hazards in the Sendai Framework.

All the three documents emphasize the relevance of the different phases of the disaster cycle, although the priority assigned to each phase seems to change from one document to another. More specifically, the Yokohama Strategy contributed to shift the international attention from disaster management (including response in the immediate aftermath of the event and the following phases of recovery and reconstruction) towards the actions to be undertaken before the event and, namely, those actions related to prevention, mitigation and preparedness, with an operational focus on the latter. Such a focus characterized also the Hyogo Framework, aimed to enhance early warning systems and strengthen disaster preparedness, although both prevention and post-disaster recovery were considered. The Sendai Framework highlights the close interdependency among the different phases: it assigns a key role to risk knowledge and assessment, which is crucial to all the phases of the disaster cycle, emphasizes the importance of prevention, mitigation and preparedness also to improve the effectiveness of response, recovery and reconstruction, and introduces the Building Back Better (BBB) principle to drive post-disaster activities towards the reduction of future risks.

An issue that deserves to be further discussed is the growing integration among DRR and sustainable development and, more recently, climate strategies: as remarked by White et al. (2001), indeed, “natural hazard problem is deeply embedded in the larger question of sustainable development, and the specific issues of reducing poverty, improving governance, increasing equity, and limiting climate change with its threat of increased extreme events”. The close relationships between disaster losses, poverty, environmental degradation and sustainable development were already envisaged by the Yokohama Strategy that explicitly recognized the key role of sustainable development in reducing vulnerability of the most affected groups and recommended the inclusion of the outcomes of the World Conference on Natural Disaster Reduction in the provisional agenda of the Assembly on Environment and Sustainable Development (UN 1994). This close relationship between DRR and sustainable development was further stressed by the Hyogo Framework: the latter identified, indeed, sustainable development, poverty reduction, good governance and disaster risk reduction as mutually supportive objectives, looking at disaster risk reduction as a cross-cutting issue in the framework of sustainable development. Moreover, one of its strategic goals was a “more effective integration of disaster risk considerations into sustainable development policies, planning and programming at all levels, with a special emphasis on disaster prevention, mitigation, preparedness and vulnerability reduction” as well as “the integration of disaster risk reduction as an intrinsic element of the United Nations Decade of Education for Sustainable Development 2005–2015" (UNISDR 2005). It is worth reminding that the Hyogo Framework closely followed the Johannesburg Declaration on Sustainable Development that recognized natural disasters as one of the numerous conditions posing severe threats to sustainable development (art. 19) (World Summit on Sustainable Development 2002). Nevertheless, it is only in the first decade of the 2000s, thanks to the outcome document of the United Nations Conference on Sustainable Development, held in in Rio de Janeiro in 2012, "The future we want" (UN 2012), and to the Sendai Framework, that DRR and climate risks became crucial components of the sustainable development discourse. The Rio Document, in fact, underlined the importance of considering DRR, resilience and climate risks in urban planning, devoting large room both to DRR and to climate change, seen as key challenges to be faced in the context of sustainable development. Two years later, the Sendai Framework explicitly recalled these principles and identified climate change as one of the drivers of climate risks. Hence, it is only in the last decade that the importance of looking at climate change into the wider framework of the DRR, placing the latter as "a subset of wider development and sustainability processes" (Kelman et al. 2015), has been stressed and progressively recognized at a global scale. Hence, the integration process briefly described above, albeit quite slow, has been crucial in bringing the issue of DRR out of the technical domain in which it has been for long confined, leading to its recognition as a strategic objective, transversal to all development policies at different scales.

The recognition of disaster risk reduction as a cross-cutting issue, to be taken into account into all development policies, paves the way to another important issue: the shift from a top-down and sectoral approach towards inclusive risk governance processes open to different stakeholders, including local communities. This aspect was already emphasized in the Yokohama Strategy, which recognized the key role of capacity-building activities in order to promote an active engagement of local communities, as well as the constructive role of media in achieving disaster risk reduction goals. However, risk governance issues were still mentioned as a crucial challenge in the Hyogo Framework that, again, emphasized the need for strengthening "institutions, mechanisms and capacities at all levels, in particular at the community level". In respect to the Yokohama Strategy, the Hyogo Framework assigned a key role to local authorities and communities, which had to be empowered through a better access to information and resources. Moreover, since it considered disaster risk as a cross-cutting issue that requires multisectoral and interdisciplinary approaches, it strongly emphasized the need of building up "multi sectoral national platforms, with designated responsibilities at the national through to the local levels to facilitate coordination across sectors" (UNISDR 2005). Ten years later the Sendai Framework identifies the strengthening of disaster risk governance as one of its key priorities (Priority 2), highlighting the relevance of an effective disaster risk governance for all the phases of disaster cycle at the national, regional and global levels, together with the need of "clear vision, plans, competence, guidance and coordination within and across sectors, as well as participation of relevant stakeholders" (UN 2015). The document recognizes the importance of "collaboration and partnership across mechanisms and institutions for the implementation of instruments relevant to disaster risk reduction and sustainable development" (UN 2015) and includes for the first time a section specifically devoted to the role of stakeholders. In this section, the responsibility of understanding and reducing disaster risk is considered as a shared one between governments and all relevant, public and private, stakeholders. Hence, civil society, volunteers, community-based organizations, academia and scientific and research bodies, business and private sector financial institutions and media should actively participate in the different phases of the decision-making process, so as to ensure both a better understanding of risks through the integration of scientific/expert knowledge with the experiential/local one (Galderisi 2018) and the development and implementation of normative frameworks, standards and plans for disaster risk reduction.

Finally, the evolution of two core concepts in the field of DRR and CCA, vulnerability and resilience, has to be deepened. The vulnerability concept, although mentioned also in the Yokohama Strategy, was firstly defined in the Hyogo Framework. The latter referred to vulnerability as "the conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards". Such a definition was then widened and refined by the UNISDR glossary on DRR (2009), which defined vulnerability as "the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard". This definition clearly recognized vulnerability as an intrinsic feature of all the exposed elements, being them communities, systems or assets, and took into account the heterogeneous facets of vulnerability as well as the numerous factors they depend on (e.g. the poor design and construction of buildings, the lack of public information, the disregard for wise environmental management, etc.). What has to be noted is that the Sendai Framework – despite emphasizing the need of understanding risk in all its components, including hazard, exposure and vulnerability – does not provide an updated definition of the term, explicitly referring to the definition of vulnerability already included in the Hyogo Framework and neglecting the large scientific debate on the vulnerability concept carried out in the late 2000s (Menoni et al. 2012; Birkmann et al. 2013).

The resilience concept was just mentioned in the Yokohama Strategy that made reference to the need of strengthening the resilience and self-confidence of local communities to cope with natural disasters through recognition and propagation of their traditional knowledge, practices and values as part of development activities. However, a first definition of this concept was provided by the Hyogo Framework, which referred to resilience as "the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures" (UNISDR 2005). The concept was then revised by the Sendai Framework that defined resilience, according to UNISDR (2009), as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions". This definition embraced the most widespread approach to resilience in the disaster field, the engineering approach, referred to the capacity of a system to "bounce back" after disturbances (Holling 1996). However, during the last decade, the initial goal of resilience studies progressively shifted from the idea of improving elements and systems' capacity to bounce back, by recovering the previous equilibrium state following a crisis, towards a "bounce forward" perspective (Manyena et al. 2011), which includes both the strengthening of systems' essential structures and functions and the improvement of their ability to anticipate in order to better drive complex adaptive systems towards new equilibrium states. Hence, grounding on the significant scientific advances, the definition of resilience has been recently officially revised, by including the crucial processes of adaptation and transformation, and it is currently interpreted as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (UN 2016).

Summing up, starting from the 1994, numerous steps forward along the path towards a better understanding of risks and an improved capacity to cope with them have been made, although numerous questions are still open, and much has still to be done. Among the main progresses, the shift from disaster-driven to proactive policies, mostly focused on risk prevention and mitigation; the widespread recognition of risk as social construct arising from interactions among hazard factors and the exposure, vulnerability and coping capacity of human societies and built environment; the shift from a top-down risk governance model towards more inclusive and participatory models, aimed at engaging all the relevant stakeholders in the different phases of the disaster cycle; and the shift from sectoral risk policies and strategies towards a wider recognition of disaster risk reduction and climate risks as crucial components of sustainable development processes.

Among the still open questions, it has to be mentioned the lack of a clear, and updated to the latest outcomes of the scientific debate, definition of the core concepts of vulnerability and resilience, as well as of their interrelationships, which is crucial to further advance in understanding risks and consequently to outline effective risk reduction strategies. For example, both resilience theory and practice continuously develop a large body of knowledge and practical experience which could significantly contribute to such an advance. Moreover, even though the Sendai Framework has largely widened the definition of disasters, all the analysed frameworks devote a limited attention to the complex and still too often unexpected chains of primary and secondary hazardous events and related impacts, against which communities and institutions are generally unprepared to promptly and effectively react, which result in a considerable increase both in the overall damage and in costs and time for post-event recovery. Finally, it is worth stressing that, although DRR has been recognized as a cross-cutting issue to all development policies, and even though land use planning is more and more widely interpreted as a policy area with leverage in both DRR and CCA, the analysed frameworks still pay a limited attention to the key role of land use planning and, namely, to its potential for favouring the shift from engineering-based measures to prevent and mitigate hazards towards multi-objective measures capable, for example, of improving green and blue infrastructures and increasing, in so doing, the quality of both human settlements and natural environment.

3 Resilience: Is It a Useful Concept to Shape Disaster Risk Management?

Throughout the evolution of disaster risk reduction and disaster management policies and strategies at an international level, from the Yokohoma Strategy (UN 1994) to the Sendai Framework (UN 2015), the increasing relevance of the resilience concept in disaster risk management has been briefly highlighted. As mentioned above, both the Hyogo and the Sendai frameworks interpret resilience as a core concept that significantly shapes their goals and priorities.

The Hyogo Framework introduced resilience in its title – “Building the Resilience of Nations and Communities to Disasters” – assuming the concept as an overarching objective of disaster risk reduction, crucial to setting up both priorities for action and strategic goals. This framework identified resilience as a key concept for improving disaster management and minimizing the negative consequences of disasters. In the Sendai Framework, the concept of resilience was removed from the title; however, it was still considered as a key for disaster risk management and explicitly referred to in targets and priorities for action.

However, both frameworks embrace an idea of resilience as an overarching goal to be addressed while refer to vulnerability analysis and assessment as operational tools supporting the provision of effective measures for enhancing cities’ resilience (Fekete et al. 2014). Hence, they neither mirror the most recent advances in scientific literature on resilience nor the numerous attempts to operationalize it. Resilience can be defined, in fact, as a concept that has constantly evolved and been specified since the 1970s. Its definition, contents and dimensions are taking shape as new theoretical discourses and empirical analyses are added to the literature.

Before its application to the field of disaster management, resilience was introduced in the field of ecology by Holling (1973) to explain change in ecological systems. However, the seminal work of Holling (1996), which gave direction to all the following resilience studies, introduced the conceptualization of “ecological resilience” as opposed to “engineering resilience”. This represented the shift from the idea of “maintaining stability” to that one of “managing change” when systems undergo disturbances (Folke 2006). Therefore, he underlined that there is no single equilibrium state for a system but different opportunities: to absorb disturbances, when they are below a certain threshold, by maintaining their own characteristics and structure; or to shift, when disturbances exceed the threshold, towards a different state, not necessarily better than the previous one. Both engineering and ecological resilience could lead to undesirable states: the first one emphasizes stability, by focusing on the capacity of a system to "bounce back" after disturbances into the previous state that is not necessarily a desirable one; the second one, despite emphasizing change by referring to the capacity of systems to shift from a state to another one, does not ensure that the new state is better than the previous one.

Then, a turning point that led to put further emphasis on change was the widening up of systems' definition to include coupled socioecological systems (SESs) (Berkes and Folke 1998), as cities are currently considered (Grove 2009). The focus on SESs was the result of a cross-fertilization between the ecological studies on resilience and those developed in the late 1990s in the domain of social sciences: these studies, building on the conceptualizations of ecological resilience, provided an idea of resilience as a dynamic process, based on the continual learning that is typical of human systems (Cutter et al. 2008).

In relation to natural disasters as well as to other chronic or unexpected shocks and stresses (e.g. economic crises, forced migrations, etc.), the focus on SESs led emphasizing adaptive capacity, transformability, learning capacity and innovation as key attributes of resilient systems (Berkes and Ross 2013; Lu and Stead 2013; Taşan-Kok et al. 2013): based on these capacities, those systems are able to reorganize, adjust or even transform themselves towards improved conditions (Béné et al. 2012).

Thus, nowadays resilience of SESs is more and more widely intended as a system's ability to cope with uncertainty, absorb disturbances and undergo and adapt to change without losing its structure, continuing functioning, and learning from past and present experiences of its own or other systems while keeping options for development or transformation open (Adger 2000; Altay Kaya 2019; Baud and Hordijk 2009; Lu and Stead 2013; Walker et al. 2004).

In sum, the definition of resilience has become as complex and multidimensional as cities, societies and the current context in which they are situated, moving from a bouncing back or at most an optimization-based perspective, proper to the engineering resilience, towards a bouncing forward perspective emphasizing the "evolutionary" capacity of living systems, which continuously adapt through incremental adjustments (adaptability) or innovate themselves (transformability) in the face of a changing environment.

Shifting the focus towards the potential contribution of resilience thinking to the disaster risk management, it has firstly to be noticed that natural hazards and disasters have become one of the most studied issues in resilience literature in the last two decades, with an increasing number of theoretical and empirical studies focused on the interactions between vulnerability and disaster risk reduction (Klein et al. 2003), on the relationships between resilience and vulnerability (Manyena 2006; Galderisi et al. 2011; Alexander 2013), and on the attributes that allow cities' and societies' to better face disasters and prolonged crises (Galderisi 2014; Asadzadeh et al. 2017).

The increasing convergence of resilience and disaster studies led to building up a significant mutual knowledge. On the side of disaster studies, resilience has been more and more intended as the overarching goal of disaster risk reduction policies, leading to emphasize the idea of "building back better" that embraces the capacity to continuously learn in order to move towards improved conditions, which is proper to resilient systems. On the side of resilience thinking, the in-depth analysis of occurred disasters and the experience on how they have been managed brought up valuable information on drivers and indicators of resilience. For instance, the analysis of the reasons behind the growing impacts and losses due to hazardous events as well as of the failures or successes of authorities and societies in coping with them significantly advanced resilience studies.

Other relevant inputs to the building up of such mutual knowledge arise from the increasing development of resilience strategies and plans. Planning for resilient cities and communities against disaster risks or other crises has recently become the most accepted approach in the field of planning too, allowing for discussions whether resilience planning is going to become the new planning paradigm (Eraydın and Taşan-Kok 2013). International networks, such as ICLEI (Local Governments for Sustainability), and initiatives as the campaigns Making Cities Resilient, launched by the UNDRR (United Nations for Disaster Risk Reduction), or the 100 Resilient Cities, launched by the Rockefeller Foundation, have largely contributed in the last decade to promoting and guiding resilience strategies and plans in the face of a wide range of stresses and shocks, including natural disasters. The latter allowed numerous advances in the operationalization of resilience, by providing local authorities with principles, tools and procedures capable to guide them through the process of resilience building (Galderisi 2018).

Hence, in the last decades, resilience and disaster studies and practices have developed hand in hand, although current frameworks guiding disaster risk management do not fully reflect the significant theoretical and operational advances so far achieved in the field of resilience studies and practices. Nevertheless, it is possible to identify at least three main reasons why resilience is currently considered crucial in shaping disaster risk management policy frameworks.

Firstly, enhancing resilience is now stated as the key goal of disaster risk management policies. The building up of resilient cities or communities, prepared for disturbances in terms of knowledge, perception, plans and actions, and capable of resisting, absorbing, accommodating, adapting to, transforming and recovering from hazards' effects in a timely and efficient manner, is nowadays interpreted as crucial for achieving the primary aim of these policies: to reduce disasters' losses and damage.

Secondly, it is widely recognized that a resilience-based approach provides more durable and long-term solutions for communities in the face of disasters. Resilience is nowadays largely interpreted as a set of networked capacities (Norris et al. 2008; Galderisi 2014), requiring all involved actors (individuals, communities, institutions, etc.) to improve resources, assets, abilities and capacities enabling them to better deal with crises and change and, above all, to constantly improve their learning capacity. Accordingly, policies aimed at enhancing resilience are largely built upon "capacity building" (Magis 2010), allowing different actors developing multiple and heterogeneous capacities to better cope with expected shocks and stresses and to prepare for unexpected changes (Cretney and Bond 2014). Availability of diversified livelihoods, for instance, is interpreted as one of the main measures for improving individual or household resilience (Adger 2000; Coulthard 2012; Marschke and Berkes 2006) and is accepted as constitutive of their adaptive capacity. Hence, capacity building is crucial in order to move away from a fragile dependency on emergency and short-term relief aid (Davoudi et al. 2012) and to empower, rather, local institutions and communities ensuring a "continual learning" process capable of providing continuity to disaster risk management policies and strategies on a long-term perspective.

Thirdly, resilience provides valuable inputs for the implementation of disaster management and risk reduction policies. The Sendai Framework highlighted the persisting gap in ensuring adequate means of implementation in the Hyogo Framework and put strong emphasis on the need for an action-oriented framework as well as a need for assessing technical, financial and administrative disaster risk management capacity at local and national levels. The ongoing resilience practices and the recent literature on resilience planning also give importance to the issue of operationalizing resilience policies into actions (Altay Kaya 2019; Foster 2007; Lu and Stead 2013). Effective management and coordination, leadership, cooperation, coherence across regulatory frameworks, integration of different actors and institutions, inclusiveness and engaged governance are mentioned as important factors within the implementation process (Lebel et al. 2006; Maclean et al. 2014; Ross et al. 2010).

4 Key Principles for a Resilience-Based Disaster Risk Management

A "new" framework for improving current disaster risk management practices should be able to respond to the changing and multiplying factors and processes that cause disasters today. As remarked above, current frameworks do not fully reflect the significant theoretical and operational advances so far achieved in the field of resilience studies and resilience planning practices. Hence, some hints for further improving disaster risk management policies and strategies, according to the latest advances in resilience thinking, will be provided.

Table 6.1 highlights, in the first column, the most critical issues that should be addressed in order to improve existing frameworks for disaster risk management. These issues have been identified based on the changes in hazards and risks landscapes that occurred in the last decades arising from available data (Guha-Sapir 2018) and on the analysis of the still open issues in current framework guiding disaster risk management. In the second column, the potential contribution that the latest advances in resilience thinking and practices could provide in order to better cope with these issues has been outlined. Finally, the last column suggests the key principles for a resilience-based disaster risk management, listed in respect to each identified critical issue. The main issues to be addressed can be summarized as

Table 6.1 Key principles for a resilience-based disaster risk management

Critical issues	Contribution of resilience thinking and practices	Key principles for a resilience-based disaster risk management
Rapidly changing risk landscapes 1. Increasing interdependency among urbanization patterns, environmental decay and risk levels 2. Increasing occurrence of simultaneous or enchained events (e.g. Na-tech events) 3. Emerging climate-related risks 4. Increasing occurrence of "beyond the expected" hazardous events 5. Change of vulnerabilities and resilience across different geographical and temporal scales	Based on an in-depth understanding of complex adaptive socioecological systems, the resilience concept is the most adequate to grasp both the complex dynamics of human systems – depending on social and biophysical ecological patterns and processes and continuously changing under the pressure of internal and external drivers (Pickett et al. 2004) – and the increasingly variable, dynamic and uncertain impacts of the heterogeneous risk factors, often mutually interacting, threatening them (Tyler and Moench 2012) As remarked by Davoudi et al. (2012), the concept of evolutionary resilience intended not as a fixed asset but as a continually changing process seems to be the most effective to tackle complexities, uncertainties and unpredictability related to the future development of both human settlements and external and internal disturbances threatening them The evolution of the resilience concept is closely related to the "panarchy" metaphor, introduced by Gunderson and Holling (2001), to explain the adaptive nature and the evolutionary dynamics of complex adaptive systems. The latter are nested on each other across different spatial and temporal scales and evolve through adaptive cycles, developing at different scales – from small to large – with different times and speeds, from slow to fast, interacting with each other through feedback mechanisms inducing cross-scale effects	*P.1. Integrated risk assessment* Ensure an integrated risk assessment, capable to take into account both individual and complex hazards (e.g. Na-techs), as well as the complex interweaving of natural and human systems' dynamics *P.2. Comprehensive risk scenarios* Develop comprehensive risk scenarios, taking into account both the events that have a higher probability of occurrence and the worst-case scenarios, the so-called black swans (Taleb 2010) *P.3. Multiscale, dynamic risk assessment* Promote the shift from local scale and static towards dynamic and multiscale risk analysis and assessment, enabling practitioners to better understand and assess the different facets of vulnerability and resilience, over different geographical and temporal scales

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Table 6.1 (continued)

Critical issues	Contribution of resilience thinking and practices	Key principles for a resilience-based disaster risk management
Still prevailing "silo" approach to disaster risk management Even though disaster risk reduction, climate change mitigation and adaptation are more and more recognized as crucial components of sustainable development, very often they are still tackled through sectoral policies and tools	The polysemic concept of resilience, bridging different research fields (e.g. ecology, sustainability, risk, climate change, planning), can play a key role for enhancing cities' capacity to deal in an integrated manner with the heterogeneous factors currently threatening them (e.g. individual and coupled hazards, climate change, scarcity of resources and environmental degradation) Resilience is nowadays more and more interpreted as the result of a set of interrelated and constantly interacting capacities: among them, cooperation and networking capacities are intended as crucial to push cities towards "a more resilient state" (Jabareen 2013). Building such capacities needs to be addressed in a multidimensional, cross-sectoral and integrated way	*P.4. Integrated policies* Promote integrated policies, capable to look at both disaster risk reduction and climate change mitigation and adaptation as crucial components of wider sustainable development processes, in order to overcome currently prevailing sectoral disaster risk management policies *P.5. Integrated strategies* Ensure cross-sectoral strategies and tools, allowing both vertical and horizontal cooperation among different government levels, different sectors and departments
Persisting lack of transformative approaches The current complex and multidimensional nature of risks affecting cities and communities brings up the necessity to make substantial transformations at various scales. As Nelson et al. (2007: 396) highlight: "Projected future climate change, for example, is likely to require system transformations as areas and economic activities may be no longer viable in particular places over the next century"	According to Folke et al. (2010) resilience can be interpreted as "the dynamic interplay" between "persistence, adaptability and transformability across multiple scales and timeframes", where transformability is "the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable" Recent findings highlight the relevance of the idea of transformation in resilience thinking (Berkes and Ross 2013; Nelson et al. 2007; Walker et al. 2004). Although resilience, when kept only as equal to adaptation, is considered as contrasting to the idea of transformation or transformability (Redman 2014; Pizzo 2015), evidence shows that adaptation is most of the time a desirable attribute, contributing to the long-term resilience of a system (Berkes and Ross 2013; Nalau and Handmer 2015; Tiernan et al. 2019; Walker et al. 2004).	*P.6. Transformational perspectives* Promote policies embracing a transformational perspective, based on a critical overview of the inherent problems and weaknesses and allowing long-term innovation, in order to overcome current approaches to disaster risk management, mostly addressed to improve local capacities of coping in the short term with heterogeneous pressure factors (persistence) or adapting in the face of changing conditions through incremental adjustments

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Table 6.1 (continued)

Critical issues	Contribution of resilience thinking and practices	Key principles for a resilience-based disaster risk management
There is therefore the need to integrate transformative approaches to the current policy framework in relation to sustainability, climate change adaptation and also other economic, political, social and spatial issues	However, systems may face situations where the resilience of a component becomes undesirable: poverty traps, loss of livelihoods, criminal organizations and dependency on fossil fuel consumption are among the examples for this kind of undesired resiliency that calls for system transformations (Redman 2014; Pizzo 2015) Walker et al. (2004) highlight that "… novelty, diversity, and organization in human capital – diversity of functional types (kinds of education, expertise, and occupations); trust, strengths, and variety in institutions; speeds and kinds of cross-scale communication…" are key attributes for transformability, in addition to common attributes as "diverse and high levels of natural and built capital"	*P.7. Scenario planning* Scenario planning techniques represent a key tool for "envisioning plausible transformations and bringing them into social decision processes" (Peterson et al. 2003)
Limited attention to learning capacity The idea of learning from experience in order to move towards improved conditions is clearly remarked by the Sendai Framework, although so far limited progresses have been registered along this line. An example is the still limited use of forensic investigation techniques in the disaster field:	Learning capacity is one of the key capacities for enhancing socioecological systems' resilience; as remarked by Bristow and Healy (2014), indeed, "learning, adaptive management and the deliberate acquisition of knowledge" are the capacities that distinguish human systems from biological ones. Learning capacity reflects "the intentionality of human action and intervention" (Davoudi et al. 2013), typical of social systems, let arising the key role of social capital and institutions in the building up of resilient cities Lu and Stead (2013) emphasize how learning from both positive and negative experiences becomes highly mentioned in studies on the organizational side of resilience, contributing to preparedness and improvement of plans	*P.8. Cyclical processes* Disaster risk management policies and strategies have to be interpreted as processes, cyclically reviewed according to continual learning processes *P.9. Knowledge integration* Disaster risk management policies and strategies have to be based on the effective integration of different sources of knowledge, including both scientific knowledge and the experiential and tacit knowledge of local communities

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Critical issues	Contribution of resilience thinking and practices	Key principles for a resilience-based disaster risk management
knowledge of past events has been for long focused on geophysical processes, on physical damage and emergency response, whereas forensic disaster investigation techniques could allow us to better understand root causes and drivers transforming hazardous events into disasters (Keating et al. 2016)	Learning capacity is intended as crucial for developing people and institutions' awareness about risk issues, to improve the capacity to anticipate likely future events, which can threaten urban systems, and, mainly grounding on monitoring and knowledge, to guarantee a continuous management of socioecological systems along the time Learning capacity is closely related to other capacities: (1) knowledge that allows to elaborate information about events and processes; (2) memory, which allows to learn from past events in order to figure out possible future scenarios; (3) communication, which allows sharing and exchanging knowledge and information (Bristow and Healy 2014); (4) collaboration, which favours interactions and synergies between different stakeholders; and (5) participation, which allows to involve people in the decision-making processes (Papa et al. 2015)	*P.10. Learning from disasters* The role of forensic investigation techniques to learn from disasters for preventing future damage has to be strengthened *P.11. Preserve memory* Memory, by enabling us to retain information and knowledge arising from past events, is crucial to anticipating, planning and preparing for future disruptive events
Weak role of spatial and land use planning in DRR The importance of considering disaster risk reduction, resilience and climate risks in urban planning has been clearly remarked by the Report RIO + 20 (UN 2012), and the crucial role of land use and spatial planning in framing and negotiating heterogeneous and sometimes competing goals has been emphasized (Estrella et al. 2013)	A resilience-based approach could significantly contribute to improve the role of spatial and land use planning in DRR, enabling planners to shift from silo-based (sectoral) planning towards integrated approaches, taking into account the complex interactions between social, economic and ecological factors, including risks	*P.12. Better linking land use planning and disaster risk management* Land use planning and disaster risk management should be better linked in order to (1) ensure a wider involvement of all the stakeholders holding a crucial role in land use decisions (planners, political decision-makers, citizens) in the process of risk knowledge building and (2) develop a risk knowledge base better tailored to planners' needs and capable to enable them to evaluate the consequences that any decision, aiming at preserving or transforming a given area, may have, directly or indirectly, on risk levels

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Critical issues	Contribution of resilience thinking and practices	Key principles for a resilience-based disaster risk management
However, embedding disaster risk mitigation and climate change adaptation into land use planning processes has proved to be extremely difficult, and most of current practices still struggle to correctly embed risk assessments (and more often hazard assessment) into zoning and design decisions (Galderisi and Menoni 2016) Finally, land use planning may play a key role for shifting from the traditional engineering-based measures to prevent and mitigate hazards, towards non-structural and often multi-objective risk mitigation measures	Since resilience thinking clearly stresses the importance to react to shocks and crises, not by restoring a pre-existing state, but foreshadowing new and more sustainable conditions in the face of a constantly changing environment, a resilience-based approach may allow shifting from a still prevailing conservative planning, aimed at maintaining the status quo, to transformative planning, which embraces change, looking at shocks and crises as opportunities to enhance the overall performance of the system	*P.13. Strengthen the role of planning measures* Effective disaster risk management policies require land use planning measures capable of (1) avoiding/reducing exposure in the most hazardous zones; (2) decreasing exposure and vulnerability in existing settlements; and (3) favouring nature-based solution (green and blue infrastructures) to preserve/regenerate natural resources and counterbalance risks *P.14. Improve planners' toolkit* In order to strengthen the role of land use planning for disaster risk management, the adequacy and effectiveness of current planners' toolkit, still largely addressed to define in a certain and lasting way what is allowed and what is prohibited (Hillier 2017), should be revised, opening the floor to more flexible and adaptive practices, capable to better cope with contingency and uncertainty, which strongly affect current risk landscapes, mostly when climate related risks are at stake
Weakness of current risk governance models The need for strengthening disaster risk governance has been identified as a priority for action in the Sendai Framework	Resilience thinking has been largely focused on the dynamics of urban systems and on how these dynamics and feedbacks evolve across different temporal and spatial scales. This emphasizes the relevance of multilevel and multi-actor governance mechanisms based on collaboration, cooperation and mutual exchange and learning between different institutional levels, bodies and actors	*P.15. Collaborative governance models* In order to strengthen disaster risk governance, collaborative governance models, capable to engage different stakeholders in outlining multiple visions, consistent with likely alternative scenarios and addressed to reach a shared and constantly updated set of goals (Loorbach 2010), should be promoted

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Table 6.1 (continued)

Critical issues	Contribution of resilience thinking and practices	Key principles for a resilience-based disaster risk management
Nevertheless, current governance mechanisms are often identified as key barriers in the implementation of DRR and CC strategies due to (1) the prevalence of top-down models, which often fail in effectively engaging all the involved stakeholders, including local communities; (2) the still prevailing siloed structure of local governments, where each "silo" acts on a specific issue (e.g. risk reduction, water management, energy, transport) without an effective vertical and horizontal cooperation; and (3) the persisting reference to linear processes (from decision-making to implementation), too often scarcely monitored and cyclically revised	Moreover, nowadays resilience being largely "understood not as a fixed asset, but as a continually changing process" (Davoudi et al. 2012), it requires a shift from linear to circular approaches to resilience-building processes. In this line, the numerous progresses aimed at "operationalizing" resilience at city scale, providing local governments with useful tools for understanding, assessing and improving their capacity to cope with different stresses and shocks, could provide relevant hints (Galderisi 2018)	*P.16. Multilevel governance models* Innovative governance models should enable multilevel processes aimed at outlining "strategic long-term scenarios" and leaving room to multiple evolution trajectories of urban system, crucial to cope with uncertainty and constantly changing environmental, social and economic conditions (Galderisi and Colucci 2019) *P.17. Circular governance models* Innovative governance models should promote a shift from linear to circular disaster risk governance models, emphasizing the key role of monitoring and learning capacity. These models could largely benefit from tools and procedures so far developed in order to support local authorities in establishing a resilience baseline, defining and prioritizing their goals and actions and monitoring their progresses towards resilience enhancement

follows: (1) to better understand the rapidly changing risk landscapes arising from the interplay between climate change, urbanization patterns, increasing hazardous events and complex interrelationships among them; (2) to promote integrated approaches to and cross-sectoral strategies and tools for DRR; (3) to embrace transformational perspectives in order to significantly reduce disaster losses as a crucial goal of a sustainable development process; (4) to invest in improving learning capacities through the setting up of continual learning processes; (5) to emphasize the role of spatial and land use planning for DRR; and (6) to develop more innovative governance models, capable to promote collaboration, shared responsibility and active engagement of all involved stakeholders.

5 Summary and Conclusions

Over the last two decades, the world has experienced accelerating numbers of disasters with increasingly devastating consequences. With the aim of providing a ground for discussion on how to improve current disaster policy frameworks, in this chapter an in-depth review of the changing definitions, approaches and contexts of policies and practices addressing disaster risk management has been carried out. Three successive policy documents marked the path towards the contemporary disaster risk management: the Yokohama Strategy, the Hyogo Framework for Action, and the Sendai Framework for Disaster Risk Reduction. The progress recorded in each document allowed important steps forward in respect to the goal of preventing and reducing the negative impacts of hazards.

The evolution path of disaster policy frameworks since the 1990s shows the progressive change of disaster risk management approaches in the face of emerging challenges and new requirements arising from the dynamic and evolving nature of hazards and disasters, which became more complex and intense than ever. In this direction, disaster policy frameworks embraced the idea that disasters result from an interplay between hazardous events, exposure and vulnerability conditions and the response capacity of the affected society. Policy frameworks have also recognized that dealing with disasters requires not only responding to and recovering from disasters but also identifying and anticipating risks, preventing and mitigating them and being prepared and ready to cope with their unavoidable impacts. In that respect, resilience thinking has surely contributed to the recent advances of current disaster policy frameworks. In fact, our analysis on the interactions between resilience and disaster studies revealed that both strands of knowledge developed hand in hand. On the one hand, resilience thinking informed approaches and goals of disaster risk management; on the other hand, the experienced disasters provided a significant knowledge base for resilience studies. However, resilience has been so far mostly interpreted as an overarching goal of disaster risk management policies, which do not fully reflect the significant theoretical and operational advances in the field of resilience studies and resilience planning practices.

The analysis of existing policy frameworks allowed outlining several gaps and needs that can be summarized as follows: (1) the persisting lack of a full understanding of the more and more complex and often unexpected chains of primary and secondary hazardous events and related impacts; (2) the still limited capacity to learn from past events for further improving the capacities to anticipate, plan and prepare for future disruptive events; (3) the still prevailing "siloed" approaches to DRR and the need to further promote a multidimensional, cross-sectoral, comprehensive and integrative approach to risk reduction and disaster management; (4) the need to better relate DRR, climate change and sustainable development; and (5) the need to improve disaster governance models for more effective and efficient outcomes. These issues are crucial for reaching the goal of further reducing the negative impacts of hazardous events. Yet, policy frameworks have not been so far efficiently operationalized and adequately implemented: the principles they provide are still struggling to penetrate current disaster risk management practices, also due to the complexity of decision-making processes in this field, which require the interaction and the cooperation of different stakeholders acting on different decision-making levels.

Hence, the main theoretical and operational inputs that resilience thinking might provide in order to address the main critical issues of current policy framework and further improve disaster risk management have been highlighted. In particular, in order to improve disaster policy framework according to a resilience-based approach, 17 key principles capable of addressing the main critical issues of current policy framework have been provided. In particular, the key principles for a resilience-based disaster risk management should allow better considering the rapidly changing risk landscapes, due to the interplay between climate change, increasing hazardous events, urbanization patterns and complex interrelationships among them; move away from a sectoral approach to disaster risk reduction, promoting integrated approaches to and cross-sectoral strategies and tools for DRR; embracing transformational perspectives to significantly reduce disaster losses and achieve sustainability goals; improving learning capacity through the setting up of continual learning processes; emphasizing the role of spatial and land use planning for DRR; and developing more innovative governance models based on collaboration, shared responsibility and active engagement of the stakeholders.

Although the provided principles might allow current disaster risk management practices to benefit most of the latest theoretical and operational advances in the field of resilience studies and planning practices, the path towards the translation of these general principles into practice is not free from difficulties and obstacles. Complexity and heterogeneity of local contexts require tailored to the site policies and strategies, capable of taking into account the heterogeneous risk landscapes, the multiple involved stakeholders as well as the different planning systems that, in many countries, are still inadequate to cope with the uncertain and changing risk scenarios related, for example, to climate change or to pandemic events.

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Chapter 7
Urban Disaster Management and Resilience

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Abstract Urban settings are areas in which wide aspects of human life are supported. In other words, they are context for economic, social, political, and other human activities and growth. Therefore, the proportion of people inhabited in cities is increasing over time. The concentration of people in urban areas leads to new problems including water resources depletion and degradation, deforestation, land use changes, environmental degradation, health problems, and epidemic risks. All these issues make cities away from sustainable development and intensify the consequences of natural disasters like earthquake, flood, and droughts. The history of disasters in urban area shows that they could cause enormous damages and deaths, and their impacts could last for a long time. It might take ages for urban infrastructures to recover from a disaster. Such concerns have highlighted the importance of urban disaster management over time, and especial attention is paid to it in recent years. Urban disaster management leads managers in a way how to deal and think about making decisions before, during, and after disasters. Resilience is an approach of disaster management that cares more about bouncing back after disturbances which has attracted researcher's attention. In this chapter we will discuss about the disasters that could happen in urban areas and the best approach in their management. Then, the resilience is defined in urban areas regarding momentous researches, and also it is discussed how urban disaster resilience helps cities to achieve sustainable development. Characteristics of a resilient urban and some frameworks to make resilient urban are also discussed in this chapter.

Keywords Disaster management · Resilience · Urban infrastructure · Resilient city · Sustainable development · DRIFT

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1 Introduction

People prefer to stay in the cities as they provide all the essential commodities and infrastructure facilities that are essential for daily needs. Around 2050, two thirds of the total world population will be living in urban areas (United Nation 2019). On the other hand, urban areas have been always threatened by many undesirable conditions and disasters which could result in immediate dramatic damages. Useful and essential resources for living have been shrunk during such unstable situations, especially in developing countries. As it can be seen in Fig. 7.1, the number of natural disasters is rising over the world (University of Oxford 2020). These events are also intensifying due to different factors such as climate change (Nazif et al. 2017). Therefore, a suitable reaction to reduce damages, start recovery and reconstruction, and return to stable situation is needed in dealing with disasters. In recent times, this has resulted in an augmented research in the field of disaster management specifically in the context of urban areas. Natural disasters (like earthquake) could hardly be controlled by human intervention, but there are many possible ways to mitigate their impacts. It should also be noted that natural disasters could be indirectly the result of human activities. As an example, floods are triggered by heavy rainfall events, but they are the result of the rainfall being transformed in discharges by the watershed. In this transformation, the watershed, modified by human actions, can aggravate floods, in a kind of disaster that is already recognized by UNESCO as a social-natural disaster. Such process in which human activities rises the potential of disasters or their impacts called anthropogenic activities (Jha 2010).

Development of cities has changed the environment in different ways such as deforestation and land cover changes, large water transfer schemes, and greenhouse gasses emissions, and all of these changes have raised the potential of disasters. For

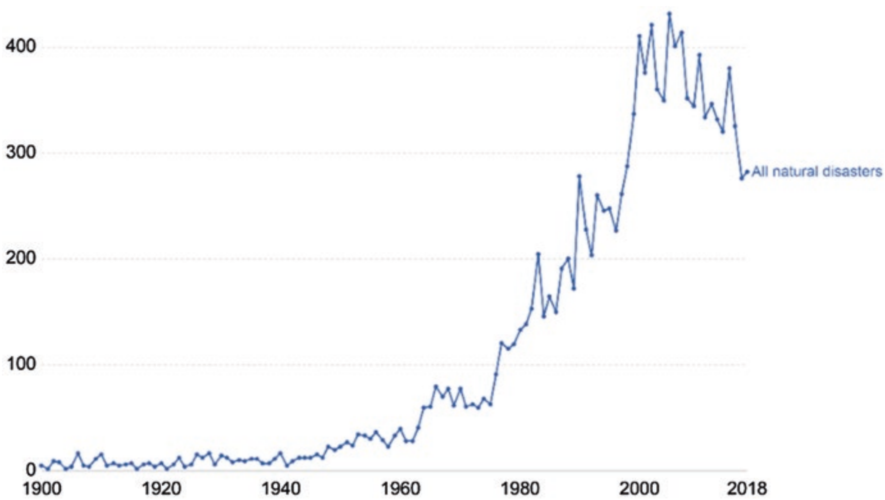

Fig. 7.1 Number of all natural disasters events during 1900–2018. (University of Oxford 2020)

example, deforestation causes deviations in hydrology cycle, soil moisture, and soil porosity, resulting in worse condition for floods. Disasters usually happen suddenly and cause great losses. They usually exceed human capacity to cope in a short time and cause damages which require long time to repair. Some impacts like death and loss of cultural heritage can never be compensated by the time. Such losses and damages have resulted in forming attitudes toward terms like "disaster risk management," "disaster management," and "urban disaster resiliency."

Urban disaster resiliency is a new concept which does not only concern the minimization of disaster impacts in the city but also considers bouncing back from the disaster and recovering as it could to be. These two important objectives have made urban resilience one of the concerns of urban planners. In other words, urban resilience is like a property of a material which always tries to keep the material in the elastic state during stress and also tries to immediately bring it back to equilibrium after the stress is removed. In terms of urban setting, resilience attempts to keep the urban area safe from a disaster, and minimize the impacts during a disaster, and also struggles to achieve the full functionality of urban systems after a disaster. In this chapter, we will explain more about urban disasters, resilience in urban areas, and its main features and how it can be accommodated in urban disaster management.

2 Urban Disasters

Different types of disaster can occur in urban areas which result in heavy damages. Although many of severe damages are reparable (like demolishing large infrastructure and buildings), many are irreparable (like human casualties). An important point is that disaster characteristics and impacts in urban areas are different, and having enough knowledge about them can help to manage their consequences in a more efficient manner (Keim et al. 2005). Emergency Events Database (EM-DAT 2020) has considered six categories for natural disasters considering their sources (Table 7.1). In this section, some of the common urban disasters all over the world are discussed.

Table 7.1 Disaster types based on their sources

Category name	Source	Examples
Geophysical	Originated from solid earth	Earthquakes
Meteorological	Originated from extreme weather and atmospheric conditions	Storms
Hydrological	Originated from surface and subsurface water	Floods and landslides
Climatological	Originated from atmospheric processes	Droughts
Biological	Originated from living organisms	Epidemic disease
Extraterrestrial	Originated from asteroids, meteoroids, and comets	Space weather

2.1 Earthquakes

Considering the very short duration and the severity of damages that could be caused by earthquakes, increasing the urban areas resiliency in dealing with them is of very high importance. Figure 7.2 shows the number of deaths caused by earthquake across the globe in the time period of 1936–2017. As it can be seen, large human losses occur after each earthquake and also tend to increase over time due to increasing population density especially in urban areas. Earthquakes could have wide range of consequences on a city. Rigid facilities like buildings and bridges can absorb higher frequency waves and be damaged in earthquakes (Earle 2018). Roads and highways can be damaged because of land motions (Panjamani et al. 2011). Due to earth motions, pipelines in water distribution systems are also at risk, putting the city in a weaker position. Soil liquefaction and slope failures are also other events which have potential to occur after an earthquake. Added to this, along the coasts, earthquake can lead to tsunamis (Maeda et al. 2011; Fujii and Satake 2007). The earth's crust has potential to break in faults, and if earthquake copes with its resistance (in ocean), big upward waves would be produced.

It should be emphasized that, even though earthquakes originate from non-manageable natural activities, human activities are important in the severity of earthquake consequences (as in any other disaster) due to the exposure of goods, assets, and lives, as well as the vulnerability of the socioeconomic systems (Wilson et al. 2017). The urban areas can be developed in places with lower risk of earthquake; however, the earthquake occurrence is unavoidable. Furthermore, considering the huge number of buildings and infrastructures in urban areas, it is not possible to retrofit or reconstruct all of them to very high levels of seismic resistance. All of these address needs for earthquake disaster management in urban setting.

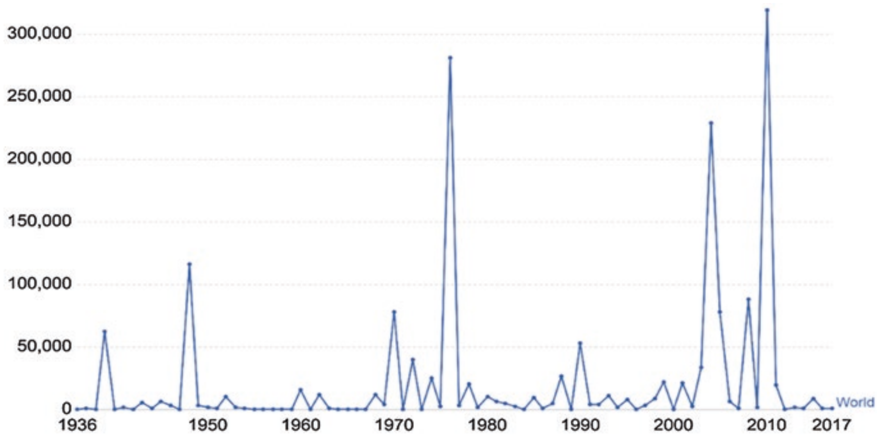

Fig. 7.2 Number of death from earthquake over time in 1936–2017. (University of Oxford 2020)

2.2 Floods

Floods are among the most frequent disasters in urban areas which occur suddenly and result in huge damages and sometimes last for a considerable amount of time. Excessive rainfall, snow melt, and storm surges could lead to flood occurrence (WHO 2020) and could be exacerbated by human activities such as increasing impervious areas and deforestation. There is increasing concerns about floods in urban areas due to climate change impacts. Climate change has resulted in intensified rainfalls (Waters et al. 2003; Krishnamurthy et al. 2009) and sea level rise (Cayan et al. 2008) which could cause severe floods especially in urban areas. Cities located in coastal regions are more vulnerable to floods. New Orleans is an example of such places which has experienced flood in August 2005, and large parts of the city have been soaked. This disaster caused more than 1100 fatalities (Cayan et al. 2008).

The Boscastle flood in August 2004 is an example of floods which was provoked by heavy precipitation. On August 16, 2004, in Boscastle (country), heavy rainfall of about 200 mm lasted for about 5 h causing significant damages to the highways, infrastructures, water supplies, and electricity supplies in the city (Cayan et al. 2008). A heavy rainfall in 2019 that occurred in Iran resulting in huge damages across 28 provinces is another example of urban flooding. Both velocity and depth of flow can harm facilities and structures in cities. Impermeable surfaces such as road pavement can increase velocity of flow and depth. Therefore, in urban areas floods effects are further exacerbated because of the increase in velocity and depth of the flow.

2.3 Storms

Storms are disruptions in atmospheric state which appear in the form of heavy winds and usually lead to intense precipitation. Similar to floods, climate change could intensify storms (Cayan et al. 2008). Storms can damage wide range of facilities in cities like buildings and trees. Airplanes and other means of transportation in cities (like trains and cars) can also be affected by gusty winds (Changnon 2009). Sea level rise which is a result of climate change can intensify storm surges in coastal areas and sea level rise induced damages as well. Different places of the world have experienced storms of miscellaneous sizes and were deeply damaged as a result. For instance, in 1970, 115 mile/h wind raged in Bangladesh and killed at least 300,000 people.

2.4 Epidemics

The source of epidemics are microorganisms and toxic substances (EM-DAT 2020). These diseases can quickly spread among human beings. The rate of spread of disease is so important that some sources identify epidemic events with the sudden and unreasonable increase of a similar disease among individuals in a specific area (International Federation of Red Cross and Red Crescent Societies 2020).

The World Health Organization (WHO 1996) has identified and announced ten most killer epidemics as given in Table 7.2. However, treatments have been established for some epidemics, but this organization has also underlined that most of epidemics are rising their resistance against treatments. In cities due to the high concentration of people, the epidemics are more serious and can result in high damages and deaths in a very short time period. For example, the COVID-19 pandemic is the defining global health crisis and the greatest challenge human has faced since World War II. Since its emergence in Asia in late 2019, the virus has spread to every continent except Antarctica. Countries try to slow the spread of the virus by testing and treating patients, carrying out contact tracing, limiting travel, quarantining citizens, and cancelling large gatherings such as sporting events, concerts, and schools. By stressing every one of the countries it touches, it results in devastating social, economic, and political crises. This example shows how epidemics can affect people's lives and also economy in urban areas; therefore, finding an immediate and accurate treatment to these kinds of disasters is imperative.

2.5 Droughts

Drought is a time period in which an area suffers from deficiency of water supplies. Potential of droughts is rising due to global warming impact which intensifies the water cycle (Mishra and Singh 2010). On the other hand, groundwater overuse

Table 7.2 The ten biggest killers

Disease name	Number of deaths all over the world
Acute lower respiratory infections such as pneumonia	4.4 million
Diarrhea diseases (spread mainly by contaminated water)	3.1 million
Tuberculosis	3.1 million
Malaria	2.1 million
Hepatitis B	More than 1.1 million
HIV/AIDS	More than one million
Measles	More than one million
Neonatal tetanus	460,000
Whooping cough	355,000 children
Intestinal worm	More than 135,000

WHO (1996)

owing to population growth raises concerns about water supply in drought condition. Different drought consequences have been expressed. Vegetation harms (Peñuelas et al. 2001), water quality reduction (Sprague 2005), biodiversity elimination (Tilman and El Haddi 1992), soil erosion (St.Clair and Lynch 2010), and economic impacts (Freire-González et al. 2017) are some reported consequences of droughts. Figure 7.3 shows the number of recorded droughts across the world in 1900–2019. As demonstrated, their frequency is increasing, so experiencing more effects from them is probable across the world. In urban areas, especially in dry regions, due to high population density and limited water resources, supplying water demands for different purposes in drought condition is a serious concern.

3 Urban Disaster Management

In Sect. 2, disaster types were briefly introduced, and the more important disasters in urban areas were explained. It was also noted that potential of disaster occurrence rises up due to increasing population and the consequent intensive activities (especially) in urban areas. Nowadays, a huge number of people are concentrated in areas with high potential of disaster occurrence due to population growth in urban areas. Since disasters are not predictable due to the high uncertainty existing in their modeling, it is necessary to have strategies and plans for disaster management in urban areas. Disaster management refers to all approaches which aim to capture disaster's dynamicity and reduce disaster impacts. Urban disaster management emphasizes managing disorders that could happen in cities as a result of disasters. Since each

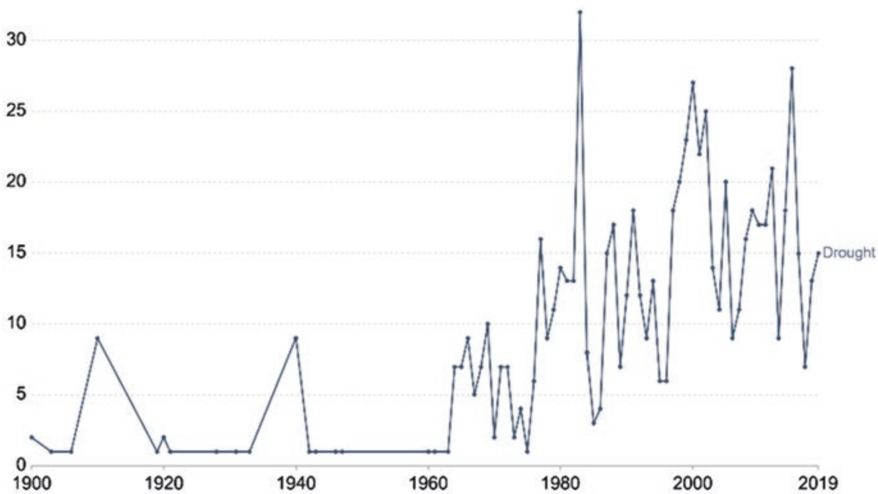

Fig. 7.3 Number of droughts across the world during 1900–2019

disaster has its specific characteristics, disaster management differs in detail by type of disaster.

Disaster management is not only about what should be done after disasters. It refers to a systematic process before, during, and after disaster (Tingsanchali 2012). For instance, risk assessment is an activity (lied in disaster management process) that helps to reduce the systems exposure and vulnerability in disasters (before disaster) and also reduce its impacts (after disaster). Emergency services during disaster to minimize harms, evacuation plans to prevent secondary impacts during disaster, and resource management to respond future probable disasters are some of disaster management activities during disasters (Ramchurn et al. 2008; Montoya 2003).

In the last decades, the main emphasis of disaster management was on increasing the systems resistance against disasters. Building stronger structures and providing more flood defense systems are among the examples of such disaster management strategies against earthquakes and floods, respectively. However, the disasters that occurred in recent years showed that these strategies are not sufficient, and the severity of disasters is increasing due to various reasons. This was especially highlighted in urban areas because of high population density. Therefore, the approach in disaster management has started to change. Disaster resilience in urban areas aims not only at minimizing the impacts of disasters but also at reducing the time needed to bounce back. In other words, the functionality of a resilient urban setting will not experience significant fluctuations. In the next section, more details on resilience in urban areas are given.

4 Urban Resilience

4.1 Definition of Urban Resilience

With the emergence of natural disasters and heavy casualties in urban areas, it was necessary to develop approaches to face disasters, so some definitions such as "resistance," "adaption and mitigation," and "resilience" have appeared (Cutter et al. 2008; O'Brien and O'keefe 2013). In fact, these terms have emerged subsequently to cover previous approaches' shortcomings. The term "resistance" refers to resist against natural hazards through decreasing vulnerability. Building city in a way that is not vulnerable against severe disasters is costly and out of resources. Furthermore, due to high level of uncertainty in predicting disaster characteristics and determining systems resistance, this approach is not considered in recent years. So the "adaption and mitigation" strategy was considered. Based on IPCC (2014), adaptation concerns about the well functioning of key systems in society in the present and future. In the adaptation approach, vulnerability and hazard reduction are bases to develop an adaptive society. In other words, the adaptation and mitigation strategy aims to subtract disaster risk and minimize the long-term effects. Risk reduction takes into account uncertainties and covers the previous shortages. Resilience is the next strategy which not only implies previous approaches but also puts city's efficiency disturbance under consideration. Resilience approach minimizes the time needed for society to rebound. In a resilient city, action and reaction plans are set up so that the city can return to equilibrium state very soon after a disaster occurred. This view has drawn the attention of urban planners and scholars, more than any of the other topics discussed earlier.

In general, the word "resilience" means "the ability of a substance to return to its original shape after it has been bent, stretched or pressed," but it means in different ways according to the discipline, which sometimes look completely different (Table 7.3). For example, in physics, resiliency means to absorb hit, adopt it, make changes, and recover to the last station. For instance, imagine a spring getting shock by a ball. In the first step, when the ball hits it, the spring absorbs and saves the energy. In the next step, it shrinks as much as it absorbs the energy, and finally the spring tries to expand and return to the initial situation. In other words, the system bounces back to equilibrium state in the final step.

Equilibrium state definition differs as disciplines differ. Engineering and ecological disciplines are two main disciplines that specify equilibrium state distinctly. This causes discrepancy in characteristics of a resilient system. In engineering discipline, resilience is defined as a restricted concept which aims to maintain efficiency of system. Efficiency, constancy, and predictably are the main features of a resilient system in engineering discipline (Holling 1996). Based on this definition, a resilient system must return to its previous state. In other words, "equilibrium state" refers to the previous state of the system. In this view resilience is conceptualized as an outcome. Ecological resilience emphasis is on struggling to maintain the functioning of the system (Holling 1996). Therefore, equilibrium states may be far from the previous state of the system. Based on Holling (1996), persistence, change, and unpredictability are the main features of such resilient system, so resilience is a process-oriented concept. As mentioned, these disciplines' definitions for equilibrium state after shocks are completely different and even, in opposite states (Table 7.4). This will result in different assessments of resilience.

Engineering resilience approach is appropriate for small engineering systems where everything is under control; therefore, it may not be a good approach for larger systems similar to a city. In other words, it is possible to return to the previous state in definite condition. A variety of factors affect the state of an urban setting, and there are considerable uncertainties in reaching the ideal condition. Therefore, bouncing back to the previous state after disasters will be both impossible and costly in an urban system. On the other hand, ecological resilience seeks to maintain functionality of the system after shocks. Hence, a city must withstand significant disturbances to continue functioning. The design of such city is very expensive and unimaginable in the current condition.

Practically, an urban setting resiliency cannot be well defined in two previous disciplines. Therefore, a more specialized view is needed for defining the urban resiliency. An intermediate view called socio-ecological resilience can be scrutinized regarding distinctive features of urban areas. Folke (2006) defined

Table 7.3 Different meaning of resilience based on different disciplines

Row	Author (year)	Subject area	Definition
1	Alberti et al. (2003)	Agricultural and biological science; environmental science	"… the degree to which cities tolerate alteration before recognizing around a new set of structures and processes" (p. 1170)
2	Godschalk (2003)	Engineering	"… a sustainable network of physical system and human communities" (p. 137)
3	Pickett et al. (2004)	Agricultural and biological science	"… the ability of a system to adjust in the face of changing conditions" (p. 373)
4	Ernstson et al. (2010)	Environmental science; social sciences	"To sustain a certain dynamic regime, urban governance also needs to build transformative capacity to face uncertainties and change" (p. 533)
5	Campanella (2006)	Social science	"… the capacity of a city to rebound from destruction" (p. 141)
6	J. A. Wardekker et al. (2010)	Business management and accounting; psychology	"…a system that can tolerate disturbances (events and trends) through characteristics or measures that limit their impacts, by reducing or counteracting the damage and disruption, and allow the system to respond, recover, and adapt quickly to such disturbances" (p. 988)
7	Ahern (2011)	Environmental science	"…the capacity of systems to reorganize and recover from change and disturbance without changing to other States …systems that are "safe to fail"" (p. 341)
8	Leichenko (2011)	Environmental science; social science	"…the ability…to withstand a wide array of shocks and stresses" (p. 164)
9	Tyler and Moench (2012)	Environmental science; social science	"…encourages practitioners to consider innovation and change to aid recovery from stresses and shocks that may or may not be predictable" (p. 312)
10	Liao (2012)	Environmental science	"…the capacity of the city to tolerate flooding and to reorganize should physical damage and socioeconomic disruption occur, so as to prevent deaths and injuries and maintain current socioeconomic identity" (p. 5)
11	Brown et al. (2012)	Environmental science; social science	"…the capacity…to dynamically and effectively respond to shifting climate circumstances while continuing to function at an acceptable level. This definition includes the ability to resist or withstand impacts, as well as the ability to recover and re-organize in order to establish the necessary functionality to prevent catastrophic failure at a minimum and the ability to thrive at best" (p. 534)
12	Lamond and Proverbs (2009)	Engineering	"…encompasses the idea that towns and cities should be able to recover quickly from major and minor disasters" (p. 63)

(continued)

Table 7.3 (continued)

Row	Author (year)	Subject area	Definition
13	Lhomme et al. (2012)	Earth and planetary science	"…the ability of a city to absorb disturbance and recover its functions after a disturbance" (p. 222)
14	Wamsler et al. (2013)	Business management and accounting; energy; engineering; environmental science	"A disaster resilient city can be understood as a city that has managed…to: (a) reduce or avoid current and future hazards; (b) reduce current and future susceptibility to hazards; (c) establish functioning mechanisms and structures for disaster response; and (d) establish functioning mechanisms and structures for disaster recovery" (p. 71)
15	Chelleri et al. (2015)	Earth and planetary science; social science	"…should be framed within the resilience (system persistence), transition (system incremental change) and transformation (system reconfiguration) views" (p. 287)
16	Hamilton (2009)	Engineering; social science	"Ability to recover and continue to provide their main functions of living, commerce, industry, government and social gathering in the face of calamities and other hazards" (p. 109)
17	Brugmann (2012)	Environmental science; social science	"The ability of an urban asset, location and/or system to provide predictable performance – benefits and utility and associated rents and other cash flows – Under a wide range of circumstances" (p. 217)
18	Coaffee (2008)	Social science	"…the capacity to withstand and rebound from disruptive challenges…" (p. 323)
19	Desouza and Flanery (2013)	Business management and accounting; social science	"Ability to absorb, adapt and respond to changes in urban systems" (p. 89)
20	Lu and Stead (2013)	Business management and accounting; social science	"…the ability of a city to absorb disturbance while maintaining its functions and structures" (p. 200)
21	Romero-Lankao and Gnatz (2013)	Environmental science; social science	"…a capacity of urban populations and systems to endure a wide array of hazards and stresses" (p. 358)
22	Asprone et al. (2013)	Engineering	"…capacity to adapt or respond to unusual often radically destructive events" (p. 4069)
23	Henstra (2012)	Social science	"A climate-resilient city…has the capacity to withstand climate change stresses, to respond effectively to climate-related hazards, and to recover quickly from residual negative impacts" (p. 178)
24	Thornbush et al. (2013)	Energy; engineering; social sciences	"…a general quality of the city's social, economic, and natural systems to be sufficiently future-proof" (p. 2)

(continued)

Table 7.3 (continued)

Row	Author (year)	Subject area	Definition
25	Wagner and Breil (2013)	Agricultural and biological sciences	"…the general capacity and ability of a community to withstand stress, survive, adapt and bounce back from a crisis or disaster and rapidly move on" (p. 114)

Adapted from Meerow et al. (2016)

Table 7.4 A comparison between engineering resilience and ecological resilience definitions

	Engineering resilience	Ecological resilience
Equilibrium state	Must return to the previous system state before disturbance	May be different from the previous system state before disturbance
Main features	Efficiency	Persistence
	Constancy	Change
	Predictability	Unpredictability
Resilience definition approach	Result oriented	Process oriented
Measuring tools	Resistance to disturbance	Magnitude of disturbance leading to uncontrolled functioning of the system
	Time needed for system to rebound	

socio-ecological resilience as "the capacity of linked social-ecological systems to absorb recurrent disturbance such as floods so as to retain essential structures, processes and feedbacks." Cutter et al. (2013) provide a better definition for socio-ecological resilience which is "the ability to prepare and plan for, absorb, recover from and more successfully adapt to adverse events." This definition can be successfully used to define resilience in urban areas (Sharifi 2016). Adaptation is one of the prominent features in developing resilient urban systems. Urban areas are social-ecological sectors where people and ecosystem have interactions. Thus, after a disaster, the equilibrium state may differ from the previous state.

4.2 Developing Resilient Cities

There are four main phases in developing resilient cities against disasters. These phases must be considered before, during, and after disasters. Each phase must be fulfilled in the allotted time to achieve resilience. Phases are further discussed in the following subsections.

4.2.1 Planning

Planning is the first step in achieving a resilient urban setting endeavoring prevention of disaster effects. Due to intensifying natural disasters, some terrible effects are happening periodically in cities. Thus, city planners must consider the past terrible events and learn from experiences to apply more efficient plans in cities for dealing with disasters (Bozza et al. 2017). In other words, they should plan how to perform well in the next steps. As resiliency is a multidimensional concept, they should perceive structural, human capital, and natural capacities and enhance them. Planning is associated with contemplating all urban areas' need to cope with disasters and then searching for an idea (Masterson et al. 2014). City resilience assessment (CRA) is a requisite feed for effective planning. CRA clarifies baseline condition and shows the city position. CRA must be performed periodically to sense and check the exerted alterations. It should be emphasized that, even though the aim of planning step is to mitigate disaster effects, it is difficult or impossible to design a city that is completely unaffected by disasters. What is important is to figure out available resources and adjust the best plan to mitigate the impacts of future disasters as much as possible.

For instance, some African cities are highly vulnerable to disasters due to high sensitivity to climate and inappropriate industrial capacities. Planning toward resilient city in these regions can mitigate the destructive impacts by planning for relief in crisis situation, setting warning systems for extreme hydrological events, and integration of adaption measures into land planning, well-functioning infrastructures, and social networks (Manfredi et al. 2014).

4.2.2 Absorption/Response

The absorption phase in resilient cities starts just after disaster outbreak. In this phase, the community struggles to receive disaster with minimum impacts. In other words, an urban area struggles to minimize the disaster impacts by keeping urban systems functionality during a disaster. This phase is responsible for reducing disaster effects on human values. Providing permanent refugees after flood or earthquake, establishment of mobile clinics to treat the injured people, and evacuation plans are some examples of the tasks that should be accomplished in this phase. Thus, some references have titled this step as the response phase (Gilbert 2010). Time is an important issue in the response phase so that the less time to respond, the more resilient city. Based on Harrald (2006), agility and discipline are two prominent features of the response phase. Agility is the bridge between rigid organization to creative one, and discipline makes action more efficient. Crisis agency must quickly absorb and respond to the disaster. If more than one agency are in charge of disaster response, a suitable intercommunication among them is a momentous issue in this phase (Gilbert 2010).

4.2.3 Recovery

Recovery is the second step of post-disaster phases. When a community absorbs the disaster, some parts of society have been harmed, so in the recovery phase actions should be taken to compensate them. The United Nations Office for Disaster Risk Reduction (UNDRR) defines recovery as “The restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and build back better to avoid or reduce future disaster risk” (UN General Assembly 2016). Urban planners should reconstruct the reverse effects after disaster according to what they learned from the previous disasters. Actually “Build Back Better” refers to integrating disaster risk reduction measures into the recovery activities in social, economic, and environmental dimensions (UN General Assembly 2016).

Recovery is a time-dependent process. In urban areas, recovery time depends on the interplay of hazard system and urban capacities (Platt et al. 2016). Large-scale disaster events need more time to bounce back; however, a prepared society with strong economy will need less time to recover. Recovery is scrutinized in two minor terms: short-term recovery and long-term recovery. The short-term recovery is the prior and faster one referring to the restoration of critical infrastructures, shelters, etc. The short-term phase of recovery is overlaid with the response phase of resiliency (Joakim 2013). The long-term phase insists on returning all systems to function, which obviously needs larger accommodation.

Recovery includes three minor terms of reconstruction, restoration, and rehabilitation (Joakim 2013). Restoration is about returning to prior condition in social and physical aspects. This term is highly related to main features like infrastructures and communications. Reconstruction is about rebuilding physical structures which were harmed by disaster. Rehabilitation also refers to rebuilding but is highly related to people. These terms can be considered in short- or long-term recovery plans.

4.2.4 Adaptation

As discussed earlier, adaptation is a remarkable property in socio-ecological resilience. That is why sometimes, socio-ecological resilience is called adaptive resilience. In fact, adaptation is an approach in which a system functioning is enhanced through a learning process. In other words, a society learns from its previous experiences and applies evolutionary process to cope with probable disasters. In this process always new challenges are detected, and previous shortcomings are eliminated.

Adaptation is much close to the evolution process of human development and is suitable for capturing dynamic process of urban threats with paying attention to uncertainties and different scenarios (Filho 2015; Sharifi and Yamagata 2016). For instance, this mindset propels designers to address different climate-related problems through different scenarios and seek for solutions. Adaptation can improve planner’s insight to turn disasters into opportunities. Therefore, threats could become a further score. For example, the huge water volume provided through floods can be used as an alternative water resource to supply water demands in urban areas or recharge decaying groundwater resources.

5 Resilient Cities Properties

There are four prominent properties that help cities to be more efficient in resilience way. These properties, which are called 4R in summary (Bruneau et al. 2003), are robustness, redundancy, resourcefulness, and rapidity. Some properties may have overlaps in some aspects, but they are marginally different. In this section, these four important properties of a resilient city are reviewed. Urban managers should pay especial attention to them and also have a sense as to how they succor to achieve resilience.

5.1 Robustness

Robustness is about being fine and strong against disasters. This characteristic is an important feature of a resilient system and is mostly related to the second phase of planning for resilience (response). A resilient system must be robust against disasters concerning about human values and getting away from failure point. This property is practically efficient during a disaster. Functionality of a city with enough robustness will not drop significantly during disaster. As infrastructures play a key role in functioning of a city, and they are also taken into consideration for better recovery, infrastructure's robustness is a notable issue. Therefore, robustness assessment of all systems is not necessary, and it must be performed for vital infrastructures. The robustness assessment should be performed regarding various possible scenarios to capture dynamics of disasters and uncertainties lying in estimation of their severity. For example, building city's main structures whit high flexibility makes structures more robust against earthquakes. This kind of activities is highly noticeable when earthquake risk is high.

5.2 Redundancy

Redundancy is another property of a resilient system mainly related to the situation in which system fails or loses functionality. It also concerns about continuing functioning after disturbance (Bruneau et al. 2003). This feature insists on existing backups to use when system fails leading to faster recovery. In other words, redundancy is another form of the saying "don't put all eggs in one basket." Based on Stockholm

Resilience Center (2015), there are two important redundancy forms which can be helpful for city planners: "functional redundancy" and "response diversity."

Functional redundancy is about the existence of different components with the same functionality within a system. Functional redundancy intends to add multiple components in a system. It is obvious that if one component of such system is affected by a disturbance, then another component could be used to have the same functionality and compensate the flaw. Thus, a system with different components would be more resilient against disasters. This kind of redundancy can also be achieved by considering different ways for the same task.

There is also another definition that emphasizes on existing different performing manners to execute the same task. In the other words, urban components that have the same functionality should perform at different ways. This diversity is titled as "response diversity" attempting to minimize component's functionality reduction after disturbance. According to Stockholm Resilience Center (2015), response diversity results in adoptability enhancement. For instance, functional redundancy of urban water distribution systems can be provided by developing loops, using lateral pipes, or using different paths for delivering water. There are four options to maintain redundancy within a system including conservation and value redundancy, maintaining ecological diversity, building diversity and redundancy into governance systems, and focusing less on maximum efficiency (Stockholm Resilience Center 2015).

5.3 Resourcefulness

Resourcefulness technically is availability of equipment and materials to restore and repair after disaster. Practically resourcefulness is the ability of managers to identify problems and initiate solutions by mobilizing resources like humans and technology (Tierney and Bruneau 2007). Resourcefulness is mainly related to the recovery phase and aims to enhance recovery time in a resilient system. According to Caverzan and Solomos (2014) adding resources in recovery phase can reduce recovery time and also improve the quality of recovery. In a virtual city where access to unlimited resources is conceivable, the recovery time would be zero. Resourcefulness can result in redundancies that did not exist before. For example, providing wells in houses in earthquake-prone zones could help people supply water when the water distribution system is harmed during an earthquake.

5.4 Rapidity

Since disasters usually are rapid onset, they may quickly disrupt the efficiency of city. So managers should consider rapidity to cope with adverse events to quickly bounce back. Rapidity is the time capacity of a city in which the city achieves specified resilience goals. Rapidity is important in two phases of response and recovery. Therefore, preparing facilities to cope with disasters and planning how to rapidly absorb adverse effects and return to the equilibrium is of high importance in a resilient city.

It should be noted that rapidity is the outcome of three previous characteristics of a resilient system. In the other words, if the three previous properties are suitably taken to account, a city would achieve resilience goals quickly. For example, if alternative water supplies are not proposed, a city would face problems after an earthquake leading to less rapidity in recovery.

6 Urban Disaster Resilience and Sustainable Development

Sustainable development is a concept brought up by the World Commission on Environmental and Development (WCED 1987). According to sustainable development concept, human's development should involve future consideration in social, economic, and environmental scopes. Sustainable development seeks to answer how human societies can grow unlimitedly on a limited planet. Human has overused sources like forests, mines, and soil which have resulted in environmental degradation. For example, a large amount of forests has been used to produce paper or supply energy. This leads to surface roughness reduction, soil permeability reduction, and some other hydrological changes. Subsequently, this activity generates a potential to worsen flood impacts such as soil degradation as well as economic and social losses. All of these impacts could lead to unstable state in the future and may cause difficulties in next generation growth.

Urbanization which is increasingly happening leads to future environmental disruptions. Human activities such as land use changes, large water transfers, and large carbon emissions raise the disaster risk and amplify disaster effects. For example, cities across the world account for a staggering 70% of greenhouse gas emissions, while they have just occupied 3% of the global land area (Clark II and Cooke 2016). By the way, sustainable development seeks some plans to move toward a stable state according to limited resources. The United Nations Development Programme (UNDP) has set 17 Sustainable Development Goals (SDGs) which address global challenges people face and emphasize that countries should achieve them by 2030 (The Sustainable Development Goals Report, 2018). The "11.B" target of the 11th SDG, which is titled as "Sustainable Cities and Communities," states that "By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR 2015), holistic disaster risk management at all levels." This shows how developing resilient urban areas could help in achieving a more sustainable society.

Two concepts of "urban sustainability" and "urban resilience" are important topics and tightly related issues. These phrases make urban planners familiar with risks and hazards that are threatening them. Although this is the primary mission of them, they can mean in a contradictory way sometimes. Many short-term efforts to achieve urban resilience can breach sustainable development goals. Sustainability in urban areas aims to optimize using of resources, while resilience in urban areas emphasizes on redundancy to guarantee fast recovery after disturbance. In other words, resilience thinking considers resource backups to use after disturbances, but this can avoid the optimal point from a sustainable development perspective and vise a versa (Zhang and Li 2018; Elmqvist 2017).

According to Elmqvist et al. (2019), the problem can be solved by getting deep on the definitions. They have argued that disaster dynamics can lead to increase challenges in urban resilience and urban sustainability, but the great questions should be answered before planning to move toward resilient urban areas: resilience of what? To what? From whom? Considering that resilience in cities is applied to all human aspects (environmental, social, and economic), it can solve the existing problem and clarify ways for planners. Actually, resilience and sustainability in cities are two sides of the same coin, and resilience in cities could be a tool to achieve sustainable development. It can be used as a tool to keep the cities in the sustainability way so that disasters cannot get the city out of that (Sharifi and Yamagata 2016).

Figure 7.4 shows how resilience and sustainable development are related to each other. As can be seen, the city is tending to achieve sustainable development over time, but each disaster plays a deterrent role and keeps the city away from sustainability. Resiliency has been specified into Fig. 7.4 by rotating arrows. Resiliency

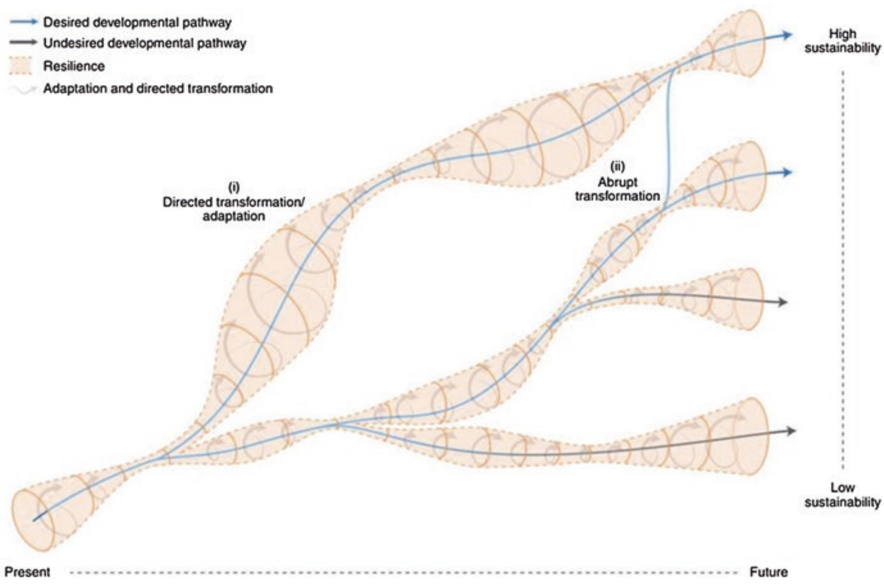

Fig. 7.4 Sustainability and resilience. (Adapted from Elmqvist et al. 2019)

here is a turning point and brings the city back to its track. Also, as it can be concluded from the previous sections, resiliency can also bring back the city over the track in a better condition from its past. The shorter rotating arrows show a more resilient city.

7 Urban Resilience Frameworks

As discussed before, human values are threatening by hazards, and urban resiliency is a concept that not only concerns about decreasing losses but also concerns about recovering some losses. To achieve the goal of developing resilient urban areas, it is required to understand resiliency and realize how it could be applied in urban settings. Urban resiliency frameworks shed lights on the complexities and concerns about applying resilience in urban areas. An urban resilience framework is a lens to scrutinize resilience concept in urban areas. An urban resilience framework articulates urban resiliency so that managers can measure it and do what they can as much as possible.

Some frameworks have a holistic view on urban areas. These kinds of frameworks do not focus on the type of disaster. PEOPLES (Population and Demographics, Environmental/Ecosystem, Organized Governmental Services, Physical Infrastructure, Lifestyle and Community Competence, Economic Development, and Social-Cultural Capital) framework (Renschler et al. 2010) and City Resilience Framework (CRF) (Arup 2014) are the examples of these kinds of frameworks. On the contrary, some frameworks are tailored to a special type of disaster. For example, Bertilsson et al. (2019) introduced a framework to achieve flood resilience in urban areas. The first group of frameworks helps us to look resilience in cities more generally. The second part requires knowledge about the first one and preparing another framework similar to them but for a specific kind of disaster. So, in this part, the first group of resiliency frameworks is discussed which are more general.

There are three main steps to design an urban resiliency framework (Arup 2014). A framework should firstly consider the properties of a resilient urban area. As mentioned before, the four main properties of a resilient urban area are robustness, redundancy, resourcefulness, and rapidity. However, as frameworks concern about the quality of resilience, some frameworks break these properties into more properties, or sometimes add some other properties, based on the quality they have considered to achieve (Arup 2014). Secondly, the aspects that have an impact on urban resilience should be identified. These parts should be commensurate with different aspects of human values in a city. They can also be related to the way that these values are managed. Human values in a city such as economy, people's physical and mental health, environment, and infrastructure are vulnerable to natural disasters and should face the least damage as much as possible. Also, many of human values, such as the environment and infrastructure, have to bounce back quickly and get the efficiency they need, in addition to being vital lines to relief. In the third part, an urban resilience framework should propose solutions and indicators to enhance disaster resilience in cities. The indicators must be defined to evaluate the properties considered in the first part for urban resiliency from different aspects. It should be mentioned that some resiliency properties are more highlighted in some aspects, while they are not very important in other aspects. For example, robustness plays a very important role in a city's infrastructure.

7.1 City Resilience Framework (CRF)

To further clarify the above parts about urban resilient framework, CRF is briefly discussed here. CRF has been provided by Arup and supported by the Rockefeller Foundation (Da Silva and Morera 2014). It considers seven properties for urban resiliency. As it is shown in Table 7.5, these properties are being reflective, robust, redundant, flexible, resourceful, inclusive, and integrated. It also pays attention to four aspects of leadership and strategy, health and well-being, infrastructure and environment, and economy and society. Some properties have higher importance in some aspects. For example, reflectiveness and flexibility are more important in two aspects of leadership and strategy and infrastructure and environment.

All of the properties and aspects in urban resiliency are embedded in three groups of categories, goals, and qualities in CRF. Table 7.5 shows items within these three groups. Each goal has different qualities. These qualities also show how each category is important in urban resilience. For instance, robustness is an important quality of infrastructures. Since infrastructures play an important role in disaster recovery, they should have the least damage. Inclusion and integration qualities are important for all goals; therefore, they play an important role in achieving urban resiliency.

7.2 Drift

DRIFT, which stands for Disaster Resilience Integrated Framework for Transformation, is another framework, among numerous frameworks, presented by Manyena et al. (2019) to simplify and operationalize resilience in policy and practice. According to DRIFT, resilience is a collection of capacities that enable a city to cope with disasters. In this framework capacity perspective connects resilience theory to practice. Figure 7.5 shows how a resilient system works against disaster. As illustrated, a resilient system experiences three processes.

1. The first process is risk assessment. Risk assessment plays a key role to be aware about probable effects. This could enhance action plans.
2. The second one emerges during disaster, when capacities enable a city to fight disaster. DRIFT considers five capacities for a resilient system:

Table 7.5 Items within the three main groups in CRF

		Qualities						
Categories	Goals	Flexible	Redundant	Robust	Resourceful	Reflective	Inclusive	Integrated
Leadership and strategy	Effective leadership and management			✓		✓	✓	✓
	Empowered stakeholders				✓		✓	✓
	Integrated development planning					✓	✓	✓
Health and Well-being	Minimal human vulnerability	✓		✓			✓	✓
	Diverse livelihoods and embayment				✓		✓	✓
	Effective safeguards to human health and life	✓		✓	✓		✓	✓
Economy and society	Collective identity and community support					✓	✓	✓
	Comprehensive security and rule of law			✓	✓		✓	✓
	Sustainable economy				✓	✓	✓	✓
Infrastructure and ecosystems	Reduced exposure and fragility			✓		✓	✓	✓
	Effective provision of critical services	✓	✓	✓	✓	✓	✓	✓
	Reliable mobility and communications		✓	✓			✓	✓

Adapted from Arup (2014)

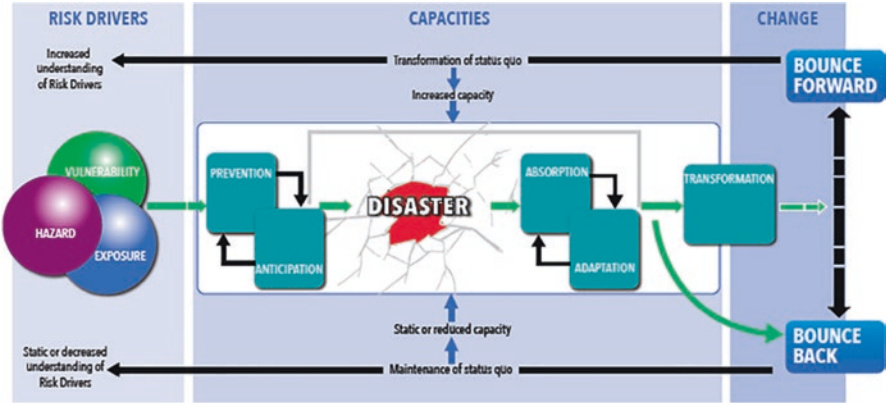

Fig. 7.5 Disaster resilience integrated framework for transformation. (Manyena et al. 2019)

- *The preventive and mitigation capacity*: This capacity conflicts unsustainability and struggles to enhance the capacity to deal with disturbances.
- *The anticipative capacity*: The anticipative capacity of a system is how the system predicts the possible effects of a disaster. Increasing knowledge about possible harms (when, where, and how) through analyzing different scenarios results in anticipative capacity enhancement.
- *The absorptive capacity*: This capacity is related to capacity of defense from system values against disasters. A system with more losses has lower absorptive capacity.
- *The adaptive capacity*: Adaptive capacity is the capacity of a system to adjust probable adverse effects. Practically, a system with diversity of values is more adaptive.
- *Transformative capacity*: Transformative capacity is about eliminating barriers that cause a system not to use the opportunities.

3. The final time step emerges after disturbances. As discussed before, a system could gain an equilibrium state after a disaster which is different from the previous one. If a system has low transformative capacity, it would only bounce back, but if transformative capacity has been enhanced, a system would use provided opportunity and gain a preferable state.

8 Urban Resilience Assessment

In fact, assessing urban resiliency seeks to measure the quality of the resilience framework implemented in a city and its plans in each phase. Therefore, after implementing the resilience framework in cities, it is necessary to evaluate and measure resilience in cities. Resiliency measurements are needed to understand deficiencies to achieve the resiliency goals. By recognizing these deficiencies, they are focused to enhance the urban resiliency. Measuring resiliency explains about the needs for improving urban resiliency and how to prioritize them. They also establish baselines, address costs and benefits, and illustrate success and challenges toward urban resiliency by monitoring the resiliency development progress. They also evaluate different policies to enhance urban resilience (Cutter 2014).

There are several metrics which can be implemented for measuring urban resiliency. Some of these metrics are used after disaster occurrence, and some of them are applied before disaster. Regarding the four phases in developing a resilient city, metrics should be defined in a way that covers all the phases. Totally, based on Sharifi and Yamagata (2016), in the *planning* phase, it is important to understand baseline conditions. So the metric should seek how planners enhance their awareness of requirements and how they implicate variety of possible scenarios. The main purpose of the *response* phase is to absorb the effects of disasters without severely impairing the performance of the system. So comparing the performance level after and before disaster can be a metric. In the *recovery* phase, the speed of recovery should be a measure. And after all, in the *adaptation* phase learning from the previous events should be measure. Some of these metrics are outcome-based (like recovery speed and performance loss) measures, and some other are process-based measures (like learning from past). Table 7.6 shows some measures which can be used for assessing urban resiliency.

Table 7.6 Measurement tools of urban resilience

	Related phases			
Measure	Prepare and plan	Absorb	Recover	Adapt
Baseline assessment	✓	✓	✓	
Monitoring and regular update of baseline conditions	✓		✓	
Comprehensiveness and multidimensionality	✓			
Forecasting/scenario making, probabilistic approaches	✓	✓	✓	✓
Comparing pre- and post-event performance		✓		
Identifying a minimum satisfactory level of post-event functionality		✓		
Loss estimation models	✓	✓		
Speed of recovery			✓	
Efficiency of actions	✓	✓	✓	✓
Identifying recovery timeline (maximum desirability)			✓	
Tracking recovery status at regular time intervals			✓	
Savings in recovery time and budget attributable to planning and absorption	✓		✓	
Adopting participatory approaches	✓	✓	✓	✓
Learning from the past events (longitudinal analysis)				✓
Prioritization	✓		✓	

Adapted from Sharifi and Yamagata (2016)

9 Summary and Conclusion

The frequency and intensity of disasters are increasing in recent years due to different human activities and climate change impacts. Regarding the high population density in urban areas, these disasters result in huge human and property loss over the world. Therefore, in recent years, disaster management in urban areas has been changed into a crucial topic. Different approaches are employed in disaster management to decrease the disaster impacts and recovery time. Two main approaches are increasing resistance and resiliency in urban areas. Even though both of these approaches are useful, considering the high uncertainties in disasters and their increasing frequency, increasing the resistance of urban areas against different disasters seems to be too expensive and inefficient. But urban disaster resilience can overcome these issues. The most important benefit of urban resiliency approach is that the efficiency of resilient city does not abruptly change during disasters. In this approach socioeconomic resiliency is considered which is defined as ability of the system to absorb, recover from, and adapt to impacts of disaster which is achieved through having preparation and having plans to get by disasters. The four phases of planning, response/absorb, recover, and adaptation are considered in this approach.

The main features of a resilient urban system can be summarized in 4R which are robustness, rapidity, redundancy, and resourcefulness. A resilient system should be strong enough against disasters (robustness), and there should be different ways/components to supply a service/good (redundancy). Furthermore, the system should be able to get back to its previous state after disaster in the shortest time (rapidity), and there should be enough resources to be used in disasters (resourcefulness). Increasing the urban area resiliency is an essential process to achieve sustainable development goals in cities. For developing resilient cities, it is needed to have frameworks. These frameworks at the first step could be general without considering a specific disaster, and in the next steps regarding the main disasters in the study area, more specific frameworks for the concerning disasters can be developed. To evaluate the progress toward resilient urban areas, specific measures are used which must cover the four phases of urban resilience. Managers should pay attention to more important backgrounds in human lives which are highly related to cities. They should set their goals which are embedded in these different backgrounds and monitor them.

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Chapter 8
Cascading Disasters: Multiple Risk Reduction and Resilience

David Alexander

Abstract The connectedness and interdependency of modern society mean that, when disaster strikes, it is likely to involve cascading consequences. This chapter examines the nature of cascading disasters in terms of the cross-sectoral linkages that they exploit. Escalation points can arise, in which interactions between different forms and scales of vulnerability lead to impacts that may be greater or more serious than those of the hazard that started the cascade. Natural and technological events combine in cascading disasters to produce complex consequences. To understand such processes, a full understanding of disaster vulnerability is required. A model is presented which avoids the usual categories into which forms of vulnerability are placed and encourages instead a more holistic, cross-disciplinary approach to the phenomenon. The chapter then examines how cause is turned into effect by the interaction of specific and general vulnerability, representing direct causes of disaster and contributory or contextual factors, respectively. Dealing with cascading disasters requires planning based upon suites of scenarios that represent different sets of cascade paths. Foresight and mitigation need plans to be based on understanding the range of possible cascade mechanisms and providing redundancy in the proposed solutions to them.

Keywords Cascading disasters · Critical infrastructure · Vulnerability · Resilience · Disaster risk reduction · Multiple hazards

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1 Introduction: The Cascading Disasters Concept

Modern society is based on a web of interrelationships. Complex flows of energy, commodities, people and information enable countries, firms, organisations, people and families to conduct their affairs safely and productively. Modern infrastructure and communications sustain the levels of interaction that most human endeavours require in order to function. Because of the high level of interconnectedness that society enjoys in the modern age, when disaster strikes, damage and interruptions may propagate through the networks and create adverse effects that go far beyond the initial impact. This is the basis of cascading disasters. Such is the complexity of modern society that, above a rather low threshold, virtually all civil contingencies will be cascading events to a greater or lesser degree (Alexander and Pescaroli 2019).

A cascade will begin with an initial impact whose consequences will then begin to work their way through the system. Many cascades are propagated by critical infrastructure failure. Thus they illustrate the degree to which society is dependent on infrastructure in order to function and the consequences when such life-support systems become inefficient or inoperable. Critical infrastructure can be defined as a set of physical and electronic assets that are vital to the delivery and integrity of essential services upon which society relies for its normal functioning (UK Cabinet Office 2010). Infrastructure is regarded as critical when its loss or compromise (at the national or local scale) would lead to severe consequences for economic and social activities and, in extreme cases, potentially to loss of life (Yates 2014).

In 1983 Kenneth Hewitt and his colleagues published a book that, with theory and examples, demonstrated that vulnerability is the principal component of disaster (Hewitt 1983). In many instances the other great constituent, hazard (or threat) is merely the catalyst. Vulnerability is therefore the key to understanding the potential for disaster and the mechanisms at work when it strikes. Vulnerability is also critical to knowledge of cascading disasters. However, it is an elusive phenomenon and one that is essentially as latent as it is manifest. Hence, it is difficult to recognise and characterise (Birkmann 2006). Vulnerability and hazard are sometimes clarified by the concepts of exposure and susceptibility. Both terms refer to the propensity of a person or an asset to be in harm's way (i.e. exposed or susceptible to risk). However, vulnerability and hazard remain the core concepts that define risk and subsequent impact.

One of the essential characteristics of critical infrastructure is the chain or web of interdependencies (Baina et al. 2008). Failure in one domain can thus have consequences in places and systems far removed from the point of origin. If this were a matter of simply transmitting failure from one element of infrastructure, or one vulnerable asset to another, it would be expected that the effect of a cascade would attenuate with time and distance. However, another factor intervenes. The interaction of different kinds of vulnerability can create *escalation points*, in which the secondary impact may sometimes be more severe than the primary one (Fig. 8.1; Pescaroli and Alexander 2015).

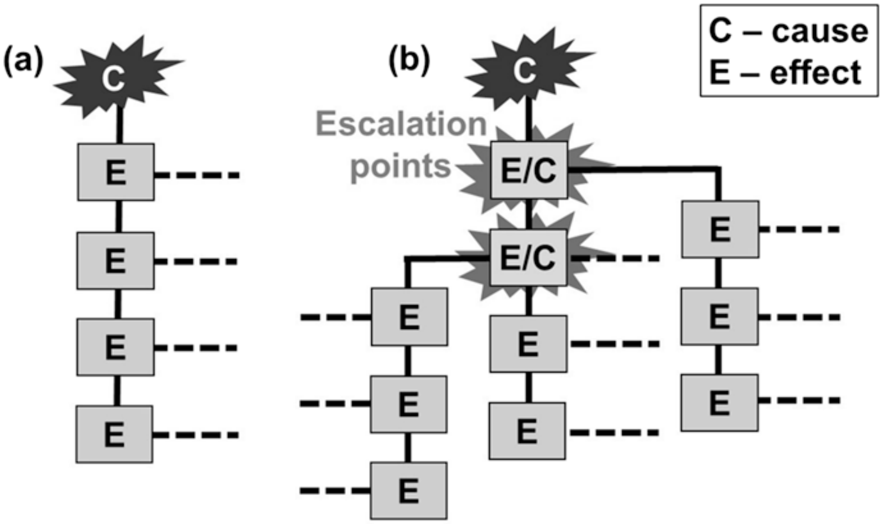

Fig. 8.1 Simple and more complex cascade chains

One of the largest, most complex cascading disasters in recent history was the magnitude nine earthquake and tsunami that struck northeastern Japan on March 3, 2011. Damage to the automotive industry caused a worldwide shortage of components that temporarily shut down vehicle production as far away as Europe. Perhaps the greatest escalation point was the set of hydrogen explosions and reactor core meltdowns that occurred at the Fukushima Daiichi nuclear plant on the coast of Fukushima Prefecture. The resulting emissions led to radioactive contamination of land that will have consequences for decades or centuries to come (Elliott 2013). To give an idea of the scope and complexity of the nuclear disasters, a selection of the consequences is listed here:

- *Social:* displacement of people from contaminated land
- *Psychological:* isolation and depression, including an increased rate of suicides.
- *Health:* monitoring, treatment and prevention of radiologically caused diseases
- *Technical:*
  - How to contain the reactors, decommission them and clean up the power station site
  - What to do with recovered radioactive soil, water and debris
- *Economic:*
  - Shutdown of agriculture and commerce in the affected area
  - The cost of decommissioning and clean-up
  - Impact of radioactive contamination on local fisheries

- *Environmental:*
  - Contamination of the Pacific Ocean and the nearshore area.
  - Contamination of wide areas of land and coast
- *Business continuity:*
  - Interruption of schooling and productive activities
  - Impact of reputation damage on tourism in Fukushima
  - Reputation damage to agriculture in Fukushima Prefecture
- *Demographic:* depopulation of affected areas, including decontaminated human settlements
- *Infrastructural:* need to build new infrastructure in contaminated lands.

This list divides the problems caused by the nuclear disaster by sector, but in reality there is also a need to consider cross-sectoral effects, such as the relationship between contamination, physical and mental health and agriculture (Kachali et al. 2018).

To understand cascading disasters and their cross-sectoral effects, it is necessary to consider the role of vulnerability and what happens when different vulnerabilities combine. Although vulnerability is now widely studied, its role in and impact upon cascading events are still relatively poorly understood, especially in the light of the growing complexity of modern life, emerging risks and interaction between risks. This poses a limitation to the present work in terms of its ability to shed light on the intricate details of cascading events. In the course of time, more research will doubtless rectify the problem.

2 Vulnerability: A Starting Point for the Analysis of Cascading Disasters

The word vulnerability is derived from the Latin *vulnerare*, meaning ‘to wound’. Broadly, it refers to the exposure of a person, asset, good or activity to potential harm or loss (see Weichselgartner 2001 for a list of definitions of the term). Several paradoxes are associated with the concept. First, although vulnerability can be disaggregated for the purposes of analysis into components such as physical, social, economic and psychological, it is nevertheless essentially holistic, i.e. the whole entity suffers harm (Cardona 2004).

Secondly, like risk, vulnerability is a hypothetical concept but one that nevertheless does not lack reality. It is simply not tangible: in the same way that in the physical world friction only comes into being when it is mobilised, so vulnerability only becomes physically apparent when it manifests itself as impact. This is one reason why the concept is difficult to measure. Confirmation of the existence of vulnerability is obtained post hoc by measuring the impact of disaster or at least by inferring that past impacts will be diagnostic of future events. Vulnerability is thus a latent or inherent property.

One of the great achievements of disaster studies in the second half of the twentieth century was to establish that vulnerability is the principal component of risk (Hewitt 1983). In the more extreme formulations, hazard (the other main component) is regarded as merely the trigger of risk conditions. Vulnerability is considered responsible for the bulk of the propensity to suffer harm. This formulation is commonly used when dealing with extreme poverty (Boyce 2000). As a result, it becomes easy to confound risk and vulnerability. Indeed, there is an element of circularity in the standard conceptual equation:

$$\text{Hazard} \times \text{Vulnerability}\left[\times \text{Exposure}\right] = \text{Risk}\ \textit{leading to}\ \text{Impact}$$

The main consequence of this is that vulnerability can be difficult to isolate from risk. In part this reflects the complexity of socio-economic factors associated with the concept, as the physical connotations of hazard are often relatively straightforward by comparison. Essentially, hazard is active, and vulnerability is passive. Hence, risk is not directly caused by vulnerability, but it is greatly, perhaps overwhelmingly, enhanced by it.

In the conceptual equation given above, the role of exposure is contentious because the term has different meanings. In the insurance world, it refers to the maximum liability for payment of compensation to policy holders (Van der Voet and Slob 2007). In the nuclear field, it represents the length of time that a subject is at risk of receiving a dose of radiation, with or without some indication of the possible strength of that dose. In hazards studies, the simplest definition refers to the proportion of time that a person or asset is threatened by a particular risk (Wacholder et al. 1994; Lerner-Lam 2007).

Given the role of exposure, it is important to note that vulnerability is not an 'all or nothing' concept. Many studies of risk conditions are based on the propensity for total losses (e.g. Hsu et al. 2011; Nadal et al. 2013; Padgett and Tapia 2013). This, of course, assumes an utter inability to resist the impact of disaster. Resilience (or coping capacity) is a concept that derives some of its most useful definitions from rheology, the physical behaviour of materials. In this context, it refers to the ability of a substance (or in this case of society) in balanced measure to absorb and resist the shock of impact. As a material needs an optimal combination of strength to resist and ductility to absorb a force, so society must resist and adapt to a hazard. Resilience, or coping capacity, is broadly the inverse of vulnerability, although, such is the complexity of society, there are circumstances when both can coexist.

$$\left(\text{Hazard} \times \text{Vulnerability} \times \text{Exposure}\right) / \text{Resilience} = \text{Risk}\ \textit{leading to}\ \text{Impact}$$

Alternatively,

$$\text{Hazard} \times \left(\text{Vulnerability} / \text{Resilience}\right)\left[\times \text{Exposure}\right] = \text{Risk}\ \textit{leading to}\ \text{Impact}$$

Hence, vulnerability can be partial. If it is quantifiable, it can be expressed as an index or percentage relative to total loss. If it can be assessed, categories may be used, such as severity of injury relative to lethality or degrees of loss of the structural integrity of a building relative to total collapse. In any event, many hazard impacts mobilise only a portion of vulnerability. For example, very few earthquakes cause total devastation to a city, and the patterns of seismic damage in urban environments can be highly complex (Wisner 1999).

The ability to disaggregate vulnerability into different components indicates that it can take different forms. The field of business continuity management (BCM) is founded on the notion that vulnerability has different components, which apply, for example, to the supply chain, the manufacturing or production process, relationships with clients, customers and suppliers, the market value of a company's shares, its position with respect to competitors and its reputation with investors and customers. Damage in any of these sectors can mobilise vulnerability in other categories (Kemp 2007).

One possible interpretation of vulnerability is that it can be defined relative to the circumstances that generate it. The following model breaks vulnerability down according to its context (Alexander 1997; Özerdem and Jacoby 2006):

- *Total vulnerability:* life is generally precarious because little or nothing has been done to reduce the sources and potential impacts of risk. This condition tends to apply to poor and marginalised societies which lack the resources to protect themselves.
- *Economic:* people lack adequate occupation, and hence vulnerability refers to the precariousness of their productive activities and sources of income.
- *Technological or technocratic:* caused by the riskiness of technology or of the ways in which it is utilised.
- *Residual:* caused by lack of modernisation, in which risk conditions evolve but mitigation strategies do not keep pace with them.
- *Delinquent:* caused by corruption, negligence or criminal activity that puts people or assets at risk.
- *Newly generated:* caused by change in circumstances, for example, as a result of newly emerging risks.

Such is the complexity of society that these categories need not be mutually exclusive. They should, however, be elements of a progression, towards either greater vulnerability or amelioration of existing vulnerability.

Like risk, vulnerability can be chronic or catastrophic, depending on whether it results in widely diffused malaise or concentrated disaster. It applies to known risks, adapting risks, emerging risks and unknown risks. Whereas the process of investigating vulnerability in the context of the first of these is relatively straightforward, it becomes much more difficult when applied to adapting risks (e.g. those associated with climate change) and emerging risks (e.g. pandemics). It cannot be achieved for unknown risks, the ones that will emerge in future scenarios. The management of vulnerability must involve holistic techniques that take account of the categories in which it occurs and the different degrees and levels of interaction between them

(Cardona 2004). This is necessarily so, as managing vulnerability with regard to single themes and cases will merely allow it to escape into other categories and will thus not reduce it. Holistic analyses must precede holistic remedies.

Vulnerability is susceptible to the dialectic of forces that act to increase or diminish it. The concept is not static but is continually modified by forces that amplify or mitigate it. Thus, the vulnerability of settlement on a floodplain can be diminished by structural and planning measures but simultaneously amplified by building new structures that are at risk of inundation (Elmer et al. 2012). Perception is the deciding factor; providing one takes into account its links with decision-making and action. Low or inaccurate perception of hazard can perpetuate vulnerability, while high perception can lead to its reduction. Given the dynamic environment in which it occurs, measures taken to reduce vulnerability need to be sustainable. If they are not, it will inevitably climb back again.

Sustainable vulnerability reduction is locally based, supported by the community, well integrated into legislation and planning instruments and part of a grand strategy to make life more resilient for the inhabitants of the area in question. It goes without saying that resilience depends on sustainability and must be a sustainable process (Wisner 2004).

3 Vulnerability and Cascades

If vulnerability takes different forms or has different components, not only will it be multifaceted, but there will also be interaction between the components. Hence, it may be additive, and there may be *gestalt* (i.e. the whole may be more than the sum of the parts). Chains of causality, interactions between the parts and collateral and secondary vulnerabilities may come into play (Pescaroli and Alexander 2018). Thus, we may define *primary vulnerability* as the direct product of cause and effect. For example, if an earthquake shakes a dilapidated house, the poor quality of the masonry may cause the building to collapse. No *gestalt* is present. *Secondary vulnerability*, potentially with moderate gestalt, results from the interaction of causes or the occurrence of coincidences. For instance, a building may resist earthquake shaking but not the water wave caused by the breaching of a seismically induced landslide dam upstream (Xu et al. 2012). *Complex vulnerability* involves high gestalt and occurs when complicated interactions between components heighten overall vulnerability. The ramified economic effects of a major earthquake in a metropolitan city would produce this.

Vulnerability can be measured or estimated directly as potential for harm or loss (Birkmann 2006). However, this requires hypotheses of the potential impact of events that have not occurred but are likely to. There is, of course, scope for inaccuracy in such theorising. It can also be measured indirectly as ‘non-resilience’, i.e. the failure to be robust in the face of a threatening event. The fault trees and event trees used in the risk analysis of industrial processes (You and Tonon 2012) are an example of this and could be adapted to other forms of investigation, for example,

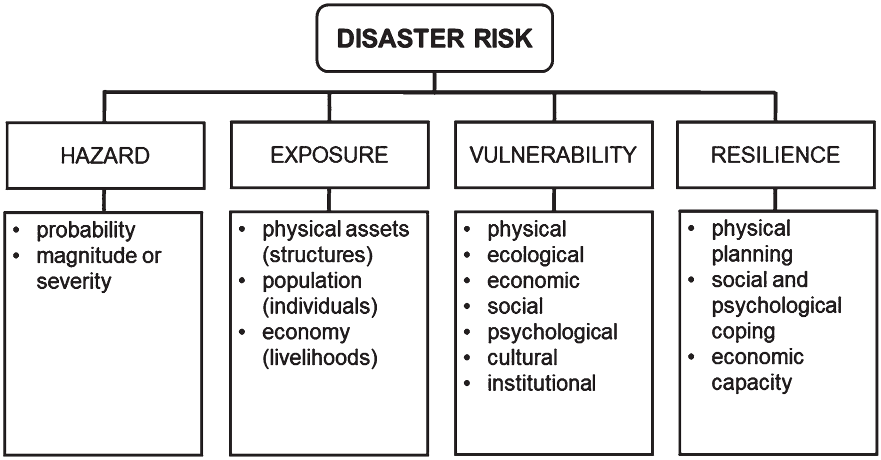

Fig. 8.2 Elements of disaster risk. (After Birkmann (2006, p. 23), and other sources)

with society. Figure 8.2 shows a simple classification of the elements of disaster, which is also a basic guide to measurement and estimation.

Vulnerability is often measured by category: physical, ecological, economic, etc. However, this tends to ignore the complex linkages and interactions between the categories. For example, economic decisions may affect the environment and hence have an impact on ecological vulnerability. The answer is to endeavour to measure vulnerability as a *process*, rather than a phenomenon, or in other words dynamically. In doing so, it is recognised that resilience is to some extent the antithesis of vulnerability, but it is also clear that the two are not polar opposites, as they can coexist in different categories and at different time and geographical scales (Manyena 2006; Miller et al. 2010; Gotham and Campanella 2011).

4 Vulnerability, Panarchy and Cascades: Linking Cause and Effect

One of the most widely used formulations of disaster causality is the so-called pressure-and-release model of Wisner et al. (2004). In this, the root causes of vulnerability are manifest in unsafe conditions. These are acted upon by dynamic pressures and hazards, so that disaster results. Poverty is a typical root cause and one that limits people's abilities to command resources that might increase their opportunities to protect themselves from hazards. Many of the world's poorest neighbourhoods are located in unsafe places, such as floodable land or unstable slopes. Dynamic pressures, such as marginalisation or population growth, increase the risk. When hazards strike, the impacts of disaster can be profound. This model emphasises the primacy of vulnerability over hazard as the main cause of disaster. It also focuses attention on root causes, the need to explain disaster in terms of fundamental processes, particularly the power structures that determine the ownership of resources and how they function.

The pressure-and-release model has enjoyed decades of success since it was first proposed in the 1990s (Blaikie et al. 1994). However, it has room for improvement. To begin with, more emphasis should be given to the context in which disasters occur. Marginalisation comes to the fore when particular groups lose political, economic and social power and thus are forced to give up some or all of their rights to self-determination. Poverty, marginalisation and disaster risk go hand in hand (Walters and Gaillard 2014). The result is general vulnerability, which is the context in which specific vulnerability to particular hazards occurs (Fig. 8.3). It can be difficult or impossible to create resilience to specific vulnerability in an environment in which general vulnerability is high. Precarious employment, polarisation of society, conflict and the rationing of basic services are all examples in which general vulnerability impinges upon specific vulnerability to hazards. In some developing countries unsafe informal housing is another major source of vulnerability (Abunyewah et al. 2018).

In reformulating the pressure-and-release model, we can define the causes of disaster as direct (immediate practical problems), long-term (engendering a predisposition for disaster) and root causes (consisting of underlying and motivating factors). Context impinges particularly upon long-term and root causes (Fig. 8.4). It also guides the progress of cascading effects by providing opportunities for, or barriers to, impacts.

Specific vulnerability is a direct function of susceptibility to disaster, whereas general vulnerability is determined by aspects of the social, economic, environmental and organisational environment that are not artefacts of exposure to potential disaster. Cascading effects manifest a form of *panarchy*, defined as ‘evolving hierarchical systems with multiple interrelated elements’ (Gunderson and Holling

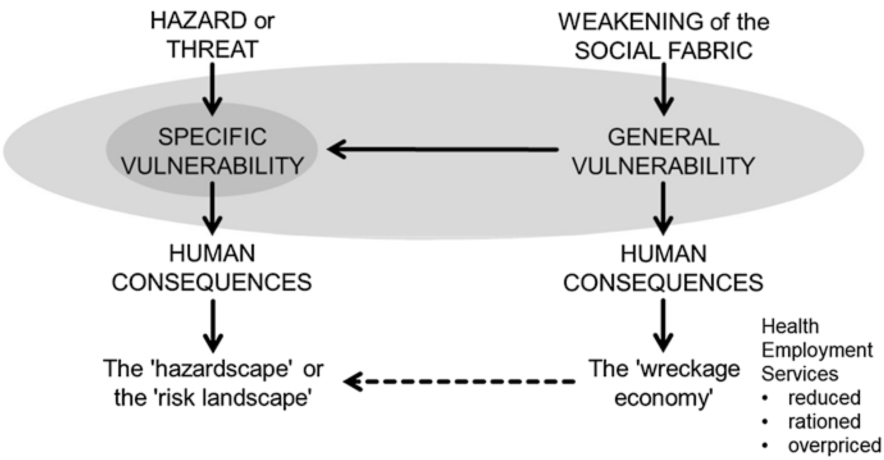

Fig. 8.3 Specific and general vulnerability

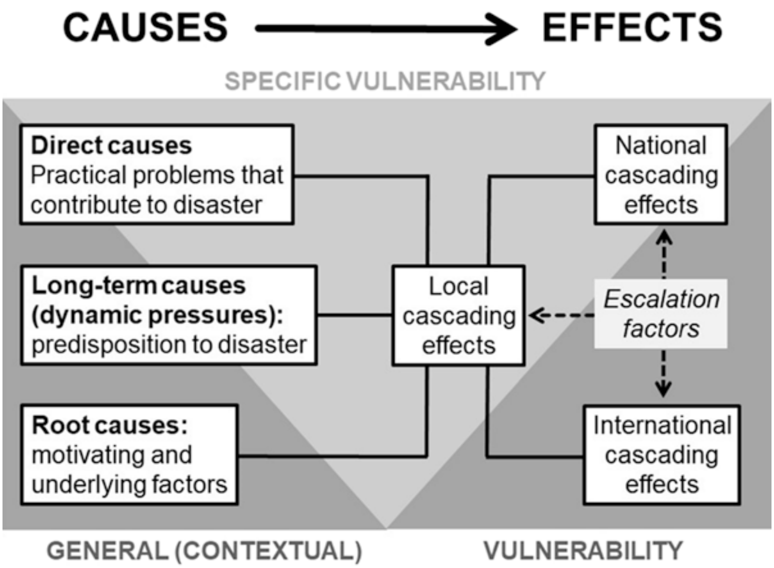

Fig. 8.4 Cause and effect in complex, cascading disasters

2002, p. 74). The interrelationships that drive the cascade involve vulnerabilities which interact at diverse spatial and temporal scales (Pescaroli and Alexander 2016). Local cascades can thus be replicated at the national and international levels. For example, the use of flammable cladding panels on a high-rise residential black in London, England, contributed to a fire that killed 72 people in June 2017, the Grenfell Tower disaster (Moore-Bick 2019). The response of the emergency services to this disaster was criticised, as it relied on assumptions about compartmentalising retarding the spread of the flames, which instead rapidly enveloped the building (Cowlard et al. 2013; LFB 2018). Both building safety and emergency response then needed to be reviewed throughout the United Kingdom. Several hundred residential tower blocks were found to be at extreme risk, and similar fires occurred elsewhere in London and England. As well as public safety, there were economic effects in terms of the loss of value of apartments and the cost of retrofitting buildings. Coupled with the continuing fire risk, these led to psychological problems for the residents. Analogous events disasters in a number of countries (notably Australia, France, Dubai and Kazakhstan). Grenfell Tower thus contributed to a problem that had distinctly international connotations, which illustrates how cascades can operate simultaneously at substantially different scales.

5 Multiple Risk Reduction and Resilience

The high degree of reliance that society places on critical infrastructure and the growing complexity and interdependency of modern styles of living indicate that cascading disasters need to be planned for as a matter of routine. A very good reason for doing so is the need to anticipate developments in order to prepare for them. Not all consequences of disaster are obvious, but very many of them can be foreseen by prudent planning.

Where possible, emergency plans should be based on scenarios (Alexander 2016, Ch. 6). These should be developed, not as attempts to predict the future, but as multiple explorations of possible future developments (Mignan et al. 2016). The result should be an envelope of outcomes that extends from very moderate impacts to the foreseeable worst case. Scenario modelling needs to be a dynamic process. Society and economy are constantly changing. Patterns of aggregate human activity vary diurnally, seasonally and by contingency. Hence, the risk landscape is constantly changing at a variety of time and space scales. The purpose of cascading crisis analysis should be to understand the changes and their relationship to vulnerability, exposure and potential impacts. Much of the scenario work is usually done by adapting past events to current and future situations. It also involves using past events in different places as guides and analogies for what could happen in the area covered by the emergency plan (Pescaroli 2018). In this respect, the cascading disasters magnitude scale (Alexander 2018) is designed to facilitate comparison among events of similar sizes, complexities and impacts that occur in different places. It is a tool for emergency planners who seek analogues of risk situations to the ones they must confront in their own area. This process can be further enhanced by using the techniques associated with case-based reasoning (Aamodt and Plaza 1994; Amailef and Lu 2013).

The resilience of infrastructure systems can be defined and measured quantitatively. Measurement of the impact of disruptions requires modellers to estimate damage states, downtimes, operational inefficiencies and the costs of repair and recovery. In areas in which hazards are prevalent, investment needs to be concentrated in strengthening weak points and links in the networks or providing redundancy so that they can be bypassed (Vugrin et al. 2010). Most general infrastructure resiliency models use electricity supply and distribution as the basis of the network (Silvast 2017). Power outages have varying impacts on the rest of the system, and these can be estimated in specific modules of the simulation model (Reed et al. 2009). Preparedness requires knowledge of hazards and the characteristics of the network, including its resistance to specified shocks and stresses. The potential paths by which vulnerabilities interact and are propagated also need to be charted (Pescaroli and Alexander 2016). An assessment also needs to be made of potential damage states. Modelling first defines network dependencies and then explores how faults are propagated. This helps define the damage state of the whole network or, in the case of various types of interdependent infrastructure, the 'network of networks'. Once damage has been predicted, a further prediction can be made of the recovery time of the network with regard to specified impact levels (Guidotti et al. 2016). In this context, one potentially controversial but vitally important question is how one decides on the worst-case scenario (Sunstein 2007).

Because of their ability to generate compound effects, cascading disasters are a serious threat to resilience. However, the very complexity that causes them can be harnessed to reduce their impacts. Foresight will enable emergency planners and managers to anticipate needs generated by cascades. When there are many possible outcomes, *redundancy* is needed. In its simplest form, this is expensive, perhaps prohibitively so. Doubling equipment in case it fails is usually only feasible for high-reliability systems, in which society is prepared to spend lavishly on safety measures. Examples of these include those technological systems that are installed in aircraft and surgical operating theatres (Rijpma 1997). However, redundancy also involves simply providing different routes to solving a problem, hence flexibility in the formulation and application of strategies (Weick 1987; Nowell et al. 2017).

The essence of the cascading disasters problem is that the cascading paths involve the interaction of vulnerabilities. An earthquake, for example, may cause landslides, liquefaction damage, toxic spills, tsunami or seiches, which may compromise human lives and activities in a wide variety of ways. Multiple hazards bring to the fore the concept of the ‘na-tech’ disaster, in which the trigger may be a natural hazard, but many of the effects are the result of damaged, compromised or malfunctioning technology (Krausmann et al. 2016). In the context of communication, Noble (1984, quoted in Quarantelli 1997, p. 96) wrote that:

> …close inspection of technological development reveals that technology leads a double life, one which conforms to the intentions of designers and interests of power and another which contradicts them—proceeding behind the backs of their architects to yield unintended consequences and unanticipated possibilities.

Although this is particularly true of means of communication, such as social media, it is equally appropriate to other forms of technology. Failure of infrastructure, for example, can lead to both shortage of life-support mechanisms and ingenious ways of substituting them. This needs to be investigated in scenario-based emergency planning by examining the consequences of failure in the widest possible way and under the broadest set of assumptions. For instance, the kinds of transportation lockdown caused by volcanic eruptions (Alexander 2013) or epidemics (Smith and Fraser 2020) can damage commerce and business revenues but also give rise to reorganisation of supply chains and substitution of alternatives to face-to-face meetings. Again, redundancy should be employed.

6 Summary and Conclusions

Future disasters have a high likelihood of being cascading events, thanks to the increasing dependency of society on networks and supply chains. Resilience is a process not a goal, as society must constantly adapt to changes in hazards and vulnerability. Nowadays, resilience tends to be a collective enterprise rather than an individual one. It also has to be practised or achieved at multiple scales, in the form of panarchy, for vulnerability can cross scale boundaries with ease. Hence, a failure of some form of critical infrastructure may result in a host of individual problems for those who depend on it but also to a collective issue for activities of all sorts that require a collaborative effort. Electricity supply is the prime form of critical infrastructure, as all the other types are dependent on it. Electricity supply failures can thus cause loss of water and fuel supplies, wastewater treatment problems, gas supply problems, banking difficulties, food preservation problems and so on. Emergency planning and risk mitigation scenarios therefore need to explore the linkages in full and rank the problems in terms of their seriousness. This is very much a cross-sectoral issue.

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Chapter 9
Building Disaster Resilience Through Primary and Higher Education

Priya Namrata Topno

Abstract Education is one of the best media to spread preparedness and awareness among communities. Disaster education is one of the effective tools to save lives. Children are more receptive compared to adults and can influence their peers and parents. The school disaster education creates awareness among children, teachers and non-teaching staffs. The school curriculum is a good source to spread information about disasters. The risk and hazard education at school will enable the children to have accurate perception of risk and better understanding of protective measures. A proverb saying "educating a child is educating a family" brings about the shift from disaster preparedness approach to disaster resilience approach. Disaster resilience education (DRE) is an educational learning about natural hazards, risk in local environment and actions to protect the communities before, during and after any disaster or emergency situations. Disaster resilience education provides the young people and their families with various information such as increased awareness about local hazards and disaster risks, increased household preparedness and planning, reduced hazards-related fears and worries and increased capacities for effective emergency response. It also helps in personal development by increasing confidence and communication skills. Thus, the children and youth become the agent of change in their communities and promote disaster risk reduction as well as resilience.

Keywords Disaster education · Primary education · Higher education · Children · Disaster risk reduction · Resilience · Preparedness

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1 Introduction

Education is one of the best media to spread preparedness and awareness among communities and takes a pivotal role in reducing disasters (Izadkhah & Hosseini 2005; Nifa et al. 2017). Lack of preparedness creates many challenges during and after disaster situation. In developing countries, due to lack of expertise and educational materials, it becomes a challenging task to make society prepared for disasters. The simplest and easiest mode to generate awareness is to integrate disaster education on preparedness and awareness into children's educational programme both in preschool and school level as well as in higher education. Children act as good messengers to transfer disaster knowledge to their families, neighbourhood and communities (Izadkhah & Hosseini 2005).

Disaster event is the same for all, but individual capability and capacity in terms of vulnerability and coping capacity differ. Among many vulnerable groups, children are one. They have very little knowledge as well as experience about the hazards. There are many incidents where children are victimised such as the school building collapse during the Bhuj earthquake in 2001 (Gujarat, India), food poisoning cases in Mid-Day Meal Scheme in schools, fire tragedy at school, school bus accident, etc. (MHA 2011).

Disaster brings potential threats to personal, natural, cultural and economic resources. The increasing risk has been identified by the formal education system of India, yet it contributes to the vulnerability of children and young people. The youth need to develop the skill to understand the nature of risk in the local environment and also learn the ability to reduce the exposure and vulnerability of such harms (AIDR b).

Disaster management practices are necessary to make the individual self-resilient. This must be adapted since the early age. The paradigm shift from the culture of response to culture of preparedness could be achieved through the education system. The third priority of action in the Hyogo Framework for Action (2005–2015) focuses on building the culture of safety and resilience at all levels using knowledge, innovation and education (WMO 2019). Some initiatives such as school safety and integration of disaster risk reduction in school curriculum have become a national agenda in India. This will increase the level of awareness among children, teachers and parents. Curricula on disaster education can be found in both primary and higher education. The government of India has included the disaster education in the syllabus of Social Studies/Sciences of Central Board of Secondary Education (CBSE) Boards for class VII in 2003, IX in 2004 and X in 2005. Later, it was progressively added to classes XI and XII. The undergraduate courses have introduced the engineering aspects of disaster mitigation, and postgraduate courses have a specialised course on disaster management. The Tenth and Eleventh Five-Year plan of India have included the disaster management education in both primary and secondary levels in Indian education system (NIDM 2016).

The lack of adequate learning materials, trained teachers and sanitation facilities makes learning difficult for children. About 617 million children are unable to reach minimum proficiency level due to sickness, weakness from exhaustive work and hungry stomach. Many children are excluded from education due to poverty, disability, location, conflict and gender disparity (UNICEF 2019).

One of the limitations is that this book chapter has been written using the secondary data source.

2 Disaster Management in Education

Disaster is inevitable, and disaster education makes the society resilient. Children with knowledge about disasters and its knowhow are assets as they know how, when and where to react and respond in such situations. Disaster education is one of the effective tools to save lives. Disaster learning is a co-learning process through knowledge transfer. It is the sharpest weapon to have culture of safety through planning, preventive actions, capacity building and swift response (Topno 2017).

Disaster education is a wide range of pedagogical tool which helps to prepare for disasters. It includes school-based initiative, public information campaigns, family and community learning and adult education. Education and training are an integral part of capacity building which helps the personnel to be trained to respond during disasters. The technological advances have widened the learning methods including social media and blogs (Preston 2012). Cartoons are the easiest mode of knowledge transfer among children.

The present school curriculum provides information about disasters to parents. Mock drills at school premises enable the students to acquire knowledge about dos and don’ts about disasters. Street plays, essay writing and debate competitions, poster painting and slogan presentations enhance the capacity and provide innovative ideas about the preventive measures of disaster. Other ways to provide disaster education are through leaflets, public information films, notices and warning sirens, television and radio broadcasting and cell phone messaging (Preston 2012). Apart from schools, there are number of universities and institutes offering, certificate, postgraduate, diploma, masters and research degrees (Girdhar 2017).

The United Nations International Children’s Emergency Fund (UNICEF) had identified three challenges: inequitable access to education for children, global learning crisis and education in emergencies and fragile situation. UNICEF has continuously provided resources to strengthen the educational services in conflict-affected countries, epidemic and pandemic-stricken situations and delivered wide range of interventions for children both in development and humanitarian settings. It provides risk-informed programmes addressing multiple hazards, risks and shocks that would help to bring up the young people as better environmental stewardship (UNICEF 2019).

3 School Disaster Management Plan

A proverb saying “educating a child is educating a family” brings about the shift from disaster preparedness approach to disaster resilience approach (Topno 2017). Each and every school must have their own plan to confine, contain, consolidate and control the emerging crisis and emergencies. The school disaster management plan should have the school profile including number of students, teachers and staffs, along with the physical location of school, surrounding areas like land uses and other vulnerabilities. There should be maps showing the available nearest critical resource, safe areas and evacuation routes, and regular emergency drill must be conducted to train student body and teachers and to check the school response plan. The emergency drills for boarding schools must be conducted during night hours, and it should be location specific of the school such as school located near the sea should master drill for tsunami, those along the rivers should master drills for floods and those at the foothill should master for landslide apart from fire drills (MEHRD 2011). Schools should have warning system and communication protocol within and outside the school, identification of evacuation routes and access to emergency vehicles along with special care for children with special need (NDMA 2014).

The mandate of school disaster management plan (SDMP) should have a stock pile of emergency equipment and materials, regular maintenance of emergency equipment and orderly release of students to parents or guardians. A site map for each floor of the building should be displayed including evacuation routes and assembly areas. The schools should adhere with the safety standards as per the National Building Code (NBC), they should not be in vulnerable locations, classes should have adequate opening for evacuation, ventilation and lightening, and the door of classes should open outside. The non-structural safety measures of schools should also be addressed on a regular basis such as school furniture, electrical items, chemical and hazardous materials in laboratory, the staircase and corridor must be free from barriers for easy evacuation, there must regular maintenance of school buses, the driver must be trained on speed limits, stoppages and emergencies, and fire extinguishers and ropes must be properly located. Capacity building training of teachers, students and school staffs should be conducted at regular intervals (NDMA 2014).

The capacity building trainings related to emergencies in school include:

- Identification of potential disasters for the school community.
- Inventory management of resources available in the school and nearby.
- Warning signals, emergency instruction and mitigation actions for different levels of responses (age specific).
- Evacuation routes, knowledge of safe place and location of emergency shelters.
- First aid and basic life support, search and rescue.
- Psychosocial support and personal and group counselling.
- Updates on disaster management plan.
- Specific task allocation to students, faculty and staffs and formation of school disaster management committee.

Different stakeholders right from the block, district, state and national levels should be linked to address the safety of school community irrespective of whether the school facilities are government aided or privately owned (NDMA 2014).

Every child has a right to learn and a chance to change the world. UNICEF is providing inclusive learning opportunities with equity even in conflict zones. The

UNICEF education strategy (2019–2030) named "Every Child Learns" is an initiative of learning and skill development of children through three strategies:

- Equitable access to learning opportunities.
- Improved learning and skills development for all.
- Improved learning and protection during emergencies and fragile context.

The above strategies are associated with six approaches:

- Systems strengthening.
- Data and evidence.
- Innovation.
- Communications and advocacy.
- Community engagement.
- Service delivery.

The innovative technologies such as adaptive learning, artificial intelligence, gaming and virtual and augmented realities can bring about changes in the learning process and create a new demand on the education system and learners (UNICEF 2019).

4 Education Pyramid

The education pyramid shown in Fig. 9.1 defines that a school comprises of mostly students followed by teachers and other staffs, and there are few people in the school disaster management committee. Hence the capacity varies among the students, teachers and staffs. On the other hand, students have basic capability, whereas the

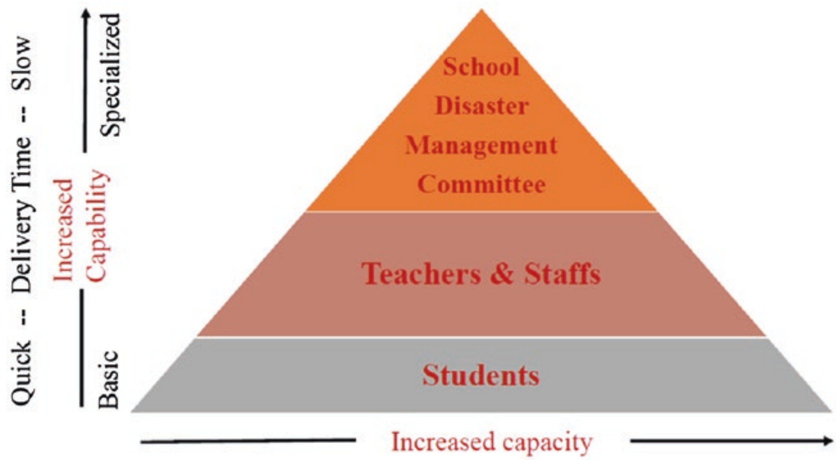

Fig. 9.1 School pyramid. (Modified from Pfeifer and Ophelia (2016))

capability increases with teachers and staffs, and it becomes specialised for the school disaster management committee. Students follow the instruction provided to them during any emergencies. Teachers follow the instruction given to them, and they guide the students to follow the same. However, the committee decides on what needs to be done to make the entire school prepared like conducting pre-disaster trainings and any important structural changes. Therefore, children are quick in delivery time, whereas it is a slow process with the school disaster management committee.

5 School Safety Policy in India

In India, the School Safety Policy was initiated by National Disaster Management Authority (NDMA) as the threat to physical well-being of children becomes visible nationally and globally. The children are extremely vulnerable section of our society due to various factors like age, gender, physical ability, health conditions and dependency on care givers. Child risks can be many such as fear, violence, separation from parents and caregivers, homelessness, exploitation and abuse. Disaster endangers the lives of children when schools are exposed to risk. As children spend their major time in school, the school must ensure safety and well-being of the children in their premises. The school is the best place to bring children to normalcy after a disaster by securing them physically, mentally and emotionally. Therefore, it is necessary to resume schools at the earliest after any disaster (NDMA 2014).

Schools should provide safe and secure environment for children and should have effective emergency management plans. School safety is defined as the creation of safe environment for children from their home to their schools and back. The safety factor includes safety from large-scale natural hazards, human-made risks, violence, pandemics as well as small-scale epidemics, frequent fires, transportation emergencies and environmental threats. School safety includes safety both inside and outside the school including structural as well as non-structural safety of educational institutions from all visible as well as invisible risks. The National Policy on Education (1986), revised as the National Policy on Education (1992), focused on “child-centred approaches” in primary education. Later, the National Policy on Disaster Management (2009) specified the safety of school buildings and hostels that they must resist earthquake and be equipped with fire safety measures, and subject concerning disaster management must be incorporated in Central and State Boards of Secondary Education. The Right to Education Act (2009) made the point that the state government and local authority shall locate school in such places where the risk of landslide, floods and lack of access to education can be avoided (NDMA 2014).

In India, the National School Safety Policy Guidelines apply for all the schools, be it government aided or private and whether located in rural or urban areas to ensure the safety of all children, teachers and other stakeholders in school community. The speed and effectiveness of disaster response will increase through teaching and practicing the emergency educational drills at school. Every school must be prepared and located at safe places. The safety of the schoolchildren depends on safe building and school environment. Education can be disrupted due to floods when schools remain closed for weeks and months, in earthquakes building may be destroyed, leading to injury or death of teachers, loss of school records, books and teaching materials, and fire can destroy the entire building. Disaster risk reduction and school safety planning should be a coherent part of reducing risk (Twigg 2015).

6 Disaster Resilience Education

Disaster resilience education (DRE) is an educational learning about natural hazards, risk in local environment and actions to protect the communities before, during and after any disaster or emergency. Disaster resilience among youth is comprised of these major functions:

- To recognise and assess specific hazards and understand risk in local environment.
- To learn from experience, knowledge, skills and cultural wisdom of others.
- To demonstrate skills and strategies for staying safe, seeking help and helping others during emergencies.
- To investigate challenges to community safety and work together.
- To design solutions to prevent hazards from becoming disaster.
- To share their learning, opinions and ideas with local decision-makers.
- To participate in actions for recovery after a disaster event (AIDR b).

Disaster resilience education system supports the primary and higher educators:

- To develop resilient, confident, successful and responsible learners.
- To implement disaster education into the school curriculum and course of higher education.
- To explore global issues of climate change and sustainability.
- To establish partnership with experts in natural hazards and emergency management.
- To transfer disaster-specific knowledge to families, young people and other diverse communities.
- To support, empower and enable children participation before, during and after disaster.
- To enhance the capacity to withstand and recover from disaster (AIDR 2019a, c).

Disaster resilience education can provide the young and their families with various information such as increased awareness about local hazards and disaster risks, increased household preparedness and planning, reduced hazards-related fears and worries and increased capacities for effective emergency response. It also helps in personal development by increasing confidence and communication skills. The youth become the agent of change in their communities.

UNICEF is working on the vision of 2030 Agenda for Sustainable Development. The fourth goal of the Sustainable Development Goals (SDGs) is to ensure inclusive and equitable quality education to all (UN 2015).

7 Disaster Resilience Education Frameworks

Disaster resilience education builds children and young people's capacity to become an agent of change in their households, schools and communities. It encouraged and strengthened the ability of teachers and other educators to deliver disaster education consistently to the young generations (Towers et al. 2017).

Many resilience and disaster risk reduction frameworks for the children and youth have been created that make them resilient and better equipped to cope with catastrophes. Disaster risk reduction needs to be included in the school and college curricula to instil the culture of safety and prevention among the children (Kumar 2012). Table 9.1 shows the key framework for disaster risk reduction and resilience in education.

8 Disaster Resilience Through Education

The world experiences natural as well as man-made calamities which are too difficult to predict. Disaster resilience means different things to different people. It is the ability of people, property and infrastructure within the community to recover from or adapt over time and to minimise the stress and shocks of different hazards. Disaster resilience can be achieved through learning, innovations and developing

Table 9.1 Key framework for disaster risk reduction and resilience in education

Documents	Focus
The Hyogo Framework for Action 2005–2015	*Priority 3: Use knowledge, innovation and education* (To build culture of safety and resilience at all levels)
Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR 2015)	*Priority 1: Understanding disaster risk* (Promote disaster knowledge in formal and non-formal education)
Comprehensive School Safety Framework (GADRRRES 2017)	*Pillar 3: Risk Reduction and Resilience Education* (Address all dimensions of risk reduction education)
National Strategy for Disaster Resilience (Commonwealth of Australia 2011)	*3.2. Understanding Risk* (Risk reduction knowledge in education and training programmes)
International Strategy for Disaster Reduction (ISDR 2003)	*Reduce risks and make community resilient.* (From protection measures to management of risk by integrating preventive actions into sustainable development)

Modified from AIDR (b)

skills and resources at individual, community and operational levels. Community awareness and education are a critical component of resilient and sustainable communities. There is a need to equip the people with more knowledge and skills to limit their vulnerabilities and to address and avoid the risks of adverse impacts of hazards.

The formative learnings in school and at university equip the professionals with skill sets through their whole of life education to achieve disaster resilience. According to the Australian government, disaster resilient education focuses on three key areas: professional, tertiary and vocational sectors and school-based sector to build capacity of teachers as well as raise awareness across all ages. In recent years, formal education, training programme and technical guidance for emergency management and disaster response have been increased for the professionals. The National Strategy for Disaster Resilience 2011 focuses on the priority area to build disaster-resilient communities and recognise that disaster resilience is a shared responsibility for individuals, households, businesses, communities and governments (CAG 2011).

Disaster education provides information about pre- and post-disaster risks so that children and youth could grow safely in resilient communities. Safe school projects like Plan International in Latin America have created platform among the children by generating awareness about identifying safe evacuation routes, practice evacuation drills and undertook child-led risk assessments by incorporating violence protection measures (Plan International 2019).

Public awareness is a process of embracing public education and simulating drills and life-saving strategies and plans. It is to achieve information exchange to ensure personal and community safety for those who are at risk. Disaster education and preparedness are to minimise long-term social and economic disruptions from hazards. The safety information and material vary from one vulnerable group to another. Materials on health safety and hazards are mostly incorporated into formal school curriculum to increase children's knowledge about understanding risk and teaching preparedness and to demonstrate how to react during disasters. (Izadkhah & Hosseini 2005).

Education is the basic human rights which is universal, inalienable and indivisible. It contributes to many of the SDGs. It empowers children, adolescents and youth (UNICEF 2019).

8.1 Disaster Resilience Through Primary Education

Children in primary schools can easily learn the culture of prevention, mitigation and preparedness. Children are the most vulnerable section of society during disaster (Nifa et al. 2017), yet they become a good channel to transfer this knowledge to their families and community. The young generation can take a proactive role in understanding risk, reducing the impact and spreading awareness. Children are more receptive towards new ideas and must be encouraged to be involved in making the world a safe place to live (Izadkhah & Hosseini 2005).

School is an important component to form culture of a society (Izadkhah & Hosseini 2005) and serves as a community's central location for meetings and group activities (Nifa et al. 2017).

The International Decade for Natural Disaster Reduction (IDNDR) is the platform where strategy to support school disaster education was developed. The main aim was to provide disaster preparedness and mitigation guidelines to children. This was to raise public awareness and knowledge of disaster. This would also help in disaster risk reduction in the coming generations and would make communities resilient. Thus, the plan was proposed to include disaster education in secondary as well as high school level textbooks. This was done to make children and their families prepared to take proper actions during hazards and to teach them the science behind all the natural hazards. The teaching materials that can be used to educate children includes comic strips, painting books, story books and crossword puzzles. Child awareness can be enhanced through different media and educational materials such as posters, pamphlets, brochures, games, drills, stories, role play, audio and visual tapes, drawing competition, writing competition, booklets, school textbooks, songs and the Internet (Izadkhah & Hosseini 2005). Other awareness programmes for children includes discussions, street plays, skits, puppet shows rallies, quiz competition, essay and slogan writing and peer to peer education (NDMA 2014).

In the USA, the Federal Emergency Management Agency (FEMA) website (https://www.fema.gov/disaster/4085/updates/fema-kids-know-facts) provides advice for children on how to be prepared for disasters. It contains connection lines for kids to kids where children can provide ideas about disaster and submit drawings. It also provides resources for teachers and parents along with disaster safety guidelines. The United States Geological Survey (USGS) website (https://earthquake.usgs.gov/learn/kids/) provides earthquake information for kids. The Australian IDNAR Committee has developed CD_ROM multimedia programme for schools known as "Hazards Happen". In Queensland, Australia, CD_ROM game called "Storm Watchers" was designed to instruct children about the preparatory behaviour during a cyclone (Izadkhah & Hosseini 2005).

The "culture of safety" is an ultimate goal for disaster reduction and mitigation. Child education plays a major role in educating the families and creating public awareness. Figure 9.2 shows the concentric circle model highlighting the interrelationship and linkages between disaster mitigation and public awareness. The clockwise movement demonstrates that educating children is the core responsibility to reduce disaster risk through mitigation.

The disaster lessons in school curriculum are incorporated into different subjects such as science, geography and exercised books. Table 9.2 shows different method used in schools to provide disaster educations in Iran.

In Iran, geography textbooks for 8, 9, 10 and 12 graders have course structure on seismic hazards and safety measures and earthquake preparedness. Textbooks for

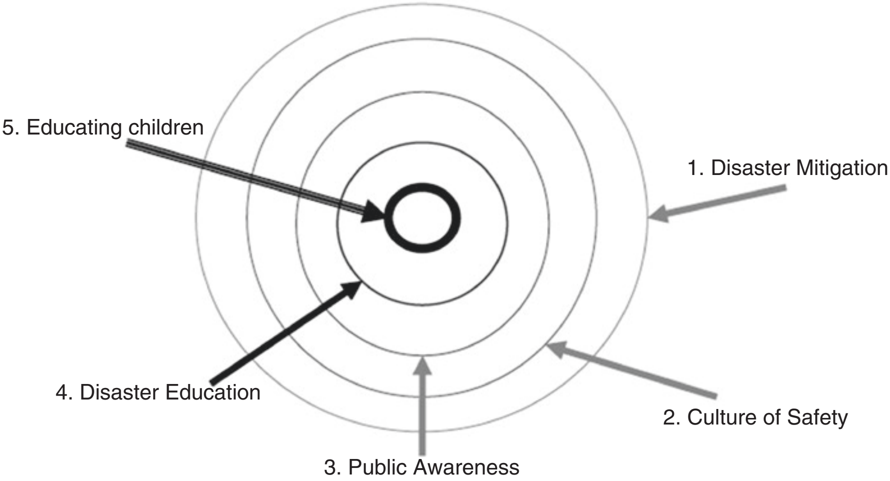

Fig. 9.2 Concentric circle model for disaster mitigation. (Source: Izadkhah & Hosseini (2005))

Table 9.2 Method of disaster education in Iran

Grade	Method of education
Preschool level	Posters, songs, role-play, drills and games
Elementary level	Textbooks, games, posters, drills, brochures and audiovisual tapes
Secondary level	Textbooks, posters, drills, brochures and audiovisual tapes
High school level	Textbooks, posters, drills, brochures and audiovisual tapes

Source: Izadkhah & Hosseini (2005)

grades 4 and 5 have a chapter on earthquake and a chapter called "Calmless Earth" in their science textbook. They also use a tool called "Shaking House" to make children understand and experience the feel of earthquake. Other modes used in disaster education at school level include mobile teaching facilities and trailers to teach them to be physically and psychologically prepared for disasters. Such techniques enhance students' interest to gain more knowledge and share it with friends and within families. Various countries have different modes to foster awareness in children such as radio and soap opera stories in Central America, puppet shows in China, disaster games in the Caribbean and mock drills in India. But the major drawback in spreading disaster education is that even though it is included in the curriculum of CBSE, the Indian Certificate of Secondary Education (ICSE) and international schools, government schools in small towns and villages lack such facilities and dissemination tools (Izadkhah & Hosseini 2005).

8.2 *Disaster Resilience Through Higher Education*

Initiatives in Australia and New Zealand on academic collaboration and partnership with government organisation have initiated an innovative and creative way to understand the resilience. They have introduced disaster education in the science curriculum of undergraduate courses which provided information on the science behind natural disaster, human behaviour and associated social factor. Students first undergo field research and then provide research finding and policy recommendation to the emergency management decision-makers. These activities provide community behaviours during disaster situation which enable them to understand the youth's and the adult's perspective on disaster preparedness and actions taken to enhance resilience. Community biasness, community risk perception and decision-making during hazards can also be understood. The potential capabilities of the students come in the forefront and enable them to choose their career pathways to extend in-class disaster management competencies and also to gain experience through internships (Bryan et al. 2017). Higher education should include both the technicalities of the process of mitigation and the understanding of sociopolitical and economical condition of the disaster-affected areas (Jayasurya 2017).

8.3 *Disaster Resilience Through Vocational Education*

Diploma and certificate courses are also offered in disaster management in various institutes where the minimum eligibility qualification is 10 + 2 or 12th grades. These courses will enable the students to know the basic skills to handle complex situation in just a year (Collegedunia 2018). Table 9.3 shows the types of programmes offered by different institutes in disaster management.

Table 9.3 Types of disaster management programmes

Programme	Institute	Duration	Eligibility
Certificate	IGNOU, New Delhi TISS, Mumbai	1 year 6 months	10 + 2 Graduation
Diploma	TISS, Mumbai Rajiv Gandhi University, Arunachal Pradesh IGNOU, New Delhi	1 year	Graduation
Online training	NIDM, New Delhi	4–6 weeks	–
Online certificate course	IFRC-TISS, Mumbai	1 year	Graduation

9 Case Studies

9.1 Coronavirus Pandemic, 2019

The coronavirus disease 2019 (COVID-19) pandemic has adversely affected the education system leading to the complete shutdown of all schools and colleges. More than 90% of the world's student got afflicted by the global pandemic which includes 1.54 billion children and 743 million girls (GEC-CP 2020). The education system has been completely disrupted such that primary to higher secondary systems of public and private education are either suspended, resort to hybrid methods of education delivery or closed. Universities and colleges have transitioned to virtual instruction system of classes, and students are admonished not to return to campus till further notice but meet academic requirements remotely (MEST 2020). Alternative learning channels including global education coalition through distant learning practice using hi-tech, low-tech and no-tech approaches, webinars, educational radio and televisions are making the learning process resilient through remote teaching and learning on online platforms (UNESCO 2019). Such initiatives are taken as mitigation measures to arrest the spread of COVID-19 in the institutions. Transitions from traditional education platforms and support to remote or virtual learning technologies have become a source for resilient education for children and youth as well as teaching staffs and professors (MEST 2020).

Children must be informed of the coronavirus disease including symptoms, complications, transmission and prevention, and they must also be made aware of fake information and myths. They can be a source of information sharing among their family and friends. Children stress must be understood by their care givers and responded supportively with age-appropriate facts and ways to protect themselves and others from infections. Children's feelings, concerns, questions and reactions should also be discussed and addressed by their care givers and teachers. The concept of social distancing, risk behaviour, good health hygiene behaviour and experimental education on spread of germs can be demonstrated, and the importance of washing hands with soap and water should be inculcated. Children must be encouraged to spread awareness and prevent stigma through songs, poems and posters (Bender 2020).

COVID-19 does not differentiate between age and gender. Children and youth are identified as the agents of change and next-generation care giver, scientist and doctors. During the crisis situation such as COVID-19, information and facts about the pandemic will reduce or diminish children's fears and anxieties about the disease and support their ability to cope with any secondary impacts. Such education can make student as advocates for disease prevention and control at home, school and their community (Bender 2020).

9.2 Cyclone Nargis, 2008

Education has been identified as a key to mitigate the impact of natural disaster. The Hyogo Framework for Action (HFA) discusses about the disaster risk reduction using education, knowledge and innovation to build the culture of safety and increase resilience (Tong et al. 2012). In 2008, about 4000 schools were destroyed, and about 600,000 children were affected by Cyclone Nargis in Myanmar. This had limited the children's access to education as the buildings were destroyed and facilities were damaged. Students remained out of schools for weeks, months and years. Disaster affects the education sector both during and after a disaster event. The National Strategy for Disaster Risk Management (2020) in Vietnam has integrated the disaster risk reduction (DRR) component into school curriculum to increase education and raise public awareness. The efforts focused are on enhancement of resilience capacity, safe schools and loss reduction by promoting multidimensional DRR education at policy as well as school level. In the primary schools located in Hue City, the learning methods have been changed, and activities are done out of class as extra-curriculum task incorporating both theory and practice. The programme focused on creativeness and proactiveness by creating interest and desire in studying. The trained teachers and students serve as a human resource to transfer disaster knowledge from one generation to another. Initiative on annual disaster response training programmes improves the practical skills. In Asian countries, education is a national product, and all decisions are taken up at the national level (Tong et al. 2012).

9.3 South Asia Flood, 2017

In August 2017, floods in India, Bangladesh and Nepal have destroyed 18,000 schools and thereby affected 1.8 million children who remained out of school. Humanitarian emergencies have less than 2% aid or funding towards education as it is not considered as life-saving activity. Many times, schools are identified as relief shelters, and this prevents the restart of schools after any disaster. School education can bring the normality among children and enable them to cope easily. Teachers know the way to deal with children who suffer from distress and provide more psychological support at school. By providing education in emergencies, children can escape many dangers like being recruited as child soldiers or sex worker or suffer rape (Their world 2017).

Many NGOs involved in such emergency situations have reported that the deaths include many children. Floods have damaged about 12,000 schools in India, 4000 in Bangladesh and 2000 in Nepal. Thousands of schools have been used as temporary shelters for displaced families. According to Jean Gough, Regional Director UNICEF, South Asia, "millions of children have seen their lives swept away by the devastating floods". Children lost their families, homes, schools, loved ones and friends. Many schools have also been converted to medical centres during crisis situations. Out of 2000 schools affected in Nepal, around 900,000 children were affected and have lost their teaching materials, classroom furniture and playing equipment due to floods (Their world 2017).

9.4 Syria Conflict

More than eight million children have been affected by conflicts. In Syria around six million children are registered as refugees. About tens of thousands of children live with permanent, war-related impairments. Almost 690,000 Syrian refugees' children were without school even after more than 2 years as promised by world leaders. About 36% of school-aged children are not getting education. The schools are being targeted continuously. In February 2018, 50 children died due to a 3-day airstrike, rocket attack and bombardment by the Syrian government forces. In March 2018, 15 children were killed by the air strike in the bomb shelters at the school basement. This leads to serious disruption in children education (Relief web 2018).

9.5 Yemen War

Three years of continuous war at Yemen has destroyed the education of hundreds of thousands of children. Since 2015, almost 500,000 children have been dropped out of school. More than 2500 schools were out of use. Two-thirds of the schools were damaged by attacks, 27% of schools were closed, and 7% were being used for military purpose or as shelter for displaced people. About 2419 children have been recruited to fight (Relief web 2018).

9.6 Kumbakonam School Fire, 2004

About 94 children of primary section of a school in Thanjavur District of Tamil Nadu, India, were burnt to death in the classroom when the thatched roof caught fire. The fire sparked from the mid-day meal kitchen and spread. There where around 700 students, and the victims were of age between 5 and 9 years mostly studying in third, fourth and fifth grades. The school had no fire safety equipment, and the teachers escaped instead of rescuing students (NDTV 2014; FP 2014).

10 Disaster Education in India

Disasters have become very common in everyday life. Disaster management enables to create a structured plan to cope with such events. Apart from introducing the disaster management-based education in the school curriculum by the Central

Board of Secondary Education in India, professional courses in disaster management are being offered by many universities in India and abroad. Courses like postgraduate degree in disaster management, MBA in disaster management, diploma and postgraduate diploma in disaster management, certification course in disaster management, master of philosophy, doctor of philosophy and postdoctoral research in disaster management are being offered. Table 9.4 shows the list of colleges/institutes and universities offering the course of disaster management In India.

Table 9.4 Disaster management institutes and universities in India

Courses	Institute/university
Certificate	K.C. Das Commerce College, Guwahati, Assam
	Nalanda Open University, Patna, Bihar
	Rajiv Gandhi University, Arunachal Pradesh
	University of Mumbai, Mumbai
	Vardhman Mahavir Open University, Rajasthan
	University of North Bengal, Bengal
	Madras University, Chennai
	Sikkim Manipal University, Gangtok, Sikkim
	Centre for Disaster management (CDM), Rajasthan
	Yashwantrao Chavan Academy of Development Administration, Mumbai
	National Civil Defence College, Nagpur
	Asian Fire engineering College (AFEC), Nagpur
Postgraduate diploma	National Institute of Disaster management (NIDM0, New Delhi
	Indira Gandhi National Open University (IGNOU), New Delhi
	Indian Red Cross Society, New Delhi
	AURA Institute, Delhi
Degree/postgraduate	Indian Institute of Ecology and Environment, New Delhi
	Tata Institute of Social Sciences, Mumbai
	Indian Red Cross Society, New Delhi
	Disaster Management Institute (DMI), Bhopal
	Guru Gobind Singh Indraprastha University, New Delhi
	The Global Open University, Nagaland
	Pondicherry University, Andamans and Nicobar
	Mizoram University, Mizoram
Independent centres	National Information centre of Earthquake Engineering, IIT Kanpur
	Disaster Mitigation and Management Centre, Dehradun
	Geological Survey of India, Kolkata
	Institute of Nuclear Medicines and Allied Sciences (INMAS), Delhi

Source: Sharma (2013)

11 Summary and Conclusions

Children become traumatised and psychologically distressed during disaster and post-disaster situations. Children's learning ability is reduced, and that impacts their academic performance. After any disasters, the humanitarian response should also focus on distributing school kits, early childhood kits and teaching and learning materials and repairing school equipment and classroom at the earliest.

Disaster education should be a continuous process by integrating it into school curriculums, and it should be revised regularly to increase the knowledge and awareness among children, teachers and parents. In the recent incident of Surat Fire tragedy in India, 19 students who were attending private coaching class died after a fire broke out on the third floor. Apart for the schools, the emerging coaching classes as well as tuition centres in the cities need to follow the safety norms and measures. Children must get the disaster knowledge from their primary education level.

Children are more receptive than their adult counterparts and can influence their peers and parents. Educational visits to or by local emergency services would increase children's understanding of risk and teach them how to prepare for and react during hazardous situation. In certain schools which are located in remote locations, there is a shortage of teachers, where the national and local NGOs working on disaster education can visit such schools, run workshops and provide technical support and help in developing educational material by taking help from the school staffs. Such preparedness initiative would be through extracurricular activities during the school assemblies, competitions, school days and after school clubs. The teacher training institutions could be another platform to raise teacher's awareness about disasters so that it could be transferred to the children at school. The challenge ahead is big but so is the opportunity.

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Chapter 10
Mainstreaming Education Into Disaster Management to Facilitate Disaster Resilience

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Abstract Disasters are increasing in frequency and intensity with impacts across all facets of human endeavour globally. Moreover, the impacts of disasters have been exacerbated by the climate change phenomenon. Climate change and weather events do not create disasters in isolation. However, disasters occur when extreme weather events intersect with vulnerable communities, dysfunctional governance and dilapidated infrastructure. Disaster education provides a viable tool for reinforcing the resilience of vulnerable communities and enhancing sustainable development. Hence, attaining knowledge and its implementation are considered as a viable approach to the management of disasters. This study employs the qualitative research method involving literature reviews on the nexus of disaster education and resilience, to assess the relationship between education and disaster management –

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particularly how it can reinforce disaster resilience – and the implications for sustainable development. Disaster education aims to capacitate vulnerable groups (in particular) and the public (in general) with the requisite knowledge and information to limit their susceptibility to disasters to the barest minimum. Study findings indicate that disaster education is a crucial element in disaster preparedness with implications for the safeguarding of developmental gains and human resources development. Inclusivity enhances community-based disaster management. Well-informed people are in a better position to protect their households and communities against the negative impacts of disasters. Ultimately, mainstreaming social media in planning and designing of holistic disaster education programs is vital for equipping people with the rightful information that can help them thrive in the face of increasing incidences of disasters in our contemporary society.

Keywords Disaster management · Resilience · Sustainable development goals · Education · Resilience

1 Introduction

The word 'disaster' connotes 'bad star' in Latin and refers to the effect of a natural or man-made hazard resulting in human suffering or engendering human needs that the victims are unable to cope without third-party support. The term is rooted in astrology and suggests that when the stars are misaligned, a catastrophe is likely to occur. There are several definitions to the phenomenon of disasters. However, the United Nations Office for Disaster Risk Reduction (UNDRR) describes a disaster as 'a social crisis situation occurring when a physical phenomenon of natural, socio-natural or anthropogenic origin negatively impacts vulnerable populations, causing intense, serious and widespread disruption of the normal functioning of the affected social unit' (UNDRR 2015). Furthermore, at the 2017 United Nations (UN) General Assembly, a fresh definition of disaster was adopted. The new definition refers to a disaster as 'A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts' (UNGA 2017). Disasters have increasingly become a common feature in global policy discourse. In 2015, more than 340 disasters impacting approximately 98.6 million people globally were recorded, costing the global economy $66.5 billion worth of damage (UNGA 2017).

The far-reaching and cross-cutting nature of disasters necessitates that they be addressed holistically (Chishtie et al. 2017). Education is a crucial tool in enhancing resilience and limiting the susceptibility of vulnerable groups to the impacts of disasters (Pereira et al. 2017). Education is vital to equip vulnerable communities with the requisite information to build resilience and enhance effective disaster management (Donkor et al. 2019). Effective disaster management is acknowledged as crucial to realising the Sustainable Development Goals (SDGs), with education serving a key enabler (UNDRR 2019). The SDGs refer to the 2030 Agenda for Sustainable Development, embraced by all the United Nations member states, providing a common pathway for inclusive global development and shared prosperity. The 2030 Agenda for Sustainable Development revolves around 17 Sustainable Development Goals (SDGs), which is a partnership between both developed and developing nations for joint action on global challenges (United Nations 2019). The partnership acknowledges that eliminating poverty and alleviating associated deprivations need to be coupled with strategies that enhance health and education, limit inequality and facilitate economic growth whilst addressing climate change and conserving the ecosystem (Amiri and Eslamian 2010; Green et al. 2011; United Nations 2019).

Climate projections indicate an increase in the frequency and intensity of extreme events with no country immune to the threat of a disaster, though they may be exposed at different levels (Pereira et al. 2017). It is hence argued that disaster preparedness is no longer an option but compulsory regardless of where a person lives (Tuladhar et al. 2015). Moreover, effective disaster preparedness feeds into successful disaster management (Pereira et al. 2017). Although there is a plethora of approaches to disaster management, the common thread is that activities be implemented in a cyclical manner (Samarajiva et al. 2005). However, there are no rigid categorisations of the diverse phases of the disaster management cycle. It is noteworthy that all the phases in the disaster management cycle are mutually interactive or overlap. Education is an enabler and plays a pivotal role in being applied throughout all phases (UNESCO 2017). Table 10.1 highlights the core stages of the disaster management cycle.

A crucial step in reducing the effect of a disaster is to correctly assess the probable risk and recognise actions that can avert, mitigate or formulate pans for disaster scenarios (Torani et al. 2019). Education can contribute to all aspects of the process in equipping people with the requisite information to cope in all areas, limit vulnerabilities and prepare potentially affected populations (Tuladhar et al. 2015). The crucial importance of education and its effect is acknowledged in both developed and developing nations. However, it is noteworthy that although destruction to property cannot be entirely averted, developed nations have succeeded in reducing disaster-related losses relatively better than developing nations (McDaniels et al. 2015). One factor for this is the introduction of far-reaching disaster education and related infrastructure in developed countries in comparison to developing nations (Haigh and Amaratunga 2012). This highlights the importance of public education and awareness creation in the dynamics of disaster risk reduction and management (Velasquez 2015). In general disaster education facilitates several aspects of the disaster management cycle (Fig. 10.1). The information equips people to mitigate

Table 10.1 Core phases of the disaster management cycle and related measures

Phase	Implications	Related activities
Risk reduction/ mitigation phase	A population is in its ideal pre-disaster setting. Nevertheless, they acknowledge the need to introduce measures to limit their vulnerabilities and enhance their resilience. In general, this phase revolves around activities that limit either the likelihood of a future hazard occurring or it developing into a full-blown disaster (Samarajiva et al. 2005)	Public education and awareness creation, hazard and vulnerability assessment programmes, improved infrastructure (Pereira et al. 2017)
Preparedness phase	Awareness is created and capacity built on conduct during a disaster amongst the population. Mapping of disaster-prone groups and individual households. All these feed into building a requisite warning system that will enhance community resilience (UNDRR 2015)	Emergency communications and response measures, training and exercises, early warning standard operations (UNICEF 2011)
Response phase	This stage involves measures introduced to safeguard people's lives and avert property damage, as well as protect the ecosystem in the case of emergencies or disasters. This phase principally involves the implementation of action plans. It follows in the immediate aftermath of a disaster and is principally targeted at saving lives (Wisner 2006)	Communicating and coordinating, saving lives, search, rescuing and evacuating operations, first aid, food and water provision (Samarajiva et al. 2005)
Recovery phase	This revolves around activities that enable a community to return to some level of normalcy in the aftermath of a disaster. Includes introduction of actions to restore the conditions of an affected community as much as possible to the optimum (Torani et al. 2019)	Restoring infrastructure, improving lives, recovery and rehabilitation of other services (Tuladhar et al. 2015)

the negative impacts of disasters to better secure their livelihoods and safeguard their communities. In addition, the Hyogo Framework for Action (HFA) (2005–2015) highlights five thematic areas that need attention in reducing the risk of disasters worldwide (Thanthathep 2015). The third prioritised thematic area is the harnessing of knowledge, innovation and education to promote a culture of safety and resilience at all levels. This is crucial to reversing critical developmental gains and facilitating robust sustainable development.

It is acknowledged that knowledge is a potent resource to aid governments, institutions and communities avert, mitigate, prepare for and recover from disasters (UNDRR 2015). Moreover, emergency, disaster management practitioners, vulnerable communities and key stakeholders operate in an atmosphere in constant flux characterised by complexity, dynamism and chaos which requires constant access to relevant knowledge and capacity building (Kahwa 2014; Pereira et al. 2017). Education is a key enabler in this dynamic; hence this paper addresses the relationship between education and disaster risk reduction, situating it in the context of sustainable development (Ayonga 2017).

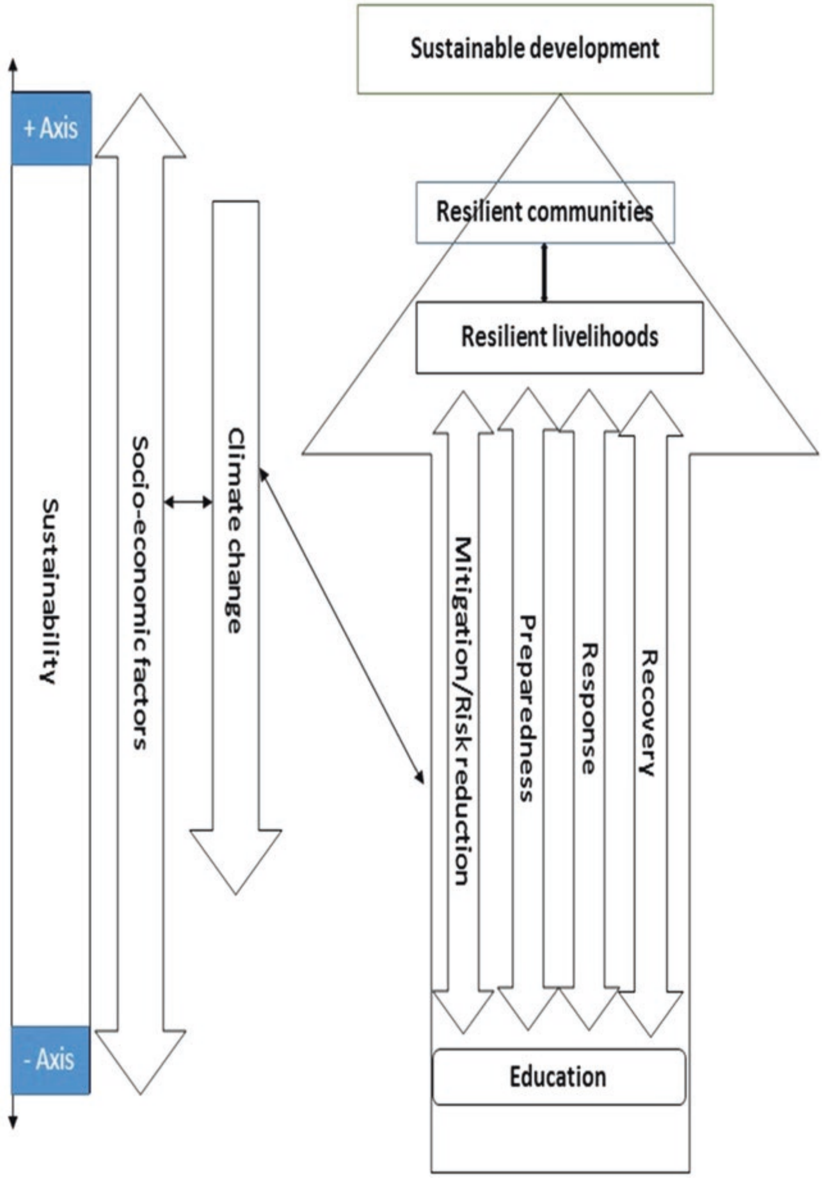

Fig. 10.1 The nexus of education and disaster management. (Source: authors)

The costly nature of disasters with regard to loss of lives and destruction to the social, economic and environmental assets undermines sustainable development (UNDRR 2015). Extreme events affect initiatives to alleviate poverty and enhance livelihoods (Donkor et al. 2019). Nevertheless, there is room to implement measures that reinforce both disaster resilience and facilitate sustainable development. This is because measures taken to promote sustainable development have the potential to enhance disaster resilience whilst advancing human development (United Nations 2018). There is, therefore, the need to couple disaster management with sustainability, guided by robust policy guidelines. This article explores the relationship between education and disaster management, particularly how it can reinforce disaster resilience.

The study is primary based on literature reviews. The sole reliance on literature reviews can affect the scope of the thematic areas covered and the diversity as well as triangulation of some the discussions.

2 Methodology

2.1 Methodological Approach

The employment of either a qualitative or quantitative approach to studying a phenomenon is mediated by the substantive issue under investigation (Karpatschof 2007). It is argued that quantitative methods are appropriate for the study of serialised phenomena (Karpatschof 2007). However, qualitative approaches are ideal for analysing contextualised phenomena, where study subjects are considered as members of social groups (Kvale and Brinkmann 2009). Given that the accounts of affected groups and core stakeholders on the relationship between education and disaster management are crucial to the research, the qualitative method was regarded as ideal (Flyvbjerg 2001).

2.2 Case Study

Case studies are employed in the empirical analyses of current phenomena within real-time contexts, when the margins between phenomenon and context are blurred and whereby diverse sources of evidence are utilised (Yin 2014). In the light of the aforementioned argument, the case study approach was utilised to enable profound understanding on the nexus of disaster management and education.

2.3 Literature Review

A literature review or study permits a critical assessment on the current state of scholarship on a subject of interest per a particular timeframe (Flyvbjerg 2001; Kvale and Brinkmann 2009). Some core literature was examined to gain great insights into the diverse thematic areas of the research.

Consequently, scientific articles and journals comprise the core information sources in the literature review. Strategic searches on scientific databases like Google Scholar and Web of Science were utilised to garner information on a myriad of themes. The searches were computed around particular keywords such as "disaster", "risk reduction", "climate change", "sustainable development", "vulnerable" and "resilience" which were coupled with *Boolean operators* like *AND* and *OR*. Typologies of these searches involve *education and disaster management, disasters and sustainable development, amongst* others. Repetitive and emerging themes were then put in categories in the context of content analysis (Hashemnezhad 2015).

3 Results and Discussion

3.1 Enhancing Inclusiveness in Disaster Risk Reduction to Address Resilience of Vulnerable Groups

The impacts of disasters cut across the social strata, and they are accentuated amongst certain groups (Haigh and Amaratunga 2012). This includes vulnerable groups such as the elderly and children, often exacerbating the well-being and conditions. However, there is the need to harness all the available human resources for effective sustainable development. The United Nations has hence foregrounded the concept of leaving no one behind as a global call to action, whereby the gains of development are equally accessible to those on the margins of society and to promote inclusive development. Therefore, mainstreaming education material in natural disaster management is necessary to equip vulnerable groups such as children with the needed knowledge and skills in risk reduction and management. This is because they represent a unique vulnerable group in society (HDRC & DFID 2011).

It is argued that the lack of inclusiveness in the decision-making process related to disaster risk reduction is one another factor that needs redress (Madu et al. 2017). Given that disasters affect all and sundry, having stakeholders from across the social strata is crucial to formulate a robust response measure (Lucero 2014; Sithirajvongsa 2017). This will equally enhance the nature of disaster education as the core needs of diverse groups are addressed and engender ownership of the process. For example, it is argued that children are predisposed to share the lessons garnered with their families and communities, thus representing a vital vehicle for successful household and community education. Nevertheless, the mode of disaster preparedness awareness can be tailored to communities as well and not limited to the school environment (UNESCO 2013; Boon et al. 2011; Boon and Pagliano 2014).

3.2 *Resilience as a Tool for Safeguarding Development to Leave no One Behind*

Moreover, a recent report by the Committee for Development Policy of the United Nations indicates that prevailing trends do not point to a degree or speed of advance attuned to the 2030 Agenda time frame. This includes trends in core factors vital to leaving no one behind, such as trends in poverty, education and housing inter alia (UN 2018). It is noteworthy that the far-reaching nature of disasters is such that they affect all these crucial elements and more, viz. poverty, education and housing. This is exemplified in the case of the recent Cyclones Idai and Kenneth. In general circa 1,800,944 people were affected with another 125,038 persons displaced across 6 provinces in Mozambique (Reliefweb 2019). In the aftermath of these disasters, people lost their livelihoods as farms, livestock and other means of livelihoods were completely destroyed. In several rural communities, farms and livestock are some of the fundamental means by which the most vulnerable thrive. This situation further worsens the poverty levels in already poor communities and households. Enhancing disaster education amongst such poor communities is crucial to their livelihood resilience (Fig. 10.1) and hence alleviating poverty levels. This also feeds into the Sustainable Development Goal (SDG) 1 of "No Poverty", seeking to alleviate global extreme poverty (UN 2019). In addition the erosion of means of livelihoods also complicates the worsening levels of global inequality as the already poor and vulnerable lose their capacity to generate income and secure the well-being of their households and communities. This worsens the plight of the rural economy disproportionately and exacerbates the goals of SDG 8 of Decent Work and Economic Growth through inclusive and sustainable economic growth. This makes mainstreaming disaster education crucial to safeguard the development gains already made whilst making further progress.

3.3 *Disaster Education for Reinforced Community-Based Disaster Risk Management*

In recent times, community-based disaster risk management has been lauded as a robust and viable approach (Sheikhi et al. 2020). Institutions such as religious and educational organisations are some of the most common and crucial units of communities across the globe. Moreover, they have access to vital resources that can be crucial to effective management of disasters. These institutions have immense potential in disaster management (Veenema et al. 2015). They can assist in providing crucial services in the response and recovery phases of disasters. Furthermore, although such services are deemed valuable, the immense potential of these groups needs to be also employed to enhance preparedness and mitigation efforts as part of disasters cycle. The synchronisation and collaboration of all stakeholders are pivotal in this regard (Charney et al. 2018).

The Sendai Framework hence espouses the goal to significantly limit disaster impact on critical infrastructure and disruption of basic services, including health and educational facilities (UNDRR 2019). Thus, the destruction of such critical infrastructure during disasters compromises the goal of sustainable development as typified in the cases of Hurricane Katrina in the United States and Cyclone Idai in Mozambique. This is a hurdle to SDG 11 which aims for "Sustainable Cities and Communities" by making cities and human settlements inclusive, safe, resilient and sustainable (UN 2019). Moreover, the structural integrity of educational and religious edifices is also a core concern in considering education and natural disaster linkages. Community members often invest a significant amount of time in religious and educational premises, but it has been generally observed that their structures are not built or managed to be disaster robust. It is common knowledge that educational and religious centres frequently serve as improvised community havens in the aftermath of a disaster. Ultimately, children and religious leaders are instrumental in both the reduction of disaster risks and enhancing their households'/communities' disaster resilience (HDRC & DFID 2011). With the projected increase of extreme events, it is crucial to capacitate young people's and faith leaders' readiness in combatting disasters. Educational and religious institutions that implement risk management measures promote a culture of prevention, which is critical to the sustainable development framework. The disaster education disseminated helps diminish disaster risks and reinforces the capabilities of highly vulnerable communities in responding to emergencies (UNESCO 2017). In this regard, religious workers or school staff may introduce first aid and deal with the special needs of students and faith attendees and upon the occurrence of a disaster (Killion 2015). Hence, such training is essentially contingent on the education of faith-based organisations and educational institutions. Equalising disaster risk management in the school curriculum and related religious programmes can therefore not be overemphasised, as the disaster education for vulnerable groups deserves increased focus (HDRC & DFID 2011; UNESCO 2017).

3.4 Social Media as a Platform for Disaster Education and Building Resilience at the Local Level

In contemporary times social media has been recognised as a platform of immense potential in emergency, disaster and crisis situations (Alexander 2014). In terms of disaster management, the use of social media revolves around blogs, messaging, sites such as Facebook and wikis, amongst others (Bird et al. 2012; Blanchard et al. 2010). These are employed in diverse modes such as being able to listen to real-time public narratives or discourse, rapid assessment of situations, provision of disaster response and related measures, crowdsourcing and collective efforts towards joint efforts, fostering social cohesion, promoting causes such as humanitarian and charitable initiatives and facilitating academic research (Yates and Paquette 2011; White and Plotnik 2010). However, the use of social media is also associated with negative activities. These include the spread of misinformation, disinformation, undermining authority and promoting terrorist acts (Castillo et al. 2011; Correa et al. 2010). This calls for great ethical scrutiny in the use of social media when it comes to disaster management especially relating to the possible violation of privacy and the propagation of false or inaccurate information.

Furthermore, social media is an effective tool for exposing corruption and malpractice in disaster management (Barr 2011; Balana 2012). The extensive usage of social media by communities across the globe heralds a new dawn in which it has become necessary for emergency managers to change their mode of operations to reflect current technological developments (Vihalemm et al. 2012; Westbrook et al. 2012). In the same vein, they need to observe ethical guidelines and guarantee that social media is not abused or misused in the aftermath of a disaster (Sykes and Travis 2012; Vieweg et al. 2010). The increasing usage of social media and other peer-to-peer communications makes it imperative for disaster management officials to reflect on ways to integrate peer-to-peer information exchange and to create novel conceptualisations of the information production and dissemination aspects of disaster response. This is to say that the integration of social media into prevailing disaster management systems is inevitable, due to the substantial use of such facilities (Boggs and Edwards 2010; Taylor et al. 2012).

Social media has great potential for interactions with the public and monitoring public concerns. It has enhanced the scope, volume and speed of information interexchange (Cheong and Lee 2010; Chung 2011). Social media has a pivotal role to play in the protracted recovery from major disasters or by mitigation (disaster risk reduction) (Reuter et al. 2012; Song and Yan 2012; Stirratt 2011). There is the need to integrate social media into these processes and related technological, cultural and social elements. Moreover, this is an opportunity for institutions like civil protection services and disaster warning systems to embrace social media and also implement cost-effective measures to address ethical dilemmas that social media usage may encounter.

3.5 The Nexus of Disaster Education and Community Resilience

Destructive natural and socio-natural hazards engender heightened levels of risk. This is exacerbated by susceptible environments and the absence of spaces for social involvement in development processes (UNESCO 2017). The Sendai Framework therefore states amongst its seven targets to significantly reverse global disaster mortality as well as the number of affected people by 2030 compared to previous years (UNDRR 2019). This has become complicated due to the impact of global climate change. Moreover, climate change and weather events do not create disasters in isolation. A disaster ensues when extreme weather events combine with vulnerable communities, poor governance and poor infrastructure (Pereira et al. 2017). This is evident in the case of Cyclones Idai and Kenneth in the case of Mozambique. The most recent Intergovernmental Panel on Climate Change (IPCC) special report (SR15) had highlighted areas in the Southern African Development Cooperation (SADC) region to which Mozambique belongs as *climate hotspots* – hot, dry and water-stressed countries. These make such areas highly prone to the negative impacts of climate change (Torabi Farsani et al. 2017). Training and capacity building on enhanced production methods such as conservation agriculture and climate smart agriculture can help in safeguarding the environmentally sensitive livelihoods of such areas, for example. Thus, education is a robust instrument for reducing the vulnerability of poor communities. The combination of disaster risk management in the education sector is important to improve consciousness of the impacts and causes of disasters. Moreover, in the aftermath of a disaster, education restores some level of normalcy of life and gives hope for the future, moreover gratifying fundamental humanitarian needs and disseminating vital messages that encourage safety and well-being (UNESCO 2017). Furthermore, in our contemporary society characterised by high technological innovation, gaining knowledge and applying it in the sphere of action are considered as the main effective approach to averting disasters or limiting its negative consequences. Disaster education should therefore aim to furnish people with the requisite knowledge to implement measures that limit their susceptibility to disasters. Hence, the notion that training people is a means of effective preparation for future disasters and response has gained currency and policy focus (Torani et al. 2019).

Even though it is argued that the susceptibility of certain people and communities to natural and human-made disasters is undeniable, affected people can help alleviate the impact of such extreme events by enhancing systemic resilience and disaster recovery capacity (Tuladhar et al. 2015; Witvorapong et al. 2015). The Sendai Framework's goal of significantly increasing the "availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030" (UNDRR 2019) is therefore in the right direction. Comprehensive disaster education is pivotal to successfully realising this objective. The increased understanding of the far-reaching nature of disasters amongst a populace stimulates the requisite cooperation whilst facilitating the prudent use of needed for effective disaster recovery (Muzenda-Mudavanhu et al. 2016). For example, in the aftermath of Cyclone Idai, there have been substantial increases in incidences of cholera, malaria, diarrhoea and respiratory attributable to impoverished conditions across Mozambique, Zimbabwe and Malawi (World Vision 2019). Moreover, in cyclone-affected areas of Mozambique and Zimbabwe, circa three million people are without proper nutrition in the aftermath of the disaster. This seriously erodes progress towards SDG 2 of ending hunger, achieving food security and improved nutrition and promoting sustainable agriculture (UN 2019). This disproportionately affects vulnerable groups in the community. Targeted disaster risk education can be leapfrogged through the novel approach of addressing the special needs of vulnerable groups (in particular) and the general public by policy makers (Signé 2017). This involves targeted training that considers the heightened threat of disasters and susceptibility attributable to climate change, increased social inequality and poor preparedness (UNICEF 2011). Furthermore, it is argued that poor consciousness and insufficient consideration of risk negatively affect people's preparedness, response to hazard notification, individual protection actions and recovery (Wisner 2006). It is noteworthy that the Hyogo Framework for Action (HFA) (2005–2015) underlined five priority areas for lessening the risk of disasters worldwide. The third prioritised thematic area is the harnessing of knowledge, innovation and education to promote a culture of safety and resilience at all levels (Muttarak and Pothisiri 2013). The HFA indicates that disasters are essentially limited when people are well informed, and the goal is to foster a culture of prevention and resilience to disaster. In light of this argument, gathering and disseminating knowledge and information on hazards, vulnerabilities and capacities, particularly for the vulnerable in society, should be given increased priority (Rundmo and Nordfjærn 2017). Furthermore, it is noteworthy that people who are prone to disasters due to their peculiar conditions definitely need specialised training and attention to reinforce their resilience and capacity to thrive (Rundmo and Nordfjærn 2017).

4 Summary and Conclusions

The frequency and magnitude of disasters has become a thematic focus of global policy given the profound impact key socio-economic indices and sustainable development in general. It has hence become imperative to enhance disaster management from merely response to recovery to embrace mitigation. This is crucial to reinforce resilience and limit the vulnerability of households and communities to the barest minimum. The enhanced resilience is vital for safeguarding developmental gains and consolidating sustainable development. Mainstreaming disaster education into disaster management measures and sustainable development is therefore of immense urgency. Moreover, for disaster management to produce the desired results, there is a need to integrate inclusivity in the decision-making process. Building resilience and preparing adequately for climate-related disasters require transdisciplinary, trans-institutional and trans-sectoral approaches that harness the synergies between disaster risk reduction (DRR) and climate change adaptation (CCA). It is increasingly becoming evident that disaster education is a useful, viable and cost-effective instrument for risk management. Moreover, it is essential for vulnerable people to be well informed about disasters. Although there are a number of media/modes for the education of vulnerable people, disaster education must consider the peculiar context of the target populace to be relevant, useful and make meaning impact. Therefore, design and implementation of holistic educational programs are essential for people to confront disasters.

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Chapter 11
Early Warning Systems to Strengthen the Resilience of Communities to Extreme Events

Ron Fisher, Frédéric Petit, and Celia Porod

Abstract Community resilience is comprised of four pillars, infrastructure, organizational, social, and personal, all of which need consideration when developing, implementing, or improving an early warning system (EWS). The complexity of assessing community resilience is exacerbated by the interconnections between the community's core components, the multiplicity of hazards that may strike, but primarily by the difficulty to obtain the data to understand these phenomena. By ensuring the four main components are integrated into an EWS, the community will be better able to anticipate and understand hazards, as well as support the preparedness of the communities and their assets to mitigate consequences. A community's ability to respond to and recover from extreme weather events resulting from climate change requires ongoing community-wide planning and preparation efforts for activities before, during, and after an event. The implementation and adoption of EWS have proved beneficial in alerting individuals of impending climate danger. While acknowledging the increase in extreme climate events, enhanced EWS are needed for greater preparedness to improve community resilience to all types of extreme events.

Keywords Community resilience · Early warning system · Extreme weather event · Disaster preparedness · All hazards approach · Risk reduction

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1 Introduction

Changes in the frequency, intensity, and predictability of extreme weather events are being driven by climate change, making disaster preparedness and the understanding of disaster risk even more critical to protecting communities (WMO 2019a, b, c, d). Climate changes and natural disasters are not the only types of extreme events that must be considered in strategies to enhance community resilience. Due to the ever-evolving hazard landscape, from catastrophic natural disasters to biological, technological, and anthropogenic hazards, early warning systems (EWS) are essential to preparing communities and building resilience (WMO 2019c, d). This chapter explores the critical link between EWS and community resilience to extreme hazard events. To better understand the role of EWS in anticipating the detrimental impacts of catastrophic events and ultimately contributing to community resilience, it is important to present an explanation of what constitutes an EWS and their specificities. It is also critical to review the complexities of community components and the diversity of core characteristics contributing to the resilience of community to disasters.

Community resilience cannot be examined in a stovepipe fashion. EWS have the potential to increase resilience at all levels of a community. Examples of past events coupled with the review of community resilience core characteristics and pillars (i.e., infrastructure, organizational, social, and personal resilience) and the presentation of current community EWS will help define the requirements for future EWS. These efforts will also identify how technology can be leveraged to develop the future generation of EWS with adaptability to evolving sociotechnical and natural environments and the occurrence of disaster events. This initial effort presents how EWS strengthens community resilience to extreme events; future research may involve the direct survey of stakeholders to increase the data set and expand upon the current findings.

2 Early Warning Systems

The expression "early warning" is used in many fields to describe the delivery of information on an emerging dangerous circumstance where that information can enable action in advance to reduce risks. EWS exist for natural geophysical and biological hazards, complex sociopolitical emergencies, industrial hazards, personal health risks, and many other related risks (Basher 2006). In United Nations Office for Disaster Risk Reduction (UNDRR)[1] terminology, early warning is defined as "the provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to take action to avoid or reduce their

[1] The United Nations Office for Disaster Risk Reduction (UNDRR) was formerly known as the United National International Strategy for Disaster Reduction (UNISDR).

risk and prepare for effective response" (ISDR 2004). The focus of this chapter is on effective utilization of EWS in building community resilience.

Timeliness is critical to EWS effectiveness. The evidence from the literature concludes that for every minute delay in primary response for certain life-threatening medical emergencies, there is a measurable effect on mortality. This research is conclusive, particularly for the first five minutes in the response interval, where rapid intervention makes the greatest difference (RAPIDSOS 2015). "It's generally accepted in the fire service that the first five minutes of a firefight sets the stage for risk and outcomes" (IFCA 2016). The amount of time needed to effectively mitigate a natural or anthropogenic disaster depends greatly on the event. For example, in 2011, Tokyo was struck by a magnitude 9.0 earthquake, the country's worst earthquake in over 300 years. While the earthquake and ensuing tsunami left most of Japan's northeast region in ruins, seismologists said the results could have been far more deadly if not for the EWS. After the system's sensors picked up the P-wave triggers, alerts were sent around the country, and residents in Tokyo, 230 miles from the quake's epicenter, had a ten-seconds warning to get cover. "Ten seconds is time to turn the gas off if you're cooking," seismologist George Mussonn stated, "and that could make all the difference between your house burning down or not" (Puleo 2019). EWS that provide even a few seconds of notification have the potential to reduce the devastating consequences of a disaster.

The accuracy of information is also critical to EWS effectiveness. World Meteorological Organization (WMO) Secretary General Petteri Taalas stated, "The dramatic reduction in the lives lost due to severe weather events in the last thirty years has been largely attributed to the significant increase in accuracy of weather forecasting and warnings and improved coordination with disaster management authorities" (WMO 2018a). For example, earthquake engineers have effectively reduced the possibility of false alarms caused by an unknown vibration event (Hsu et al. 2016). Technology advancements with sensors, analysis of historic events, improved communications, and increased data availability all factor into increasing EWS effectiveness.

Technology is the driver of improved timeliness and effectiveness of EWS. Communities are embracing technology through new communications media (e.g., text messages, social media) and advanced decision support systems. As technology continues to advance, the potential of EWS to substantially aid the outcome of natural disasters has proliferated. Disaster forensics analysts forecast that "sensor networks will revolutionize conceptual and empirical approaches to research in the social sciences…by providing unprecedented volumes of high-quality data on movement, communication, and response activities by both formal and informal actors" (Moss and Townsend 2006). Geographic information systems have provided new flows of data that increase the nation's ability to "reconstruct detailed timelines and maps of disasters" (Moss and Townsend 2006). "Digital communications networks leave traces of a social nervous system," and each disaster leaves a greater volume of data than the one before it (Moss and Townsend 2006). Data from previous disasters, as well as research recorded and analyzed post-disaster, can be used to prevent future disasters and create future warning systems (Deiminiat, and Eslamian 2014).

Another positive trend is communities turning to disaster simulation technology to stress test their current EWS and improve on the weaknesses of current technology. In one example, the "use of the simulation resulted in active and engaged participation by learners, increased capacity for well-reasoned perspective taking, and improved analytical confidence in complex scenarios" (Harding and Whitlock 2013).

EWS continue to make a difference in communities' abilities to respond to and recover from extreme weather events, ultimately fostering community resilience. Over time, these systems have become more effective through timeliness and accuracy, while integrating advanced technology to improve forecasting and notification of individuals. Through the implementation of EWS, communities become better prepared for specific hazards and allow for stronger resilience measures to be put in place, providing the community a greater chance to withstand and recover from incidents.

3 Community Resilience

A community is characterized by different factors. It is both a group of individuals constituting a population characterized by its geographic boundaries and the socio-economic characteristics of its members but also an autonomous actor with its own interests, preferences, resources, and capabilities (Patterson et al. 2010). In the context of disaster management, a community is generally seen as the administrative or political subdivisions, which has authority to adopt and enforce emergency management regulations for the areas within its jurisdiction (FEMA 2020a).

These jurisdictional entities may be vulnerable to various natural and anthropogenic hazards whose impacts can last long past the event (NIST 2019). Our world is faced with ongoing and evolving hazards from severe weather and climate-related events to emerging threats related to the use of new technologies. Between 1998 and 2017, natural disasters generated direct economic losses valued at USD 2908 billion,[2] which constitutes a major increase compared to the USD 1313 billion losses reported between 1978 and 1997 (UNDRR 2018). Over this 20-year period, the United States suffered the biggest losses with USD 945 billion declared, which can be explained by high asset values but also by events that are more frequent (UNDRR 2018). During 2018, the United States experienced the fourth highest total number of natural disasters of their history creating $91 billion in losses (National Oceanic and Atmospheric Administration (NOAA) NCEI 2019). During the first 6 months of 2019, in the United States alone, six natural disasters generated economic losses exceeding USD 1 billion each (NOAA NCEI 2019). This increase in disasters is not limited to natural events. Cyber criminality is also on the rise, with

[2] All economic losses and GDP are adjusted at 2017 US$ value.

the use of advanced methods and techniques designed to target and exploit the cyber system vulnerabilities. In 2017, two billion data records were compromised, and more than 4.5 billion more records were breached during the first half of 2018 alone (WEF 2019). Cybersecurity Ventures predicts cybercrime will cost more than USD 6 trillion annually by 2021 (Cybersecurity Ventures 2019).

Communities' vulnerabilities to extreme natural and anthropogenic hazards can vary not only in relation to potential changes in the threat landscape but also because of changes occurring within the communities themselves. Communities are generally comprised of individuals and families, including those with access and functional needs; businesses; faith-based and community organizations; nonprofit groups; schools and academia; media outlets; and all levels of government, including state, local, tribal territorial, and federal partners (FEMA 2020b). Therefore, when a disaster strikes, impacts will be felt across entire communities and within all their components. It is difficult, if not impossible, to fully protect a community against all types of hazards, especially when considering emerging and hybrid threats not experienced before. It is important to develop resilience measures to support adaptive and flexible risk management processes and to promote sustainable development for communities.

Despite a consensus on the importance of promoting community resilience, the definitions of this concept vary among researchers and practitioners (Patel et al. 2017; CARRI 2013; Carlson et al. 2012). However, all these definitions usually consider measures that can be implemented before, during, and after a disaster. Among all existing definitions, those proposed by the US Department of Homeland Security (DHS) and the UNDRR represent a good synthesis of the different abilities generally identified to enhance resilience to disasters.

- The UNDRR defines resilience as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" (UNDRR 2017).
- The DHS defines resilience as "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents" (The White House 2013).

These two definitions highlight the strong connections between the core capabilities contributing to community resilience and the five phases of emergency management (Table 11.1).

Consistent with this diversity of definitions, there is no real consensus on the number and types of core characteristics contributing to the resilience of community to disasters (Patel et al. 2017; Carlson et al. 2012). For example, the study by Patel et al. (2017) conducted a systematic literature review of definitions of community resilience and defined nine core elements that appeared to be common among the definition:

Table 11.1 Relationships between emergency management phases and abilities contributing to the resilience of community to disaster

Emergency management phases			
Prevention/preparedness	Mitigation	Response	Recovery
Anticipate Prepare for	Absorb Resist	Accommodate Adapt to Transform	Recover

Adapted from Carlson, et al. (2012)

- Local knowledge.
- Community networks and relationships.
- Communication.
- Health.
- Governance and leadership.
- Resources.
- Economic investment.
- Preparedness.
- Mental outlook.

This taxonomy combines core elements that characterize primarily resilience capabilities (e.g., communications and preparedness). On another hand, other taxonomies such as the one proposed by the United States Federal Emergency Management Agency (FEMA) as part of the whole community approach focus primarily on the following entities constituting a community (FEMA 2020b):

- Individuals and families, including those with access and functional needs.
- Businesses.
- Faith-based and community organizations.
- Nonprofit groups.
- Schools and academia.
- Media outlets.
- All levels of government, including state, local, tribal, territorial, and federal partners.

These two taxonomies provide a solid overview of the diversity of elements to consider when assessing the resilience of a community to multiple hazards. However, the different entities that usually constitute a community can be categorized in four main pillars:

- *Infrastructure Resilience* considers the continued operations of utilities (e.g., energy, water, and telecommunications), businesses, industries, and critical infrastructure systems (e.g., public health, emergency services sectors), as well as their interdependencies, which can affect community supply chains.
- *Organizational Resilience* considers the ability of governmental and nongovernmental organizations to continue to function in the event of a disturbance. This directly reflects the governance capability of the community.

- *Social Resilience* considers the ability of individuals to organize in structured groups, combining diverse interests, skills, and resources, and to coordinate their efforts.
- *Personal Resilience* considers the ability of the general public to respond to challenge, setback, and even crisis. This includes not only psychological aspects but also the ability for individuals to be self-sufficient and provide support to others in the community when needed.

The ability of a community to implement effective risk and emergency management processes is directly tied to the community's ability to effectively identify and address items within the four resilience pillars, understanding and assessing community needs to determine the best ways to organize and strengthen assets, capacities, and interests (FEMA 2011).

It can be difficult for communities to develop and structure emergency management procedures that will integrate the needs and requirements of all entities constituting a community and the multiple hazards that may affect them. Building community resilience requires ongoing collaboration and information sharing, as well as proactive assessment approaches. Table 11.2 shows some examples of existing community resilience frameworks.

These different frameworks highlight the importance of planning, collaboration, communications, and information sharing to inform resilience strategies. Achievement of community resilience, and especially preparedness, is a responsibility shared between all the actors within the community (FEMA 2020b). This

Table 11.2 Examples of community resilience framework

US National Institute of Standards and Technology (NIST) Community Resilience Planning Guide (NIST 2018)	*Step process to planning for community resilience*: Form a collaborative planning team Understand the situation Determine goals and objectives Plan development Plan preparation, review, and approval Implementation and maintenance
Global Facility for Disaster Reduction and Recovery (GFDRR)	*Pillars to improve in-country capability to prepare for and recover from natural disasters*: Risk identification Risk reduction Preparedness Financial protection Resilient recovery
International Federation of the Red Cross and Red Crescent Societies (Red Cross 2016)	*Stages on the Road map to community resilience*: Engage and connect Understand community risk and resilience Taking action for resilience Learning for resilience

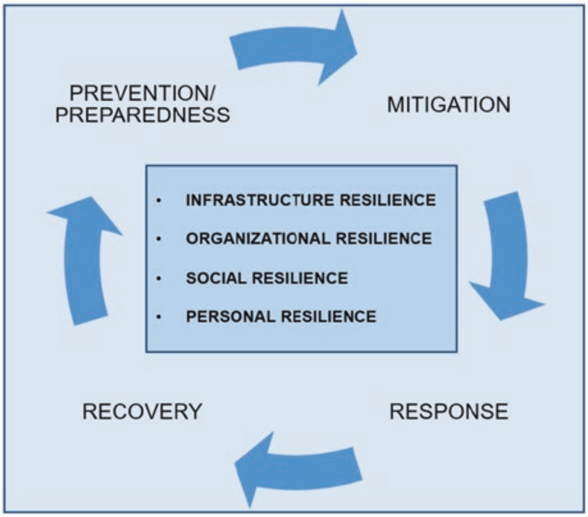

Fig. 11.1 Core characteristics contributing to community resilience to disaster

requires leadership from governmental and nongovernmental organizations, as well as legal and budgetary capacities (FEMA Ready 2019; UNDRR 2017).

The resilience of a given community can therefore be characterized by the capabilities of its core constituents (i.e., resilience pillars) to implement flexible and adaptive risk and emergency management processes to sustain all types of hazards (Fig. 11.1).

The complexity of assessing the resilience of a community is exacerbated by the interconnections existing between the community core components, the multiplicity of hazards that may strike, but primarily by the difficulty in obtaining the data to understand these phenomena.

In this context, EWS deliver unique capabilities to enhance community preparedness to face extreme natural and anthropogenic hazards by providing appropriate processes to collect and analyze data, develop hazard monitoring and early warning services, and share relevant information in a timely manner with community stakeholders (UNDP 2016; ISDR 2006a).

4 EWS Requirements to Support Community Resilience

An EWS is "an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events" (UN 2016). The primary objective of an EWS is therefore to better anticipate and understand hazards and support the preparedness of communities and their assets (e.g., infrastructure, organizations, and population) to reduce detrimental consequences (UNDP 2016; GPDPC 2017). In order to do this, EWS must combine four main components to collect and analyze data, develop hazard monitoring and early warning services, share hazards and risks, and inform emergency management processes (Fig. 11.2).

Risk knowledge refers to the understanding of the hazards susceptible to strike a community, the vulnerabilities of the community's core components to these hazards, and the potential consequences that result. This first component of each EWS is conducting a risk assessment to identify and analyze natural and anthropogenic threats, vulnerabilities, and consequences to inform emergency management processes. Risk assessments require systematic data collection and analysis processes to consider all changes in the community operating environment (e.g., land use, socioeconomic characteristics, governance, regulation) that may influence the nature of hazards and vulnerabilities (ISDR 2006a, b).

Initially, EWS focused primarily on specific types of meteorological phenomena and natural hazards. Current EWS tend to favor multi-hazards approaches to consider a variety of hazards and assess their synergetic effects. A multi-hazard EWS increase the efficiency of emergency management processes with their ability to warn of one or more hazards and to support more coordinated response mechanisms and capacities (UN 2016). Furthermore, a multi-hazard EWS can address anthropogenic hazards (e.g., social, technical, cyberattack, and terrorism) and functional interdependencies occurring among connected infrastructure systems that may result in cascading failures.

Risk knowledge builds the scientific baseline for predicting the risks faced by a community, informing the development and implementation of efficient and coordinated emergency management procedures. Using multidisciplinary approaches, this first EWS component helps define the hazard parameters to monitor to anticipate disruptive events.

Monitoring and warning services constitute the core of the EWS. Based on the risk knowledge resulting from the risk analyses, the EWS monitors hazard precursors, forecasts, and generates warnings. To be effective, monitoring and warning

Fig. 11.2 Four elements of effective early warning systems. (Adapted from ISDR (2006b))

services must (i) operate continuously (i.e., 24 h a day), (ii) ensure the monitoring of the correct hazard parameters, and (iii) issue accurate warnings in a timely manner. The objective is to keep community stakeholders informed of the evolution of risks over time. This information is essential to be proactive and adaptive and to activate, if necessary, emergency management procedures.

Dissemination and communication are important to convey understandable alert messaging that will answer community stakeholders' needs in appropriate frequency through appropriate communication channels (ISDR 2006a). Warning communications should provide clear and actionable information to enable appropriate responses and reduce detrimental consequences. Communication channels should be identified before hazards strike and be strong enough to sustain potential disruption. Furthermore, several communications media should be utilized to reach as many people as possible but also to adapt the messages to the audience (i.e., use of different languages or specific information for first responders). Utilizing several options to disseminate a warning is also important to mitigate the potential failure of communication systems.

Dissemination and communication systems must be coordinated to avoid duplicative or conflictive messages. This is particularly important for multi-hazards EWS, for which warnings must consider different risks, vulnerabilities, and their synergic effects. EWS must also use standards and protocols such as the Common Alerting Protocol developed by the Organization for the Advancement of Structured Information Standards (OASIS) to ensure the effectiveness of their warning messages (WMO 2019a, b, c, d).

Emergency management capabilities are the components through which EWS integrates fully into the management of community operations. The primary purpose of EWS is to support response capabilities (ISDR 2006a, b). However, the development of risk knowledge will also inform prevention, preparedness, and mitigation activities. The risk assessment conducted to develop the risk knowledge will inform the development and revision of business continuity and contingency planning. This information is also useful to make an inventory of the community response capabilities and to identify structural and nonstructural mitigation measures.

Figure 11.3 shows how the four components of an EWS are integrated in a coordinated "end-to-end" system that connects all community stakeholders.

For the EWS to be fully efficient, its four interconnected components need to closely coordinate with each other but also with the four pillars that contribute to community resilience. For example, a disconnect between warning communication and community preparedness would lead to a failure to meet the objective of the EWS. Without proper education and training, community stakeholders will not know which communication media to connect to stay informed, and even if they receive a warning message, they may not know how to react (i.e., what to do to remain safe).

Over the past 10 years, it is evident that multi-hazard "end-to-end" EWS have become a central component in effective disaster risk management, as emphasized during the 2017 Global Platform for Disaster Risk Reduction (McElroy 2017;

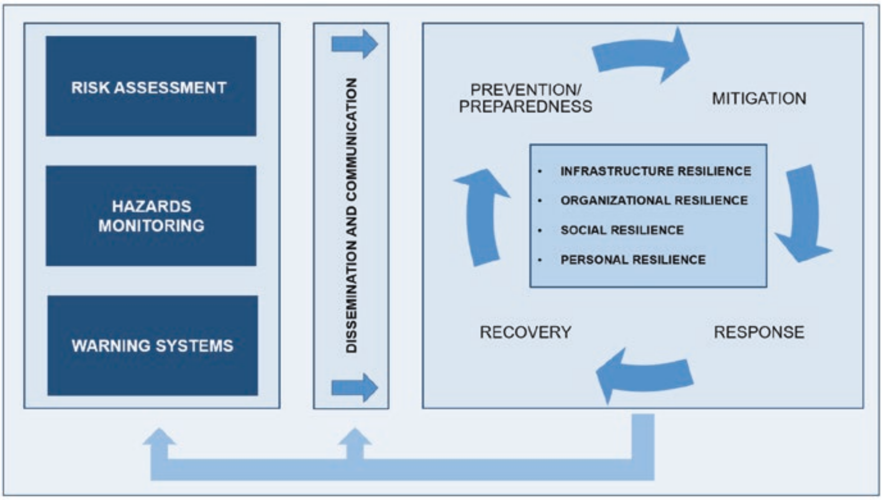

Fig. 11.3 "End-to-end" early warning system. (Adapted from ISDR (2006a, b))

WMO 2018a, b). However, several challenges remain to make these systems fully efficient and available to all:

- *Development of risk identification and knowledge*. Risk precursors and parameters still need to be defined for some hazard types. Meteorological phenomena are better understood, but this is not always the case for all natural hazards (i.e., the proverbial Act of God). Furthermore, even for known phenomena, data availability and accessibility can remain a problem. Predicting anthropogenic hazards can also be difficult. They involve human intent and capability, which can be difficult to monitor, as well as some aspects of technical threats, such as infrastructure interdependencies, are still not well understood or modeled.
- *Capability to monitor phenomenon of different natures while providing clear and useful warnings.* This involves the ability and tools to collect and manage a large quantity of data that must be analyzed in real time.
- *Ensure effective distribution and communication systems for all communities.* This challenge is not just about the availability of adapted communication mechanisms (e.g., radio, television, wireless communications, and the Internet) but also the difficulty to share information that could identify vulnerabilities. This is particularly true when considering synergetic and industrial hazards.
- *Complexity and cost to deploy EWS for all communities and all hazards.* It can be difficult for poorer communities, which are generally the most vulnerable, to finance equipment needed to support EWS.

Advances in technology (e.g., machine learning, artificial intelligence, Internet of Things, weather satellites) and the development of multidisciplinary research centers and international initiatives (e.g., Climate Risk and Early Warning Systems [CREWS] initiative) will certainly help to overcome these challenges.

5 Current Community Early Warning Systems

As stated previously, communities rely on EWS to enhance their resilience to extreme weather events, developing strategies to withstand and recover from disasters at all levels: infrastructure, organizational, social, and personal. The intensity, frequency, and complexity of climate and natural hazards are continually increasing, and effective EWS could foster livelihood resilience by improving coping mechanisms and enhancing adaptive capacity (Baudoin et al. 2014).

Warning mechanisms and alert systems have been around since the beginning of civilization, where the use of fires, smoke signals, drums, and horns notified others of danger. Today, sirens, broadcasted alerts, and warnings sent directly via personal electronic devices are used to produce immediate alerts and inform individuals and communities of potentially devastating weather occurrences. EWS continue to evolve in both the technology employed and the methodological approaches used to forecast disruptive climate events. These system implementations and improvements have enhanced the ability of early warnings to help prepare communities and minimize the potential devastating impacts these weather events could cause. The examples outlined below provide a high-level overview of the evolution of just a few EWS.

Tornado Sirens in the United States Tornado warnings were banned in the United States from 1887 to 1938 because scientists believed they could do more harm than good. Following a successful tornado forecast in 1948 resulting from weather radar and storm spotter network developments, the use of tornado warnings in the United States began to expand rapidly. In the 1950s and 1960s, the public relied on tornado warning dissemination through radio and television after the stations received a phone call from the US Weather Bureau (USWB). In 1970, outdoor "air raid" sirens were used for tornado warnings. It was after 1974 that NOAA's Weather Radio was expanded, allowing millions of Americans to receive tornado warnings in their homes from the National Weather Service (NWS). In 2007, the NWS switched from county-based warnings to storm-based warnings, leading to GPS-based warning dissemination (Coleman et al. 2011). Counties are large relative to tornado damage areas; therefore, county-based warnings often "overwarned" for tornadoes, unnecessarily warning those at safe distance from the storm who were not in immediate danger (Sutter and Erickson 2010). Along with tornado sirens, automatic telephone-based warnings were disseminated to the area of potential impact (Coleman, et al. 2011). Today, tornado warnings in the United States are dispersed through the following mechanisms, reaching people via multiple avenues in a quick, efficient manner: outdoor warning sirens, local television and radio stations, cable television systems, cell phone apps, and NOAA Weather Radio (NOAA).

Heat-Health Warnings in France Following the deadly 2003 heat wave in which the death toll reached 14,802, (Vandentorren and Empereur-Bissonnet 2005), France developed a Heat Health Watch Warning System to anticipate heat waves with the potential to result in high mortality rates (Pascal, et al. 2006). The main goal of this warning system is to alert authorities of anticipated heat waves, allowing citizens enough time to implement preparation and preventative measures (Pascal, et al. 2006). Following 2004 implementation, numerous alterations were made to the warning system to redefine heat thresholds (Pascal, et al. 2006). In a comparison of Paris heat-related events in 2003 and 2006, the lower-than-expected mortality was attributed to a decrease in population vulnerability, along with an increase in awareness of risks associated with extreme temperatures, better implementation of preventative measures, and the established heat warning system (McGregor 2015). In 2015, the WMO and World Health Organization (WHO) published "Heatwaves and Health: Guidance on Warning-System Development" to provide detailed guidance on development and implementation of heat-health warning systems, addressing the fact that heat-health warning systems are best developed specific to local conditions (McGregor 2015). Across Europe, June 2019 was the hottest on record for the continent; however, the heat-health early warnings limited the death toll according to initial reports (WMO 2019b).

Tsunami Warnings in Japan In the 1940s, the evolution of EWS for tsunamis began in Japan. This continued through 2004 when the Indian Ocean tsunami killed over 235,000 people and officials called for global action. The first instrumental warning system to detect earthquakes and warn of an impending tsunami was developed in 1941. By 1946, the Japanese government established a plan for tsunami forecast and dissemination, and in 1952, the Japanese Meteorological Agency (JMA) operated this system along the coastlines and established national standards for detection and warning. Significant progress was made in 1999 when JMA could determine the location and size of an earthquake and issue a tsunami warning within 3 min. However, this earthquake-centric approach to tsunamis presented challenges related to warning accuracy and public misunderstanding. Following the 2004 Indian Ocean tsunami, a global system was put in place along tsunami-threatened coastlines, with plans underway from the Intergovernmental Oceanographic Commission (IOC) to develop international standards for regional warning systems designed to ensure interoperability and understanding (Bernard and Titov 2015). A coordinating group was established by the United Nations (UN) for the Indian Ocean Tsunami Warning and Mitigation System, which "recommended the establishment of a web-based community tsunami-flooding model" (Bernard and Titov 2015). The Community Model Interface for Tsunamis (ComMIT) provides users with access to tools and capabilities across the tsunami forecasting community, and over 300 students have been trained on use with models covering the coastlines of the Indian Ocean and most of the southwest Pacific Islands (Bernard and Titov 2015).

EWS and the technologies they rely on continually emerge and evolve, providing more successful approaches to notifying communities of potential impending climate danger. Various notification techniques are being used throughout the world that demonstrate both best practices and lessons learned for these EWS. The examples provided below include just a small sampling of the systems in place that are enhancing community resilience through the ability to plan for, respond to, and recover from extreme climate events. It is critical that communities are aware of the potential climate risks they face in order to prepare for, respond to, and recover from extreme weather events. Within the community, information shared in the early warnings must effectively communicate the hazard, reach vulnerable populations, and encourage people to act (Rogers 2011). Early warning systems are in use around the world for various climate-related events, from flooding, wildfires, and tsunamis to health-related events such as epidemics. Increases in the frequency of weather and climate extremes will encourage communities to install, adapt, or improve their EWS in order to build resilience, with the goal of withstanding and recovering from such events.

Semarang, a 100 Resilient Cities member city in Indonesia developed an EWS for flooding to enhance their broader resilience strategy (Junmookda 2015). Following a flood in 2010 that claimed 6 lives and resulted in over 100 injuries, and after accessing vulnerability data that projected flooding would worsen without the widening of a nearby river, Semarang began the development of a flood EWS in 7 communities, with the support of the Rockefeller Foundation's Asian Cities Climate Resilience Network (ACCCRN) (Junmookda 2015). This collaborative effort pulled in stakeholders from various entities: governmental departments and sectors, Diponegoro University, the Indonesian Red Cross, and Bintari Foundation. One of the communities adopting the flood EWS conducted an exercise focused on notification and evacuation, educating the community on signaling through use of a siren, gathering supplies, and traveling evacuation routes to the flood shelter (Junmookda 2015). The adoption of the EWS, along with the exercise conducted, prepared the community for future flooding events with the goal of reducing death and injuries through increased knowledge and action planning.

In Southeastern Europe, specifically Bosnia and Herzegovina and Serbia in 2014, historic flooding resulted in USD 2 billion in damages and severe economic impacts (Kull and Staudinger 2018). Another storm in 2016 caused flash flooding in Macedonia and killed 21 (Kull and Staudinger 2018). It was determined that residents in certain areas were given little preparation time and insufficient data, acknowledging that improved cross-border monitoring and forecasting along with an enhanced EWS could have reduced the impacts and devastation resulting from these storm systems (Kull and Staudinger 2018). As a result, the South-East European Multi-Hazard Early Warning Advisory System (SEE-MHEWS-A) was developed as a multi-government, cross-border collaboration, initiated by the WMO with financial support from the United States Agency for International Development (USAID). This system later gained financial support from the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) (Kull and Staudinger 2018). This approach provides cost savings for the participating countries as meteorological model results are shared as part of a consolidated effort, which both improves local weather forecasts and enhances EWS effectiveness. According to the WMO, current funding for this effort is USD 2.4 million with implementation in the following countries: Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Hungary, Israel, Jordan, Lebanon, Montenegro, Republic of Moldova, Romania, Serbia, Slovenia, North Macedonia, Turkey, and Ukraine (WMO, 2019c). This example not only highlights the importance of an EWS in flood-prone areas but also highlights the benefits of multiple countries working together to build greater resilience to flooding within their communities.

The WHO has identified numerous diseases with a climate-epidemic link, including influenza due to decreased winter temperatures, cholera due to increases in sea and air temperatures, and meningococcal meningitis due to increased temperatures and decreased humidity, along with many others (Rogers, 2011). Malaria, which is transmitted by female *Anopheles* mosquitoes, has been a continued concern due to the changes in temperature and rainfall in countries in the tropics, subtropics, and some temperate areas (Rogers, 2011). In Africa, the Malaria Early Warning System (MEWS) uses vulnerability indicators, transmission risk indicators, and early detection indicators to predict the timing and severity of a malaria epidemic (Thomson and Connor 2001). Prediction of malaria epidemics is based on weather forecasts, while providing a longer lead time (Maharaj, 2017). A 2017 article noted that countries in Africa and Asia have successfully reduced the burden of malaria to low levels and are now in the process of eradication (Maharaj, 2017). The use of the EWS led to proactive action to be taken to reduce and contain the outbreaks while focusing on decreasing the rate of transmission.

Along with best practices, many lessons learned can be identified and addressed in moving forward with current or new EWS initiatives designed to enhance community resilience. Certain questions must be considered, such as (1) how to combine relevant science, technology, and local knowledge; (2) how to build trust among experts and users of the early warnings; and (3) how to create a sense of ownership among EWS beneficiaries (Baudoin et al. 2014). The lessons learned outlined below provide an overview of the valuable information that could be leveraged to improve existing EWS or enhance the capabilities of newly developed or implemented systems.

In March 2016, UNDP Programme on Climate Information for Resilient Development in Africa published the "Climate Information and Early Warning Systems Communications Toolkit" to guide communities on the strategies necessary to develop and implement an effective EWS. In a review of EWS in Africa, the following challenges were identified: lack of reliable data; lack of credibility; lack of protocols; limited sophistication in packaging; limited relationships with traditional media and other actors; lack of distribution systems; and limited business development capacity and necessary frameworks, along with cultural, political, economic, and climatic challenges (UNDP 2016). By identifying and understanding these challenges, communities implementing an EWS can consider these factors prior to system implementation within their community with the goal of mitigating such potential roadblocks to progress.

This year in Los Angeles, California, the ShakeAlertLA app was introduced to provide early warnings to app users of earthquakes via push notifications. However, following a 6.4 magnitude earthquake in Southern California, users were unhappy when they did not receive a notification due to the magnitude threshold set for the warning. Initially, creators believed app users would not like to be overwhelmed with notifications but quickly realized they would prefer more information than less (Nieto Del Rio 2019). This is an example of an effective system people relied on and wanted to continue to use, where an adjustment to the severity threshold would allow for more frequent user notifications.

Following two cyclones that hit Mozambique in 2019, the WMO recommended strengthening southern Africa's EWS. In addition, the WMO Secretary General Petteri Taalas stated, "The two cyclones are a wake-up call that Mozambique needs to build resilience" (WMO 2019a). Unfortunately, it was this devastating event that resulted in the realization that the EWS needed to be strengthened, along with reconstruction, rehabilitation, and modernization for the meteorological and hydrological sector. The cyclone and flooding resulted in more than 600 deaths and 1600 injuries and impacted more than 1.8 million people. Although it was found the cyclone warnings were sufficient, improvements needed to be made in flood warnings. It was also found that communication messages needed to be simplified and include potential impacts, along with ongoing education and awareness of the community (WMO 2019a).

6 Leveraging Technology for Future Warning Systems

Technology advances continue to contribute to rapid improvements in EWS used for extreme climate events. From the use of social media and mobile phone apps to the use of sensors and advanced data collection and analytic techniques, EWS are becoming substantially more than simple sirens alerting individuals to take cover. Leveraging technology such as social media and mobile apps allows for ongoing communication before, during, and after a disaster, providing communities with greater detail and direction.

Social Media Facebook, Twitter, YouTube, and Instagram are increasingly a source of news and information sharing worldwide (Bui 2019). Social media networks can be used to share information before, during, and after disasters as a means for sending warnings, conducting situational awareness, as well as catalyzing action and sustaining feedback loops (Bui 2019). In an after-action study following Hurricane Maria that hit Puerto Rico in September 2017, multiple findings were identified outlining the benefits of social media use for early warnings. Prior to the hurricane, social media was used to mitigate misinformation, provide warnings in both English and Spanish, and convey information to native Spanish speakers who do not rely on official communication channels. The study also found the need for emergency management authorities to update risk communication platforms to utilize social media, ensuring warnings are inclusive of smartphone technology to reach the larger community (Bui 2019).

Apps The use of mobile phone applications has been on the rise, allowing communities to quickly and easily notify individuals of extreme climate events. One example is the "DisasterAlert" app, which alerts users in the United States of earthquakes, tornadoes, hurricanes, tsunamis, ice, flood, freezing, fire, wind, and snow. In Lebanon and Haiti, apps are used for agro-meteorological early warning to notify farmers of potential heat waves, flooding, and drought. Multiple apps have been developed and deployed for earthquake early warnings, such as "Yurekuru Call" in Japan, "SkyAlert" in Mexico, and "ShakeAlert" in the United States (UNDP, 2018). As part of a World Bank initiative, "Code for Resilience" is an effort to foster a global community to identify and reduce risks from natural disasters, bringing together citizens, government, and technologists to use open innovation, open data, and open software and hardware tools (UR, 2019). Through this program, apps for early warning are designed and deployed for real-world use (UNDP 2018). One of the challenges with apps, however, is that in order to receive any warning or communications, users need to have already downloaded the apps onto their phone.

Sensors The use of sensors to detect or predict potential climate events has been and continues to be tested and implemented to enhance EWS. From 2009 to 2012, the European Community's Seventh Framework Programme supported the project, UrbanFlood. The project investigated "the use of sensors within flood embankments to support an online EWS, real time emergency management and routine asset management" (UrbanFlood 2015). Through the creation of this EWS framework, the sensors were linked via the Internet to predictive models and warning systems, demonstrating the benefit of sensor use and implementation at multiple locations (Simm, et al. 2012). There are also multiple technologies in use today that leverage sensors for offshore tsunami observations: (1) DART: bouy-based technology offering local and distant tsunami detection and portable standardized sensors and sharing data in real time with other countries through a distributed system; (2) cable observations: local and distant tsunami detection, the same sensors as DART, four countries have installed cable observatories, supporting dense network of pressure sensors; and (3) differential GPS bouys: local tsunami detection and portable, distributed system (Bernard and Titov 2015). These systems allow for real-time information sharing among multiple countries.

Another example is the use of sensors in China for landslide detection and EWS that provide an accurate, reliable approach to alert individuals of potential disaster. A primary goal of this approach is to minimize landslide disasters through early warnings. The Chinese system can achieve real-time sensor data acquisition and remote transmission and query display at a remote monitoring center (Gan and Jin 2018). Technologies continue to advance the capabilities employed for forecasting, data collection, and EWS implementation and enhancement. These systems continue to progress in both timeliness and efficiency, as well as in accuracy.

7 Summary and Conclusions

Early warning systems have changed the way communities prepare for, respond to, and recover from disasters. A greater emphasis is now placed on when the event will occur as well as how to best respond, allowing communities to become more resilient to extreme weather events and man-made threats at all levels: infrastructure, organizational, social, and personal. As previously stated, it is important to develop resilience measures to support adaptive and flexible risk management processes and to promote sustainable development for communities. Timeliness and accuracy are two primary components to an effective EWS within communities, along with four key elements: risk knowledge, monitoring and warning services, dissemination and communication, and emergency management capabilities. Communities can continue to enhance their EWS by applying best practices and lessons learned, as well as implementing new technologies as they become available. EWS are not a singular solution to making a community resilient, but they are a key component to helping communities respond to impending danger and recover from disasters, ultimately enhancing resilience to all hazards including climate change.

In addition to the EWS discussed in this chapter, there is a growing prevalence of multi-hazard early warning systems. According to the WMO, MHEWSs "address several hazards and/or impacts of similar or different type in contexts where hazardous events may occur along, simultaneously, cascadingly, or cumulatively over time, and taking into account the potential interrelated effects." To learn more about MHEWSs, review the associated chapter.

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Chapter 12
Developing Partnerships for Building Resilience

Christian Fjäder

Abstract Resilience partnerships have become the new norm in disaster risk reduction and resilience (Action and the Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework)). The International Strategy for Disaster Reduction partnership, facilitated by the UN Office for Disaster Risk Reduction (UNDRR), specifically advocated for an inclusive, multi-stakeholder and shared responsibility approach to disaster resilience and risk reduction. Consequently, an ample selection of collaborative partnership between different levels of government, and between governments and business and civic sectors, has blossomed across the world. Whilst the need for multi-stakeholder cooperation is undeniable, such partnership are, however, often either ad hoc and reactive in nature or principally limited to sharing of information and good practices. Hence, whilst useful, in a sense of developing capabilities in resilience, partnerships should be more long term and concrete and have a clear value proposal throughout the entire life cycle of disasters.

Keywords Disaster risk reduction · Resilience · Public-private partnerships · Hazard risk

1 Introduction

Disaster resilience and risk reduction have gained increasing attention globally as disasters have affected more people and assets. For instance, between 2005 and 2014, disasters affected globally 1.7 billion people and caused US$ 1.4 trillion in economic damages (Melkunaite 2016: 4). Building collective resilience has become

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a key strategy for reducing the impact of such events and recovering from them. Building communal, national, regional or any other collective form of resilience against threats such as natural disasters, violent conflict, other catastrophic events or any other type of major shocks requires coordinated and cohesive efforts from multiple actors. The 'whole of society' and 'all hazards' approaches to disaster resilience and risk reduction by default require engaging multiple stakeholder groups ranging from national, regional and local governments together with the civil society and the private sector. These principles have been integrated in all relevant global and regional standards, for instance, in the Hyogo Framework for Action and The Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework). The International Strategy for Disaster Risk Reduction partnership, facilitated by the UN Office for Disaster Risk Reduction (UNDRR), specifically advocated for an inclusive, multi-stakeholder and shared responsibility approach to disaster resilience and risk reduction. Consequently, an ample selection of collaborative partnership between different levels of government, and between governments and business and civic sectors, has blossomed across the world. In fact, such partnerships have become the new norm in disaster resilience and risk reduction. Whilst the need for multi-stakeholder cooperation is undeniable, such partnership is, however, often either ad hoc and reactive in nature or principally limited to sharing of information and good practices. Hence, whilst useful, in a sense of developing capabilities in resilience, partnerships should be more long term and concrete and have a clear value proposal throughout the entire life cycle of disasters. This would require such partnerships to have a clear scope, extending from pre-disaster activities to actions taken during as well after the disaster, in order to produce long-term sustainable benefits to the parties involved and the shared mission. Whilst there is ample literature on the role of partnerships, in particular public-private partnerships, in community resilience in the context of disaster resilience (e.g. Chatterjee and Shaw 2015; Chen et al. 2013; Watanabe 2009), there is still a shortage of literature exploring the utility and limitations of such partnerships. After all, as Dunn-Cavelty and Suter (2009) point out, public-private partnerships have considerable potential, but they should not be considered a 'silver bullet'.

This chapter seeks to explore the critical elements of partnering in disaster risk reduction and resilience. It suggests that for resilience partnerships to become successful, they must present a unique value proposal, that partners must present a high level of awareness about the benefits and limitations of the partnership and that partnerships themselves should aim at becoming resilient by being robust and focused enough to stand the test of time whilst being adaptive and learning capable in order to maintain their relevance in the infinite variety of disaster scenarios. It does not seek to provide practical guidance in what specific activities such partnerships should, and should not, include, but rather it focuses on the critical elements that should be covered in order to make them genuinely value-adding and sustainable.

2 Public-Private Partnerships in Disaster Risk Reduction and Resilience

Public-private partnerships (PPPs) have rapidly become a norm in DRR across the world. Such partnerships are, however, somewhat different from PPPs in other policy areas, not least in a sense that their focus is so critical to the survival of communities and their populations. They do, however, have the same essential building blocks with other PPPs in other policy areas. As such, the basic logic of PPPs in DRR does not significantly differ from any other area. Like in any such partnership, the keys to success are a clear focus and objectives that are shared among all the partners and culminate in a unique value proposal. In DRR partnerships, however, scoping the partnership requires first a shared understanding about what is meant by 'resilience' and 'partnership' in the unique context it is established for. This section explores these central concepts in the context of disaster risk reduction and resilience.

2.1 Disaster Risk Reduction (DRR) and Resilience

Disaster risk reduction (DRR) has become a standardized approach across disaster preparedness efforts globally, enforced by global programmes and initiatives, such as the Hyogo and Sendai frameworks. The primary vehicle for the promotion of the concept initially was the United Nation's Hyogo Framework for Action (2005–2015). The Hyogo Framework for Action (HFA) was agreed upon in the aftermath of the devastating Indian Ocean Tsunami of 2004. The HFA defined disaster resilience as 'the ability of individuals, communities, organisations and states to adapt to and recover from hazards, shocks or stresses without compromising long-term prospects for development' (UNISDR 2005). It also introduced two fundamental pillars for disaster risk reduction: (1) that so-called 'natural' disasters are a consequence of development practices and (2) that the responsibility for disaster risk reduction goes beyond the State and that all stakeholders, from individual citizens through to the private sector, have a critical role to play (UN System Task Team: 5). The Hyogo Framework for Action (HFA) was followed by the Sendai Framework for Disaster Risk in 2015. Launched at the third World Conference on Disaster Risk Reduction in Sendai, the Sendai Framework (2015–2030) is a voluntary programme that recognizes that the primary responsibility for disaster risk is with the State but also proposes that the responsibility should be shared between the state, local governments, businesses and other relevant stakeholders. The Sendai Framework's goal is 'the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries' (UNISDR website). The Sendai Framework established four priorities for action: (1) understanding disaster risk, (2) strengthening disaster risk governance to manage disaster risk, (3) investing in disaster risk reduction for resilience and (4) enhancing disaster preparedness for effective response and to 'Build Back Better' in recovery, rehabilitation and reconstruction.

The definitions of 'resilience', in contrast, are notoriously numerous and diverse, with no single universal definition available as a reference. The definitions of the concept of resilience vary depending on the point of view and field of science in question, for example, in material sciences, psychology, ecology, business and economics. Moreover, the diversity is just as high even within the policy areas of topics that are related, including in the security- and crisis-related ones, such as national security, civil emergency management, crisis management and critical infrastructure protection (CIP).

Disaster resilience, on the other hand, has been defined as 'the ability of individuals, communities and state and their institutions to absorb and recover from shocks, whilst positively adapting and transforming their structures and means for living in the face of long-term changes and uncertainty' (OECD 2013: 1). The effectiveness of disaster resilience is thus determined by the degree to which individuals, communities and public and private organizations are capable of organizing themselves to learn from past disasters and reduce their risks to future ones, at international, regional, national and local levels (OECD 2013).

The practice of risk reduction largely derives from a notion that it is both possible and advantageous to attempt to reduce the exposure of vulnerable populations to risks observed based on past events by a variety of planning efforts. The idea of risk reduction and resilience building complementing each other is a result of evolving practices, in particular in context of hazards and disaster management. In principle, such approaches are pragmatic and, in the simplest of terms, rely on the notion that risk reduction is a practice aimed at responding to the expected (based on the information gained from the observation of risk events that have taken place in the past), whilst resilience is primarily focused on the ability to survive the unexpected. There are, however, some notable differences between practice and theory on how the relationship between risk and resilience is perceived in a specific context.

2.2 Public-Private Partnerships (PPPs)

The term 'public-private partnership' (PPP) has been utilized in numerous contexts, often quite loosely but generally referring to a relatively broad range of possible relationships between public and private entities, most often between central governments and private businesses and in the context of infrastructure. PPPs are also common in other policy areas, such as urban development, transportation, water services, utilities and education (OECD, Principles for Public Private Partnerships). The motivations for government often revolve around money, more specifically in efforts to attract capital investment from the private sector in order to compliment public financing in important infrastructure development projects. In addition to financing, the governments are keen to leverage on private sector's capabilities to utilize resources more effectively and bring in specialized knowledge that is not widely available in government. The value for businesses, in addition to gaining access to lucrative contracts, includes the opportunities for showcasing of their capabilities and demonstrating good corporate citizenship. Often the term PPP refers to arrangements where private businesses assume roles traditionally fulfilled by the government. OECD's definition for public-private partnerships is illustrative of this: 'arrangements whereby the private sector provides infrastructure assets and services that traditionally have been provided by government, such as hospitals, schools, prisons, roads, bridges, tunnels, railways, and water and sanitation plants'. The *OECD Glossary of Statistical Terms* states that the context in which the term is used is 'cases where the private operator has some responsibility for asset maintenance and improvement are also described as concessions. While there is no clear agreement on what does and what does not constitute PPP, they should involve the transfer of risk from the government to the private sector' (OECD Glossary of statistical terms).

2.3 Partnering in DRR

Resilience partnerships have indeed become the norm in DRR around the world. Whilst such partnerships are as diverse as the geographical and topical areas they are intended to cover, they have certain commonly shared characteristics in them. This section will explore issues with the private sector participation, which, in addition to providing many benefits, also has its limitations that should be considered in establishing and developing public-private partnerships. It also provides examples of partnerships across policy and geographical areas.

2.4 Issues Regarding Private Sector Participation: Benefits and Limitations

Private sector participation is, as has been already noted earlier, fundamental for the success of disaster risk and resilience initiatives and programmes. It is also one of most difficult aspects of such programmes to achieve in a sustainable manner. Considering that disaster risk and resilience partnerships are rarely profitable to private businesses, the principal motivation for participation must come from other sources. Whilst preparedness legislation is in place in some sectors, especially those considered critical infrastructure and services, for the most part the private sector participation is viewed as voluntary in nature, in particular in the response and recovery stages of a disaster. Hence, the issue of incentives is critical in engaging with the private sector in DRR. The most quoted potential sources of motivation are corporate relations- and responsibility-related disciplines (good corporate citizenship, sustainability) and security- and risk-related disciplines (risk management, business continuity management, emergency and crisis management, health and safety and supply chain resilience). Corporate relations-related disciplines all have the potential for motivating the company to participate in DRR partnerships due to potential gains in corporate reputation, but they do not necessarily link DRR sufficiently to corporate operations to create maximum valued added to the overall DRR effort.

Security- and risk-related disciplines on the other hand have the potential for being the glue between corporate and community interests in just that, as they generally have a shared aim. First and foremost, there is a clear planning and policy interest for corporate business continuity, as the resilience of the operating environment is an essential enabling factor for the objectives of business continuity planning. After all, stability of the communities where the company operates is essential for its success and its survival in the worst case. Achieving the continuity of operations and/or their recovery is at the minimum difficult, if not impossible, if the community in which the company is located continues to be disrupted by the disaster in question.

For the corporate staff, the DRR partnership can also offer an opportunity to gain new knowledge and competences that are not necessarily available in the corporate environment. In particular, information about risks and best practices in planning, response and recovery gained through the partnership can be valuable information that is difficult to source elsewhere.

The benefits to the businesses in more general terms are related to protecting its business, customers, supply chain and staff from adverse effects of a disaster. The additional benefits include the opportunities to enhance corporate reputation and brand image by demonstrating good corporate citizenship, to enhance relationships with government agencies and other external stakeholders or even to improve staff motivation and retention. In the best case, successful cooperation with the public sector in DRR can even provide new business opportunities (Izumi and Shaw 2015: 31–2).

The benefits to the community, on the other hand, are first and foremost that companies that supply products or services that are critical to the local population in crisis situations may gain improved capabilities that enable them to guarantee service delivery to a certain point also during exceptional circumstances. Even if these capabilities are not enough to satisfy all the needs of the community, at least the awareness about possible limitations is very helpful, as these should be then covered in the community's planning. This of course applies both ways; companies also need to know to what extent they can rely on resources from the community. Cooperation with private sector BCM planners can also be a valuable source of best practices to the community's planners, as their corporate counterparts tend to possess capabilities and skills in emergency, crisis and business continuity management that their public sector counterparts do not. Perhaps the most concrete benefit to the government, however, is that if the private sector actors are sufficiently mature in their preparedness, it will most likely lessen the burden on government and, thus, provide it with the possibility to focus finite resources towards vulnerable communities. In the minimum, partnering with the private sector also increases the government's awareness of the interests and capabilities of the private sector actors and in determining how to best focus its own resources in the most meaningful manner.

Hence, as such there is clearly a synergic win-win relationship between communal DRR and BCM interests, as both can accomplish gains in capabilities, skills and resources that support both their individual and collective objectives.

Limitations, however, are nonetheless unavoidable, and it is helpful to acknowledge them before they materialize in real life. Much of the limitations are limited to the use of finances and resources towards ends that do not directly support business goals. For instance, the focus of BCM is generally in the continuity of mission-critical activities of the company, which may not always and automatically correspond with the community's interest. After all, in some cases it may be in the interest of the company to accept the disruption of the local operation if they are not mission critical to its business. It may also be in its interest to steer away, or even relocate, business function from the disaster area in order to secure the continuity of its mission-critical activities elsewhere or in order to continue serving other markets that are more critical to its business survival. If the local community is a critical market, the potential for this problem is greatly reduced, but the more global the company's business is, the more likely it is for this type of conflict of interest to arise. However, in many cases the business locations where natural disasters and alike are more frequent are not the major target markets for the products manufactured there. The automotive and electronics production zones in Southeast Asia are a good example of this. Hence, it is likely that in such cases, production would be shifted to another manufacturing location in the interest of supply chain resilience and in order to avoid disruptions elsewhere along the chain, either on temporary basis until production in the original site has been restored or, in the worst case, on permanent basis.

Ultimately, the response of a company depends on the type of business it is in. For instance, critical infrastructure operators in general have to consider DRR participation as part of its licence to operate, often made mandatory in the sectoral preparedness legislation. Consequently, they have an inherited incentive to respond effectively to any event that endangers service delivery. Retail companies, as well as other businesses that rely on the local community for their business, tend to be more reactive towards the community's needs in the event of a disaster. Hence, there is no one standard response one could expect from the businesses, but rather responses will vary greatly throughout the disaster cycle and across different businesses.

On the government side, limitations stem from the fact that the government's responsibility towards the safety of people takes precedence, whilst most governments have limitations regarding supporting individual companies in a manner that has the potential to produce unfair competitive advantage in relation to their competitors, no matter how critical they are in the delivery of critical services or their recovery.

3 Examples of Public-Private Partnerships in Resilience

Public-private partnerships in DRR are numerous and diverse, both in their focus and their composition. Some illustrative examples of collaborative partnerships across different levels include global, regional, national, local and thematic initiatives. The following partnerships provide indicative examples of alternative ways to organize, maintain and develop public-private partnerships in DRR.

3.1 Global Partnerships

In the global level, partnerships are principally connected to the global frameworks of the United Nations' (UN) programmes and initiatives. The principal umbrella for such global partnerships is the Global Platform for Disaster Risk Reduction, which is also the UN's main forum for strategic advice, coordination and partnership development in DRR in the global level. The Global Platform has resulted in the establishment of national platforms in over 80 countries, as well as several regional platforms, around the world (UNISDR website).

In addition to the global platforms, the programme has led into the establishment of several regional partnership platforms, which in turn support numerous local arrangements. Hence, it provides a link from global to local level as well as provide a platform for thematic partnerships that are not limited to any specific geographic locations.

The Global Resilience Partnership, sponsored by the Canada, UKaid, USAID and SIDA (the Swedish International Development Cooperation Agency), is an example of a resilience initiative aiming at improving the resilience of people in vulnerable areas by bringing public and private sector organizations together to increase the awareness and investments in resilience (Global Resilience Partnership).

3.2 Regional Partnerships

In the regional level, the Association of Southeast Asian Nations (ASEAN) Agreement on Disaster Management and Emergency Response (AADMER) is perhaps the most ambitious and comprehensive DRR treaty in the world (ERIA 2015). ASEAN, founded in 1967, is comprised of ten member states in Southeast Asia with a total population of 600 million and is the world's third largest economic region with a combined GDP of US$ 2.7 trillion in 2017. In addition to being one of the world's major economic regions, Southeast Asia is one of the most disaster-prone areas in the world with approximately 100 million people having been affected by disasters since 2000. Moreover, the annual losses from natural disasters in the region exceed US$ 4.4 billion annually (World Bank 2012). Moreover, the disaster risk in the region is predicted to increase due to, for instance, urbanization and climate change (Maleksaeidi et al. 2017). Majority of the disaster losses and impact on people are from natural disasters, such as earthquakes, floods, volcanic eruptions and tropical typhoons. Some examples of such major disasters in recent years include the typhoon Nargis in 2008; flooding in Cambodia, Laos, Vietnam and Thailand in 2011; the Aceh earthquake in 2013; and typhoons Bohal and Haiyan in 2013.In order to enhance regional coordination in disaster management, ASEAN established the ASEAN Committee on Disaster Risk Management (ACDM) in 2003. In July 2005, the ASEAN foreign ministers signed the ASEAN Agreement on Disaster Management and Emergency Response (AADMER) in order to further enhance regional cooperation in disaster management. AADMER entered force in December 2009, and its objective is to reduce disaster losses and to jointly respond to disasters in the region. Unlike other related agreements, AADMER provides a joint legal framework for ASEAN member states in DRR, as well as a common platform for joint response to disasters. AADMER – adhering to ‘One ASEAN, One Response’ philosophy – incorporates a comprehensive set of DRR measures, such as disaster risk identification, assessment and monitoring, disaster prevention and mitigation, disaster preparedness, emergency response, rehabilitation and technical cooperation and scientific research. The ASEAN Coordinating Centre for Humanitarian Assistance (AHA Centre) was established in 2011 to operationalize the AADMER objectives (AHA Centre website). The AHA Centre has since proven its worth in several regional natural disasters.

ASEAN’s commitment to disaster management has been even further advanced since. For instance, the 2015 Declaration of Resilience envisions a disaster-resilient ASEAN community, whilst the ASEAN Vision 2025 on Disaster Management provides a strategic framework for the implementation of AADMER over the coming decade.

The primary platform for the action plan and regional cooperation in implementing the framework is the Asian Ministerial Conferences on Risk Reduction (AMCDRR). The AMCDRR was established in 2005 and is organized biennially jointly by the United Nations Office for Disaster Risk Reduction (UNISDR) and a rotating Asian host country. The AMCDRR is intended as serving the regional states as a forum for agreeing on shared responsibilities and actionable commitments for DRR in the region. Altogether seven AMCDRR conferences have been arranged since 2005, the latest being the 2016 conference in India, which adopted the ‘Asian Regional Plan for Implementation of the Sendai Framework’ (UNISDR 2016). Another important UNISDR platform supporting the implementation of the Sendai Framework is the ISDR Asia Partnership (IAP) forum. The IAP forum is intended as the operational arm of the UNISDR regional platform and focuses on providing a regional mechanism for consultation and technical support for the implementation of the regional plan (UNISDR 2015).

The partnerships’ track of AADMER includes several initiatives to address partnerships in DRR and resilience. It was further enhanced in the sixth ASEAN ministerial meeting on the AADMER in October 2018 held in Putrajaya, Malaysia. The meeting instigated an enhanced focus on community-based collaborative partnerships across the region in order to ensure the community aspects of AADMER. The AADMER Partner Group (APG), for instance, is a network of non-governmental organizations working with the ASEAN Committee on Disaster Management (ACDM), the AHA Centre and the ASEAN Secretariat in order to advance AADMER's people-centred goals. APG's membership includes non-governmental organizations such as the ChildFund International, HelpAge International, Mercy Malaysia, OXFAM, Plan International, Save the Children International and World Vision International (APG Profile).

ASEAN also released principles for public-private partnership framework in 2014 in order to provide non-binding guidance to member states on implementing partnerships in DRR. The principles cover four main areas of partnership policy implementation: (1) policy and organizational framework for private participation; (2) project selection, development and implementation; (3) affordability and budget transparency; and (4) transnational infrastructure connectivity. The principles are based on OECD's *Principles for Public Governance of PPPs*.

Other international organizations that have DRR-related initiatives concerning the region include a variety of United Nations (UN) agencies, international financial institutions and bilateral assistance organizations. The World Bank's East Asia and the Pacific Disaster Risk Reduction programme, for instance, provides a DRR-related support in forms of 'lending, technical assistance, institutional strengthening and capacity building, and provision of knowledge in the form of best practice, on-demand analytics and just-in-time assistance' (World Bank 2017). The Asian Development Bank (ADB), on the other hand, links DRR with climate change adaptation (CCA) in the context of its flagship DRR project, the Regional Partnerships for Climate Change Adaptation and Disaster Preparedness. The focus of ADB is to provide tools and methodologies to integrate DRR and CCA approaches in the region (ADB 2013). The ADB also runs a fund supporting such initiatives. The Integrated Disaster Risk Management (IDRM) Fund was established by ADB in 2013 and is supported by the Government of Canada (ADB website).

The Asia-Pacific Economic Cooperation (APEC) Disaster Reduction Framework, on the other hand, is a call for action to the APEC member countries to strengthen DRR in all policy areas. It focuses on risk reduction and disaster resilience in variety of areas in order to secure sustainable economic development regardless of the frequent disasters in the region (APEC 2016).

3.3 Local Partnerships

Local partnerships are probably the most important and effective form of partnering for resilience from the communities' point of view. It is after all usually the local partnerships that are in the forefront of any disaster response and recovery. They also form the backbone for implementation that the regional and global partnerships rely on. Examples of local partnerships producing invaluable contributions in crises include during Hurricane Katrina, when Wal-Mart played a critical role in supplying local residents and providing logistics support to the delivery emergency supplies (Chandra et al. 2016: 7) and during the 2011 Great East Japan Earthquake, when the local supermarket chain Maiya, leveraging on its good planning, managed to not only stay open and continue to supply local residents but also set up temporary satellite stores to supply emergency supplies, such as generators, fuel, floodlights and plastic tarps (UNESCAP 2015: 17).

The other important local-level focus in recent years has been the resilience of cities. The UN Office for Disaster Risk Reduction (UNDRR),[1] for instance, launched the Making Cities Resilient Campaign (MCRC) in 2010 in order to enhance local resilience through engaging local governments and mayors. Its strategic aim was to support the implementation of the local-level objectives of the Hyogo Framework and then, consequently, the Sendai Framework. The MCRC is led and supported by UNDRR but aims to be self-motivating partnership that is city-driven in order to effectively raise DRR awareness of local governments and city administrations. It has until date involved over 4000 cities and 40 partners around the world (MCRC website).

Another significant cities-focused initiative with global scope, also supported by the UNDRR, is the 100 Resilient Cities (100RC) initiative launched by the Rockefeller Foundation in 2013. The 100RC initiative promotes a view of resilience that goes beyond shocks – such as earthquakes, fires, floods and other natural disasters – addressing also other stresses that weaken the fabric of a city on day-to-day basis. The examples of such stresses include high unemployment, endemic violence or chronic food and water supply shortages. 100RC member cities were chosen from over 1000 applications and include cities across the world.

The initiative supports member cities by providing them with the resources required for developing a roadmap to resilience. The support is divided into four main pathways: (1) financial and logistical support for establishing a position of a Chief Resilience Officer; (2) expert support for the development of a resilience strategy for the city; (3) access to solutions, service providers and partners from the private, public and NGO sectors who can assist the city with the implementation of its resilience strategy; and (4) membership in the 100RC network and its information-sharing platforms (www.100resiliencities.org).

3.4 Thematic Partnerships

Thematic partnerships range greatly in scope and address a broad variety of policy areas, e.g. climate resilience, ICT, food and water, agriculture and disaster insurance.

The UN Environment Programme's Finance Initiative (UNEPFI) Principles for Sustainable Insurance (PSI) Global Resilience Project is an example of a

[1] The UN Office for Disaster Risk Reduction changed its acronym from UNISDR to UNDRR in May 2019.

partnership that aims at providing a global framework for the insurance industry towards addressing environmental, social and governance risks and opportunities in a more sustainable manner. Its strategic objective is to provide a global roadmap for the insurance industry to develop innovative risk management and insurance solutions that help in promoting renewable energy, clean water resources, food security, sustainable cities and disaster-resilient communities and economies (The PSI Global Resilience Project). PSI has been adopted by 90 organizations by November 2015, including insurance providers representing approximately 20% of global premium volume and USD 14 trillion in assets under their management (The PSI Global Resilience Project). PSI promotes a view that states the importance of multistakeholder partnerships in leveraging diverse expertise and resources of governments, businesses and NGOs towards addressing the ever-increasing need for investments in disaster resilience. Some of such partnership supported include the Bangladesh Cyclone Preparedness Programme, Myanmar's Earthquake Monitoring System, Vietnam's Thanh Hoa Mangrove Project and the Philippines' Response to Typhoon Washi and Bopha. Examples of other initiatives supported include the Australian Business Roundtable for Disaster Resilience and Safer Communities, Disaster Risk Reduction Insurance (DERRIS) Climate Change Adaptation Project for SMEs and Municipalities in Italy, the Partners for Action (P4A) in Canada and the Resilient New Zealand initiative. Of these, the Australian Business Roundtable for Disaster Resilience and Safer Communities is a good example of an initiative that includes the private sector. The roundtable includes multisector partners from the insurance industry (IAG), banking (Westpac), telecommunications (OPTUS), property development (Investa), reinsurance (Munich Re) and the not-for-profit sector (Australian Red Cross). Another illustrative example of initiatives supported is Japan's earthquake insurance system for homeowners. The system is backed by the Japan Earthquake Reinsurance Company (JER), a special purpose company co-managed by leading private non-life insurance companies. This way the risk is shared collectively, protecting the individual insurers' bottom lines and, thus, benefitting the houseowners with more affordable policies and faster claim handling. The system proved indispensable in the 2011 Sendai earthquake and tsunami, when economic losses totalled approximately USD 210 billion and the total insured losses approximately USD 35.7 billion (UNEP 2014).

4 Developing Resilience Partnerships

Continuous development of resilience partnerships should be the norm, as partnerships not only need to continuously evolve to fulfil their current mission but also because each disaster is unique and responding to wider variety of incident types requires developing not only a robust set of capabilities but also a broad selection of thereof. Achieving partnerships that can fulfil such requirements and produce long-term sustainable impact must be clearly scoped, present a unique value proposal, have clear roles and responsibilities with credible arrangements for accountability established and adhere to a life-cycle approach to development in order to enable continuous improvement.

4.1 Establishing a Clear Scope and a Unique Value Proposal

The scope of a partnership is what ultimately determines the success of any PPP in DRR. Scoping the partnership includes establishing a common purpose, objectives, roles and responsibilities between the involved parties. The common purpose and objectives should not only be jointly agreed but also be as concrete as possible, so that both the parties and the relevant external stakeholders can easily understand them. The purpose and objectives of the partnership should be also understandable to the members of the communities that it covers. In this regard, it is important to go beyond the obvious of stating the promotion of risk reduction and disaster resilience against natural disasters as the purpose of the partnership. Instead, it is essential to provide clarity as to whether the partnership aims to only establish 'soft' mechanisms, such as awareness raising and information sharing, or, for instance, establish joint response capabilities or other pooling and sharing arrangements that require investments and requisition or dedication of assets for disaster situations (Fig. 12.1).

The scope should also clearly reflect to which stage/s of the DRR phases the partnership aims to contribute: (1) pre-disaster preparedness, (2) disaster response or (3) post-disaster recovery (Fig. 12.2).

Whilst it is entirely possible to aim at contributing in all phases, it is more likely at least individual partners within the partnership have specific capabilities in one of the phases, thus creating an opportunity for a unique contribution to the overall effort. Pre-disaster phase can include contributions towards innovations in technology or methodologies that support the development of DRR, the use of financial instruments towards investments in risk reduction measures and development assistance or competency contributions towards the overall planning effort. The response phase contributions could include direct material or staff contributions to community response and sharing of equipment and specific knowledge and capabilities, such as supply chain continuity. In the recovery phase, the key contributions are likely to be channelled through business continuity plan (BCP) implementation,

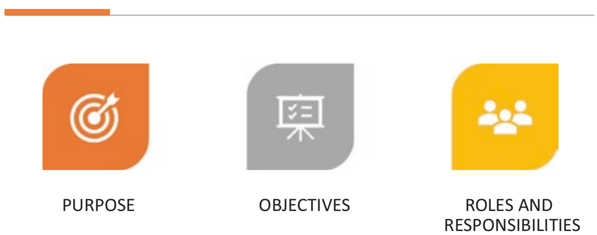


Fig. 12.1 Scoping partnerships. Source: Authors

Fig. 12.2 DRR phases

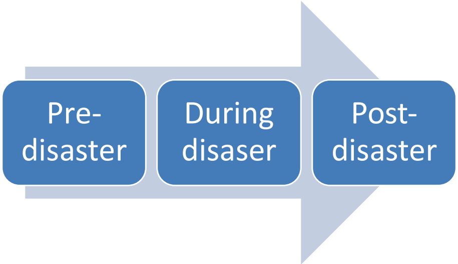
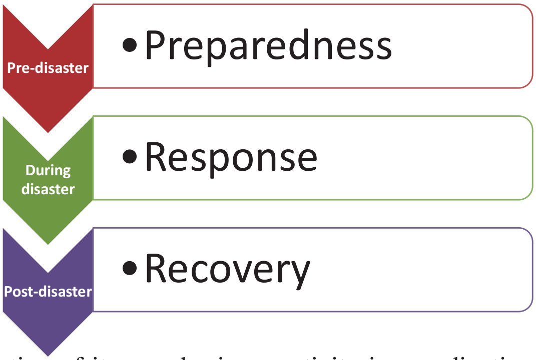


Fig. 12.3 Actions in different stages of DRR



principally in the form of restoration of its own business activity in coordination with community recovery efforts. Technical knowledge and specialized equipment required for the recovery efforts may also come into question (Fig. 12.3).

Finally, the partnership should be clear about its value proposal, what is the problem it seeks to solve and what is its unique contribution to the solution. After all, partnerships are not necessary for problems or challenges that the government or the business sector can solve on their own. In other words, partnerships should focus on areas where there is a clear demand but no supply. The complicating factor with this is that the notion of 'burning need' must be shared, not only by the partners but also the relevant external stakeholders in the community. Otherwise, the partnership is destined to fail from the very beginning.

4.2 Accountability, Roles and Responsibilities

In addition to clear purpose and objectives, partnerships should establish clearly assigned roles and responsibilities between individual partners, in addition to defining which responsibilities are intended to be shared. As such the division of labour should reflect both the overall goals of the partnership and the individual unique capabilities of its individual members. Moreover, these should not be overlapping in a competitive manner between various partners, which requires that partner selection is based on objective assessment of needs, capabilities and resources and is done in the early stages of the partnership. It is essential that each partner feels capable of bringing unique value to the partnership whilst feeling confident it can fulfil the role assigned to it without being concerned about possibly being set up for failure. Whilst all parties probably have the best intentions for joining the partnership, a failure in filling its role in the event of a disaster would easily surmount to the realization of significant reputational risk. Such failure could of course also endanger the entire mission of the partnership and in the worst case lead into a failure to limit the damage from the disaster. Even if the worst possible consequences are avoided, it is unlikely the partner continues being committed to the partnership in the future. Given the fact that most partnerships are trust based, rather than relying on strict contractual obligations, this could well endanger the future of the partnership and its 'licence to operate' from the government and the community. Having clarity beforehand of what is expected of you enables successful planning and preparation. The more clarity the partners have about their own and others' roles and responsibilities, the more likely it is that the partnership will perform as planned during a disaster.

Accountability is possibly the most difficult issue to solve, as this automatically also involves the assignment of liability in the event of a failure to perform or in case of errors having been committed in the response phase of a disaster. As mentioned earlier in this chapter, the global standards and guidelines in DRR assume that the accountability for citizens' safety and security must remain with the State. Whilst it is unquestionable that the final accountability in this regard must be retained by the State, some level of accountability must be assigned to the private and civic sector participants as well. Otherwise there is no guarantee that the capabilities and resources such partners have pledged for disaster response are truly available in the event they are needed. Contractual arrangements are of course of possibility in this regard, but given that disaster situation by default are normally regarded as *force majeure* condition under contractual law, the reliability of such contracts in terms of legal liability is always somewhat questionable. If legal liability is a major issue in the partnership, it is also less likely the business leadership will have the will and mandate to sign up to such an agreement. The pursuit of liability also brings technical complications to contract design, as it cannot work unless the terms are exceptionally well defined. Thus, instead of legal liability, it is more pragmatic to focus on ensuring the availability of capabilities and resources that the parties have pledged by making service-level agreements (SLAs) for capabilities and resources, with fines for non-compliance. SLA's are a mechanism that private businesses are familiar with, and healthy businesses consider non-compliance fines as incentives for service improvement, rather than punishment. A good example of a contractual arrangement that establishes clear roles and responsibilities, as well as accountability, is the emergency agreements in Japan. The Emergency Agreements (EA) system is a contractual form of PPP that has bilateral written agreements between the public (usually local governments) and private sector actors. As a pre-disaster written and public agreement, the EAs provide an ultimate motivation for the private sector signatories to fulfil their role to the maximum in the event of a disaster. Such agreements exist across the country, thus providing an effective network of predetermined disaster capabilities from the private sector (UNESCAP 2015: 29).

4.3 Life-Cycle Approach to Partnerships

The common trap of partnerships in DRR is their ad hoc nature. Whilst it is still very useful that in the event of a disaster a network of partners comes together and mobilizes towards a common goal in an ad hoc manner, based on pre-disaster networking and information and good practices sharing, the (often positive) result is somewhat unpredictable and potentially non-replicable in future disaster events. In order to avoid such shortcomings, the partnership planning process should be long term in nature and seek to guarantee replicable results. The essential requirement for achieving this is a clarity of what the objectives of the partnership and roles and responsibilities of partner are in the pre-disaster measures to be taken and actions expected during a disaster and in the post-disaster recovery stage. The final stage – lessons learned – should feed back to the pre-disaster planning stage in order to produce sustainable efficiency gain in the long term. In this regard, the plan-do-check-act (PDCA) process cycle is a helpful guide. However, PDCA alone is not quite enough, but instead the continuous development cycle must specify which measures are intended to be taken and by whom in the different stages of the DRR life cycle. Otherwise the partnership is unlikely to produce long-term benefits and become able to sustain itself in the long run (Fig. 12.4).

What does it then take to establish long-term partnerships that provide sustainable benefits to all parties involved over time? The first requirement, as has been pointed out before, is having the right scope, right partners with the right competences as well as realistic but sufficiently challenging objectives, complemented with the awareness of the limitations of the partnership. As with any venture, it is all about managing the expectations.

Moreover, since these partnerships focus on resilience, they should make use of the concept towards ensuring the resilience of the partnership. Hence, resilience partnerships must be robust in their foundations in a sense that they must stick to their mission and keep its partners engaged when disaster strikes.

On the other hand, they must be adaptive in a sense that they need to learn and adapt to the unique conditions of each disaster, as well as for the sake of continuity, constantly find new ways to fulfil their missions and keep delivering.

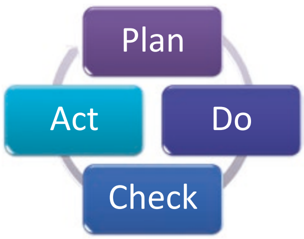


Fig. 12.4 PDCA cycle. Source: Adaptation by the Authors

5 Summary and Conclusions

The significance of partnerships in resilience is undeniable. Without multi-stakeholder partnerships, much of the success stories, saving countless of lives and limiting economic and physical damage of disasters, would have not been possible. Moreover, the number and effectiveness of such partnerships has been constantly growing across the world.

However, as has been demonstrated in this chapter, there is still plenty of room for improvement. Many such partnerships either are still ad hoc in nature or have a focus that is either too specific to have significant society-wide impact or too broad to be effective. Hence, DRR partnerships should be developed systematically so that they contribute towards more long-term sustainable impact with a clear statement of value added. This requires numerous measures to be taken in partnership initiatives across a number of levels and stages. As such, success requires a clear focus that is specific enough to support concreteness yet broad enough to have significant impact on the overall DRR effort. Finally, successful partnership requires high levels of shared awareness about the partnership's limitations in order to avoid disappointment and disillusion among the partners and the relevant stakeholders in the community.

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Chapter 13
Disaster Resilience and Computational Methods for Urban Infrastructures

Saeid Eslamian and Mousa Maleki

Abstract Urban infrastructures are mostly interdependent in various ways. A variety of qualitative explanations is presented in the literature to analyze and address resiliency and vulnerability. Unfortunately, most of the explanations do not provide an objective resilience index computation. This chapter attempts to develop resilience indices and computational methods for urban infrastructures in order to lower disasters risk subjected to urban infrastructures.

Keywords Resilience · Disaster · Risk · Computational methods · Urban

1 Introduction

A new paradigm for complex systems performance and maintenance decision-making is developing in the form of resilience engineering. Resilience engineering represents a major step forward by proposing a completely new vocabulary rather than simply adding one more concept to existing lexicons. These disturbances can ultimately affect the smooth and efficient operation of systems and may demand a shift of process, strategies, and/or coordination. Urban infrastructure systems in most cases are interconnected, and the analyses should consider properties of this strong interdependency. In this paper, we develop a resilience index using a framework capable of addressing the interdependencies and uncertainties of urban infrastructure.

Infrastructure can be succinctly described as the systems and organizations required for the function of a society. This somewhat nebulous description can include static public works, such as roads, bridges and buildings; functioning facilities such as water and wastewater treatment plants and distribution systems; communications networks; and social structures. Despite the fact that urban infrastructure

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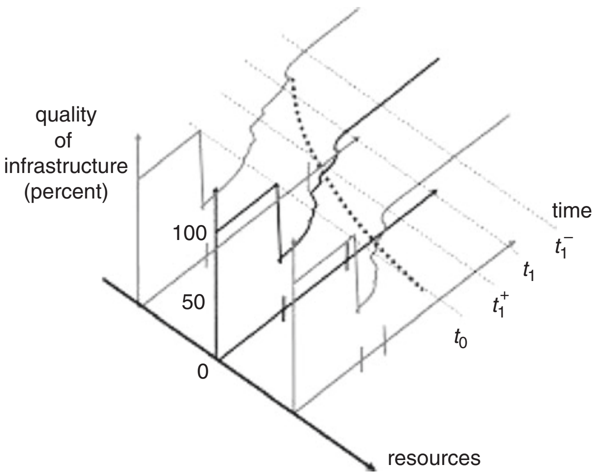
networks and systems have significant differences, they all are vital to most other human activities and represent large social investments in facilities.

2 Resilience Necessity

A resilient system is one that shows (a) reduced failure probabilities; (b) reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences; and (c) reduced time to recovery (restoration of a specific system or set of systems to their "normal" level of functional performance) (Bruneau et al. 2003). A resilient system exhibits the following:

- Robustness strength or the ability of elements, systems, and other measures of analysis to withstand a given level of stress or demand without suffering degradation or loss of function.
- Redundancy or the extent to which elements, systems, or other measures of analysis exist that are substitutable, i.e., capable of satisfying functional requirements in the event of disruption, degradation, or loss of functionality.
- Resourcefulness or the capacity to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other measure of analysis. Resourcefulness can be further conceptualized as consisting of the ability to apply material, i.e., monetary, physical, technological, and informational and human resources, in the process of recovery to meet established priorities and achieve goals. Its impact is shown in Fig. 13.1; and, risk management and sustainability are two ends of the resiliency continuum as resiliency is a feature of systems perpetually evolve through cycles of growth, accumulation, crisis, and renewal, and often self-organize into unexpected new configurations (OSU 2014).

Fig. 13.1 Effect of resources on resiliency



3 Resiliency Applied to Urban Infrastructure

The concept of resilience was originally introduced by Holling (Holling 1973) in the field of ecology wherein resilience was used in the following context: "resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb change state variable, driving variables, and parameters and still persist." Walker et al. (2004) defined resilience as "the capacity of a system to absorb sdisturbance and re-organize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks." The concept of resilience and its applicability to ecological, social, and business systems are capable of restructuring itself and recovering from a perturbation which corroborates.

Civil infrastructure systems which are developed as a process of hierarchical decomposition tend to have rigid operating parameters, are resistant to stress only within narrow boundaries, and may be vulnerable to small, unforeseen perturbations. The purpose of resilience engineering is to anticipate the changing potential for failure considering that plans and procedures will always have limits and gaps, and the environment constantly changes in terms of design, external shocks, and policies.

4 Seismic Resilience

4.1 Infrastructure Seismic Resilience

Critical infrastructures such as electricity, oil, gas, telecommunications, transportation, and water are essential to the functioning of modern economies and societies. As the world is increasingly interconnected, long-haul trans-regional, transnational, or transcontinental links are playing a crucial role in transporting critical resources and information from one location to another. For example, it is known that submarine telecommunications cables carry over 95% of the global voice and data traffic (Carter et al. 2009).

Among various natural disasters, earthquakes often cause the most catastrophic effects. For example, in 1987, the Ecuador earthquake resulted in the damage of nearly 70 km of the Trans-Ecuadorian oil pipeline. Loss of the pipeline deprived Ecuador of 60% of its export revenue, and it took 5 months to reconstruct the pipeline (Schuster et al. 1991). In 2006, the Hengchun, Taiwan, earthquake damaged eight submarine cables with a total of 18 cuts. As a result, Internet services in Asia were severely disrupted for several weeks, affecting many Asian countries (Qiu 2011). It was estimated that, for a well-developed economy that is largely reliant on the Internet, 1 week of Internet blackout can cause losses of over 1% of annual GDP (mi2g 2005). These events signify the impacts of earthquake hazards and the importance of enhancing the seismic resilience of critical infrastructure links (Cao et al. 2013, 2016; Cao 2015).

4.1.1 Concepts of Endurance Time Method

A reliable estimation of the damage to various structures and their compartments requires realistic evaluation of seismic response of structures when subjected to strong ground motions. This, in turn, requires the development and utilization of advanced numerical techniques using reasonably realistic dynamic modeling. While any serious development in the area of seismic-resistant design has to be backed up with decent real-world experimental investigation, the type and number of decision variables are usually so diverse that numerical investigations remain to be the only practical alternative in order to seek good solutions regarding performance and safety.

In the endurance time (ET) method, structures are subjected to a predesigned intensifying dynamic excitation, and their performance is continuously monitored as the level of excitation increases (Estekanchi et al. 2004). A typical ET excitation function (ETEF) is shown in Fig. 13.2.

Level of excitation or excitation intensity can be assumed to be any relevant parameter considering the nature of the structure or component being investigated. Classically, parameters such as peak ground acceleration (PGA) or spectral intensity have been considered to be the most relevant parameters in structural design. More recently, parameters based on input energy, displacement, and damage spectra are also being proposed as a better representative of the dynamic excitation intensity considering structural response. Figure 13.3 shows the response spectra produced by a typical ETEF at various times. Various ETEFs are publicly available through endurance time method website (Estekanchi 2014).

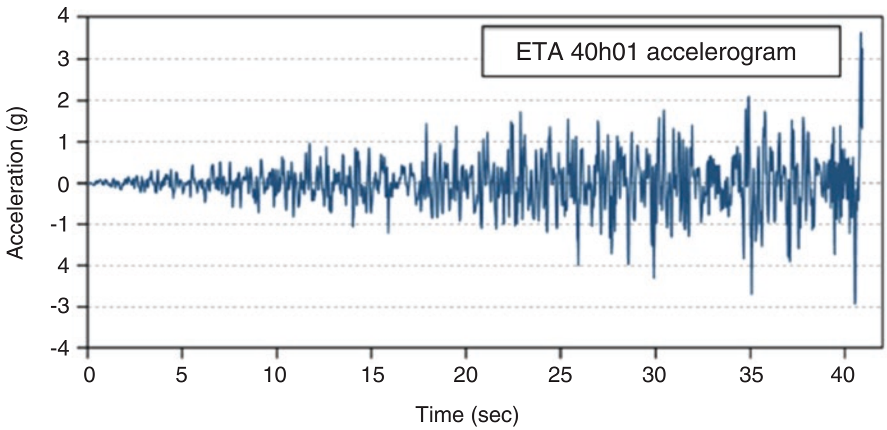


Fig. 13.2 Typical ET record incorporating intensifying dynamic excitation

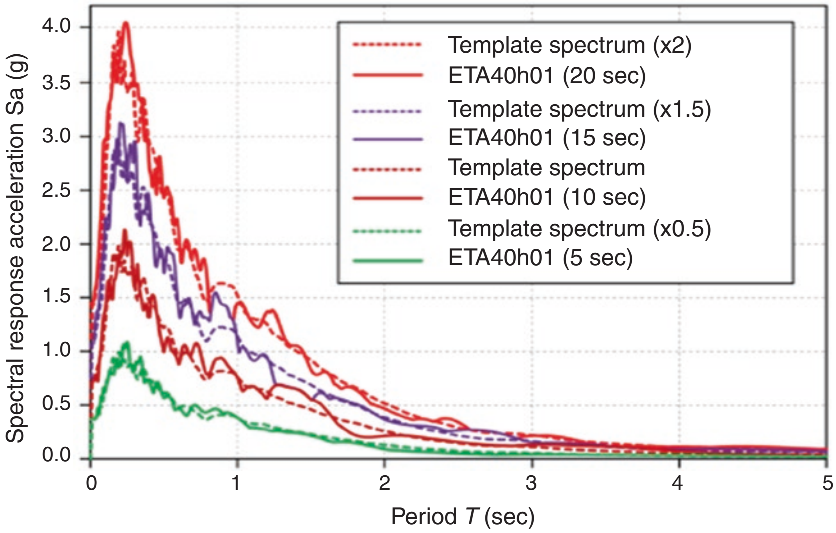


Fig. 13.3 Typical response spectra of ET records at various times (Estekanchi 2014)

While response spectra have been considered to be a standard measure of intensity in producing currently available ETEFs, other intensity measures can also be considered as well. As can be expected, most of these intensity measures correlate with each other, and the problem is to choose the best combination of various parameters to achieve better intensifying excitations that can produce better output. Here, the response spectra have been considered as the intensity parameter, and ETEF has been produced in such a way that the response spectra produced by each window from time 0 to t are proportional to a template response spectrum.

The application of the ET method in performance-based design was studied by Mirzaee et al. (2012) introducing "ET curve" and the "target curve," which, respectively, express the seismic performance of a structure along various seismic intensities and their limiting values according to code recommendations. Substituting return period or annual probability of exceedance for time in the expression of the performance will make presentation of the results more explicit and will increase their convenience to calculate probabilistic cost (Mirzaee et al. 2012). Also, damage levels have been introduced to express the desired damage states in quantifiable terms.

Hazard return period corresponding to a particular time in ET analysis can be calculated by matching the response spectra at effective periods, e.g., from 0.2 to 1.5 times of structure's fundamental period of vibration. The procedure is based on the coincidence of response spectra obtained from the ET accelerogram at different times and response spectra defined for Tehran, at different hazard levels. In Fig. 13.4, a sample target curve and ET curve considering various performance criteria is depicted where ET analysis time has been mapped into return period on horizontal axis. As it can be seen, the structure satisfies the code IO level limitations, but it has

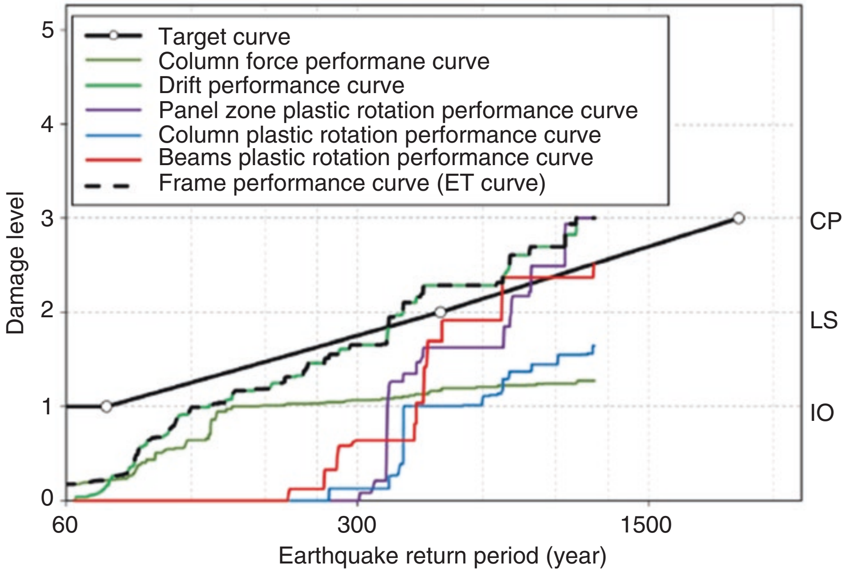


Fig. 13.4 Performance assessment by ET method. (Estekanchi et al. 2016)

violated the LS and CP level limitations, and the frame does not have acceptable performance. As it can be inferred, one of the advantages of ET method is that the performance of the structure in continuous increasing hazard levels can be properly depicted in an easy-to-read figure (Estekanchi et al. 2016).

5 Flood Resilience

Increasingly severe and frequent wet weather events and higher population pressures have prompted an ever more encompassing range of methodologies and solutions for flood risk management aimed at protecting people and assets from the impacts of floods. A European-wide definition of flood risk management, developed and established during recent EU-funded projects such as Floodsite (2015), FloodProBE (2015), and Corfu (2015), is “the continuous and holistic societal analysis, assessment, and mitigation of flood risk.” Included in this definition is the analysis of flood risk, on the one hand, and risk mitigation measures on the other, which are intrinsic elements in the search for effective solutions (Escarameia and Stone 2013). Within the specific context of urban communities, Zevenbergen et al. (2013) have provided a comprehensive analysis of the urban aspects of flood management, integrating knowledge from a range of relevant disciplines, from hydrology to urban planning and from sociology to architecture and construction. In the years since that publication appeared, further significant developments have taken place, focusing on specific aspects of urban flood risk management.

6 Storm Water Resilience for Coastal Regions

Severe weather disturbances such as tropical cyclones and hurricanes cause massive destruction leading to extensive economic losses (CRED2015; Knabb et al. 2005), injuries and loss of lives (CRED 2015; UNISDR 2015a, b; Munich Re 2015), and damage to structures (CRED 2015; UNISDR 2015a, b). Among the structures typically damaged are houses, which may lead to massive displacement of people for a single disaster incident (Boughton et al. 2011; Ginger et al. 2007; National Disaster Management Office 2016; Prevatt 1994). Recent times have also seen an increasing trend in both frequency and magnitude of destructive tropical cyclones (Guha-Sapir et al. 2016), as such need arises to learn from previous disasters in order to better prepare for the onset of much bigger hazards.

On a synoptic forecast scale, pre-event preparations typically involve actions such as evacuation operations, pre-positioning materials, and the operation of water control and transportation infrastructure. At this time scale, models and data assimilation play important roles in maximizing the utility of available resources and minimizing loss of life. However, there is often little that can be done on this time scale to prevent or reduce damages to the built environment and the natural environment. Thus, in addition to improving modeling and sensor technology, new strategies for rapidly disseminating data for adaptive management purposes must be developed. This will be particularly important at the local level. The preparation of the populations to coastal hazards through outreach is particularly important. To be effective, education of the populations exposed to the danger must be prepared well in advance of events. While reminders of past events such as flooding are important, it is also necessary to convince stakeholders that future threats may be more severe than those they remember. Understanding the sensibility of communities in the face of coastal hazards is crucial when designing risk management plans.

Most oceanographic data assimilation related to resilience is currently associated with forecast-scale operations. Although this can be extremely valuable to decision-making and for overall guidance at event time scales, the application of coastal observations for improving objective model validation in long-term planning scales has not received the same level of attention. Models cannot replace measurements without introducing large uncertainties and biases into critical decisions. Most models today contain numerous parametric approximations and empirical coefficients. Careful tuning of coefficients is often performed after a devastating event in forensics studies, but it has been found that these coefficients must be varied significantly to obtain optimal performance at different sites and for different events. There is a need for more focus on high-quality, event-based measurements as well as long-term datasets. Many deficiencies in today's models have been identified with respect to the physics of nearshore processes. On time scales relevant to long-term planning, potential landscape and ecosystem evolution remain speculative, adding uncertainty to predictions of change in both environmental and anthropocentric factors such as economic and community health. Predictions of waves, surge, and pollutant transport are better than models of coastal evolution.

The overall balance of effort expended on fixed measurements should place more emphasis on event-based sampling. This will require the development of an integrated suite of instruments that could function over a substantial range of spatial and temporal scales in estuarine, riverine, and open coast environments as well as on flooded lands and roads. Such instrumentation suites would have to be deployable within 24 h and contain sufficient quality and number of sensors within an integrated telemetering and self-recording system (an event-based infosphere) to provide needed data to validate the physics and numerical approximations imbedded in models. The potential contribution of such measurements to improved modeling systems and predictions for resilience cannot be overstated. As noted in the section 6.1 "Next-Generation Coastal Data Acquisition," observing future environmental changes in coastal urban areas will require new sensors along with new data pathways and workflows that enable a range of users to collect data and that allow data to be centrally processed for quality control and utility. Some of the phenomena to be observed must include the following:

- Storm surge
- Hydrology
- Pluvial flooding
- Compound flooding
- Water quality
- Socioeconomic behavior and vulnerability
- Pathogens and pollutants
- Urbanization and urban renewal trends
- Urban and coastal management principles and practices

Obtaining the needed observations from coasts and coastal communities in developing countries where the threats and vulnerabilities are most acute is a serious challenge but one that must be overcome with the help of international organizations. Some potential strategies are discussed in the following section "Data-Intensive Infrastructure for Rapid Dissemination of Information." Coastal slums in impoverished coastal megacities require.

6.1 Coastal Risk Assessment and Adaptive Management

In order to enhance coastal risk assessment and adaptive management, we advocate the establishment of partnerships that transcend geographic and disciplinary boundaries. Partnerships that include representatives from state and federal agencies, nonprofits, conservation groups, and the business, health, and industry sectors provide an effective constituency for the needed information. These data provide the basis to develop a conceptual framework for coastal risk assessment in a structured process that is based on the specification of geographic patterns of hazards overlaid by patterns of vulnerability (life loss, damages, critical infrastructure, social hubs, etc.). In this context, the risks can be quantified to meet the needs of a variety of stakeholders who must make data-driven decisions. The value of accurate estimation and the consequences of inaccuracies in the hazard and risk estimations make a strong case for a unified approach to this issue. A good example of this is the dramatic rise in losses and casualties due to natural disasters such as storm surge-induced flooding, seismic hazards, and tsunami incidence along many coasts over the past few decades that have prompted global concern on impacts and mitigation strategies (Wright and Nichols 2019). Marine scientists analyze and forecast coastal changes such as regionally varying sea-level rise (e.g., Thompson et al. 2014, 2016). Government officials have already started to plan for sea-level rise by completing coastal hazard assessments and developing maps showing areas which are expected to be affected over the next 50–100 years. In some cases, these planning guides support activities such as restricting development in areas prone to coastal erosion, moving structures away from the coast, and discouraging the construction of shore protection.

Government organizations including ocean and meteorological agencies, local universities, businesses, and citizens have provided discoverable data from networked sensors that are included as big data resources which can support decision-makers. These data come in various forms including historical archives from national data centers, in situ data from the neighbor's weather station to ocean observing systems, handheld to satellite imagery, and numerical model output. Users need to sift through data from local, national, and globally available datasets that can help address environmental issues, ranging from recurrent flooding to sea-level rise. Local university researchers are already applying new technologies such as unmanned vehicles to fill data gaps that may mask important processes, providing algorithms as evidenced by the COMT, and are defining levels of uncertainty in the data that are available for analysis (Luettich et al. 2017). Private sector companies are also applying big data for targeted solutions and predictive power such as apps that provide weather data to commercial and recreational fishermen. Crowdsourcing and citizen science like the Hawaiian and Pacific Islands King Tide Project and Geofeedia – a social media intelligence platform that associates social media posts with geographic locations – are increasingly popular tools for creating information where there previously was none. Open hardware and software are expanding to offer widely distributed, inexpensive tools to enable crowd-sourced data collection and analysis.

Coastal risk assessment and adaptive management can employ big data to resolve spatially and temporally variable phenomena that impact coastal communities. Environmental phenomena such as flash floods manifest themselves quickly whereas sea-level rise is slow. Big data include historical information, in situ data, imagery, and model output. Next-generation tools will need to aggregate these vast amounts of data to aid decisions. Baseline information will be key to identifying the magnitude of current changes in coastal processes. Government-funded infrastructure such as the National Ecological Observatory Network, Long-term Ecological Research stations, and the US IOOS should collaborate to improve our understanding about issues such as sea-level rise, recurring flooding, land use change, harmful algal blooms, hypoxia, and invasive species impacts. These efforts require the sharing of data through open automated resources at both national and international levels. Through this collaboration, next-generation models and data analytics can be applied in an iterative decision-making process. Research is still needed on contextual explanatory models that are reflective of real-world situations. For example, through "on the fly" skill assessments, operational users can select the best model to use for their particular applications.

7 Computational Methods in Disaster Resilience

It is apparent that the need for the integration of disaster resilience management into planning, design, and operational policies is strong. Sufficient literature is available on the conceptualization of disaster resilience (Bruneau et al. 2003; Cutter et al. 2008). More recently, however, researchers have found merit in defining resilience quantitatively (Bruneau et al. 2003; Ayyub 2015). Most of the proposed approaches are estimating the resilience as a time-independent measure and do not provide much insight about the recovery capability of the system over time. The time-independent static resilience is merely an abstract attribute of the system and do not completely describe the state of the system under disturbance. Thus, the time-independent static resilience measures are practically ineffective for planning and developing appropriate system recovery strategies from a disaster.

The first significant attempt to quantify resilience as a function of time and space is made by Simonovic and Peck (Simonovic and Peck 2013) and since then has emerged as a critical characteristic of complex dynamic systems in a range of disciplines – ecology, engineering, health sciences, social sciences, and economics. Implementation of dynamic measure through simulation in time and space enhances the understanding of the system capability to recover from a disastrous event. Simulation is a natural systems modeling approach that can be used in the analysis of dynamic systems. The resilience metric of Simonovic and Peck (Simonovic and Peck 2013) allows for prioritization of regions and systems (and their components) that requires adaptation upgrades. It also allows for the comparison of adaptation options that improve community resilience and the functioning of critical facilities in the event of a disaster.

Many optimization problems in disaster management always start with spatial and temporal information about communities and infrastructures. It is critical, for instance, to know where people live and where hospitals and distribution centers are located, as well as to have accurate models of various networks, such as the transportation and power systems. The second key input is a prediction about what the disaster might do and how it will affect communities, assets, and infrastructures. For hurricanes such as Irene and Sandy, the National Hurricane Center (NHC) of the National Weather Service in the United States is highly skilled at generating ensembles of possible hurricane tracks. 1 These tracks are then run through fragility simulators to determine their impact, identifying resource needs and damages to assets and infrastructures. These simulation steps are illustrated in Fig. 13.5. The resulting

Fig. 13.5 The simulation steps before optimization. (Van Hentenryck 2013)

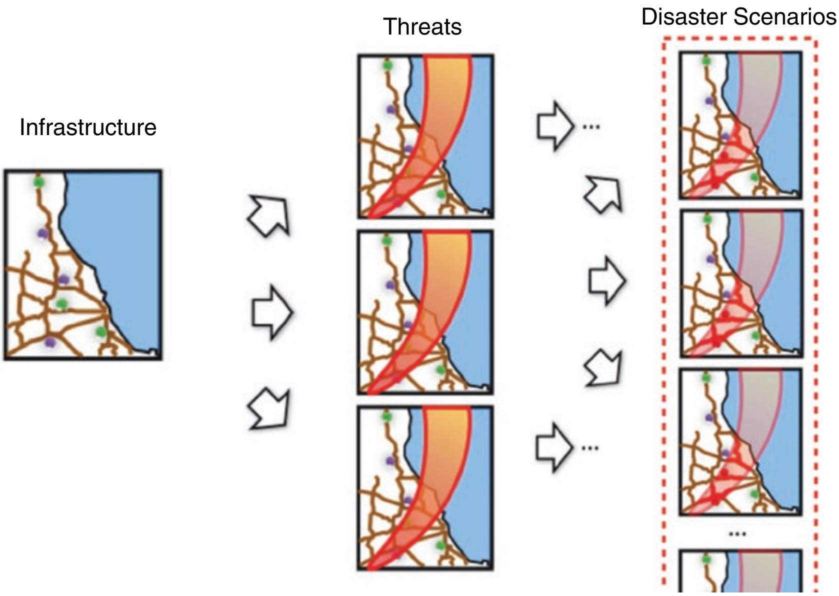


Fig. 13.6 Optimization for disaster management: inputs. (Van Hentenryck 2013)

scenario sets, illustrated in Fig. 13.6, is the input to various types of optimization problems (Van Hentenryck 2013).

Optimization problems exploiting these inputs arise at different levels: strategic, tactical, response, and recovery. Optimization at the strategic level includes applications such as how to stockpile relief supplies or repair parts for infrastructures, how to schedule planned burns for minimizing the risk of bushfires, where to build levees for flood management, and how best to evacuate a region. Strategic planning typically takes place before the hurricane, bushfire, or flood seasons. The tactical level starts when a disaster first materializes, e.g., from a few days before a hurricane hits, and ends at the time of impact. It considers problems such as asset repositioning, sandbagging, and evacuation and sheltering in place. Responding to a disaster involves search and rescue operations, relief distribution, evacuations, and damage assessment to name only a few. Finally, the recovery phase, which is often critical for social and economic welfare, is concerned with all aspects of restoring critical infrastructures such as the transportation network, the power system, and telecommunication networks (Van Hentenryck 2013).

7.1 Computational Complexity

In disaster management, decision-makers are faced with optimization problems of daunting complexity, which explains why they may be overwhelmed by the magnitude of the task. The field of humanitarian logistics has investigated some of these problems since the 1990s, and recent disasters have brought increased attention to the logistics aspects (Wassenhove 2006; Beamon 2004; United-States Government 2006; Fritz Institute 2008). It is well recognized that innovative research is required to meet the underlying challenges (e.g., [Wassenhove 2006; Beamon 2004]). The complexity of computational disaster management can be attributed to many factors. Here are a few that are particularly striking for optimization experts.

1. Large scale. The optimization problems are large scale and concern the entire cities or states (Van Hentenryck et al. 2010; Coffrin et al. 2011) or even international multimodal supply chains.
2. Nonstandard objective functions. In computational disaster management, the goal is not to maximize profit or minimize costs: Rather it is to maximize some notion of social welfare or an equability objective (Barbarosoglu et al. 2002; Campbell et al. 2008; Balcik et al. 2008). These problems are much less studied and often harder than their traditional counterparts.
3. Stochastic aspects. Computational disaster managements operate in inherently uncertain environment due to the disaster itself, the way people react, and the limitations in information gathering. Preparations and recovery plans must be robust with respect to many scenarios (Duran et al. 2011; Gunnec and Salman 2007).
4. Multiple objectives. High-stake disaster situations often have to balance conflicting objectives such as operational costs, speed of service, and unserved demand (Barbarosoglu et al. 2002; Duran et al. 2011; Balcik et al. 2008; Gunnec and Salman 2007).
5. Complex infrastructures. Disasters typically damage complex infrastructures such as the transportation network and the power system. Optimization applications make discrete decisions over these complex infrastructures, which are often modeled by complex systems of constraints.
6. Multiple stakeholders. Disasters often involve multiple infrastructures, agencies, and communities. It becomes critical to incentivize different stakeholders to maximize social welfare.

As a result, disaster management applications present unique computational challenges for optimization. Commercial, off-the-shelf packages simply do not scale for these applications (Campbell et al. 2008).

7.2 Human-Centered Simulation Modeling Design Framework

In this section, we lay out a conceptual design framework for developing human-centered simulation models. For this purpose, we collected and reviewed relevant data from three sources: (1) resilience planning initiatives, (2) post-disaster recovery assessments, and (3) research articles. We then qualitatively analyzed them to understand potential end-users' points of view related to the recovery and recovery planning. The collected data are briefly introduced below.

1. Resilience planning initiatives: Three initiatives have taken place in the United States in the last 10 years to envision seismic community resilience on the state or city scales – the San Francisco Bay Area Planning and Urban Research Association (SPUR) Resilient City initiative, Resilient Washington State (RWS), and the Oregon Resilience Plan (ORP). These initiatives are valuable sources of information. They were performed by experts, managers, and decision-makers who would be the potential end-users of human-centered simulation models for critical infrastructure disaster recovery planning. Resilience planning is heavily connected to and has much in common with recovery planning, especially the pre-disaster recovery planning phase. Reviewing the initiatives provides insights into the objectives, concerns, and limitations of end-users (Barkley 2009; WASSC 2018; OSSPAC 2018).

The initiatives commonly aimed to establish and present the target recovery time frame of various components of the community subjected to the expected seismic hazard and estimate expected recovery time frames of potentially damaged components. They also offer recommendations to improve community seismic resilience. The initiatives organized focus groups, for example, a transportation group, and categorized the participants into these groups based on their areas of expertise. Each group or sector presented target and estimated expected recovery time frames of services and components of the group. These estimates were obtained from debates, discussions, and participants' judgment. Noticeably, no analytical computer-based tools such as models were used in the resilience planning process. This shows the potential for using human-centered simulation modeling to support resilience and recovery planning (C. Barkley 2009; WASSC 2018; OSSPAC 2018).

2. Post-disaster recovery assessments: Another source of understanding real-world recovery processes and experts' perspectives is post-disaster recovery assessment reports published after investigation of post-disaster recovery of infrastructure disruptions. These after-action recoveries assessments are usually prepared for governmental departments to assess efficiency of recovery processes and provide recommendations for infrastructure system operators to be prepared for

future disasters. These documents are beneficial for our purposes because they assess practical planning operations performed by emergency managers and infrastructure system agents. These reports offer recommendations from various agents and organizational collaborations and identify the need for creating and using appropriate tools for damage assessment, recovery monitoring, and decision-making (South California Edison 2011, 2012; Entergy New Orleans, Inc. and Entergy Louisiana, LLC 2013; Davies Consulting 2015, Westport Fire Department Westport Emergency Management,2012; U.S. Department of Commerce, Service Assessment 2012).

3. Research articles: Emergency management and infrastructure experts' experience are also addressed in research articles. Although we found representations of agents, practitioners, participants, and decision-makers to be poor in research studies, several articles do provide relevant information. We reviewed abstracts of papers published in and after 2000 in the journals *Natural Hazards Review* and *Earthquake Spectra* and identified articles that presented the experience and concerns of end-users. These studies investigate end-users via interviews and participatory studies or by presenting frameworks for tools and usability testing (Fothergill 2000; Hecker et al. 2000; Flax et al. 2002; Uddin and Engi 2002; Gillespie et al. 2004; Erez and Bowman 2006; Wald et al. 2008; Perry et al. 2011; Liel et al. 2013; Chang et al. 2014; Holand 2015; Little et al. 2015; Nastev et al. 2017; Unal and Warn 2017).

7.2.1 User Interaction

User interaction addresses design features that the end-user interacts with in human-centered simulation models. This construct has four elements, comprising of model parameters assignment, decision-making support, task queries, and usability. The model parameters construct consists of three components: (a) hazard status parameters that provide hazard information such as scenario, size of disaster, and aspects of disaster (e.g., earthquake, liquefaction, landslide, hurricane, flood); (b) system status parameters such as vulnerability and resilience of components, damaged components and level of damage, time, cost, and resources required for recovery of damaged components, type of clients, and number of impacted clients; and (c) resource parameters that define system resourcefulness such as number of available crews, budget, materials, etc.

We conducted qualitative content analysis of the literature described above to create a human-centered simulation modeling design framework shown in Fig. 13.7. Three main constructs emerged from the qualitative analysis: user interaction, system representation, and computation core. Collectively, the three constructs include 11 elements, which are described below.

Task queries point out information that the end-user desires to track within the recovery process and consist of time-variant indicators, critical path, and comparative analysis. Time-variant indicators enable the end-user to track desired recovery indicators over time such as recovery time frames of components, sectors, or an entire modeled system; budget, cost, and resources over time; and social indicators.

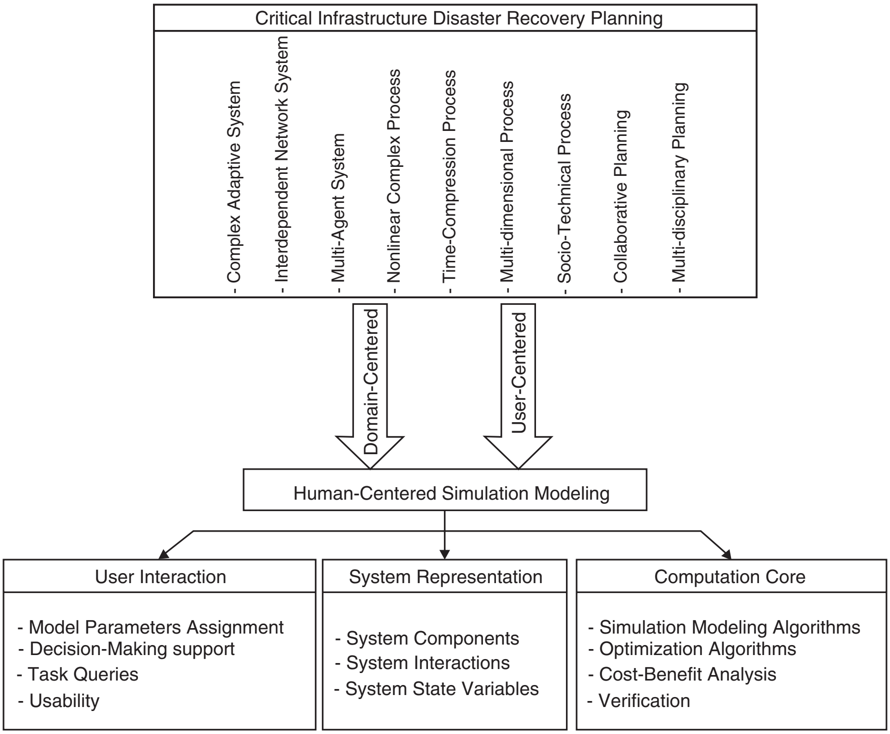


Fig. 13.7 Conceptual design framework of human-centered simulation modeling for critical infrastructure recovery planning

Critical path identifies critical recovery paths based on desired criteria such as finding the closest recovery path that provides services to a client or the least expensive path to recovery of selected clients. Comparative analyses facilitate end-user's comparison of the consequences of different parameters or decisions such as cost-benefit analysis, sensitivity analysis, and scenario analysis.

Usability represents the ease of use and learning by the end-user, including data navigation (e.g., simplicity of import and export of data with different formats, appropriate and understandable visualizations), help bar (e.g., memo, tutorial, item definition, guide documents), and knowledge transferability (i.e., transferability of organization and distribution of knowledge from researchers and tool developers to end-user and improvement of end-user's communication).

7.2.2 System Representation

"System" refers to entities, components, networks, and interconnections of a modeled infrastructure sector. Systems in this framework can be used for any type of infrastructure systems such as built or social systems. Systems can be conceptually broken down into system components, state variables, and interactions. System components represent (a) entities of systems under consideration such as electric power entities, water system entities, clients, and geographical information of entities and (b) resources involved with the recovery process for damaged systems, such as time, cost, crews, and material required. System interactions illustrate connections between components categorized into (a) in-sector interactions, which represent network and directivity of connections in a sector, (b) cross-sector interactions, referring to interdependencies between two different sectors, and (c) system state variables that refer to the state of components and entities such as the functionality of an electric substation, recovery time frame of a component, or the available budget.

7.2.3 Computation Core

In order to perform appropriate tasks and produce outputs of modeled systems, computational algorithms are expected to be implemented in simulation modeling. Computation core consists of processes as “mechanisms by which the system and its components make the transition from one state to another over time. As discussed earlier, simulation modeling has the capability to simulate processes in critical infrastructure disaster recovery and estimate time frames of variable changes. Computation core contains numerical methods to determine the required time, budget, and resources for recovery of a damaged component or sector. It also includes optimization algorithms to support optimal values such as minimum time and resources and optimal number of crews required for recovery. Cost-benefit analysis entails implementation of computational algorithms in this regard. The critical path for recovery of targeted components or clients can be determined by implementation of appropriate shortest path methods depending on the type of directivity of connections. Similarly, evaluation of system resilience from a redundancy perspective entails employing corresponding computational methods. Finally, another aspect of computation core that has been frequently mentioned by potential end-users as a necessity is verification of results of human-centered simulation models by simulation of a previous real-world disaster recovery experience.

8 Summary and Conclusions

Disaster recovery planning for critical infrastructure is complex and heavily reliant on expert judgment. In this paper, we presented its characteristics based on a spectrum of domain- and user-centered dimensions. We discussed the capability of human-centered simulation modeling to simplify the recovery planning process for decision-makers. We proposed a conceptual design framework for design and development of human-centered simulation modeling. This framework consists of three constructs. User interaction represents design features for end-users to interact with simulation modeling. It enables end-users to assign desired model parameters of hazard status, system status, and resources in models. System representation indicates components, interactions, and state variables of modeled systems. Lastly, computation core contains computational algorithms to perform processes and analyses and produce desired outputs. This framework helps human-centered simulation modeling developers be informed about the components required to be incorporated in the design and development of models to support end-users. It is worth noting that the use of the framework is focused on planning for recovery of damaged components of communities. However, recovery planning comprises other various aspects that do not fit in this framework such as damage assessment, inter-organizational decision-making hierarchy, public awareness and engagement, and so on. Future studies may explore other aspects of recovery planning and the potential for creating computer-based tools to facilitate those aspects.

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Chapter 14
Dealing with Uncertainty Using Fully Probabilistic Risk Assessment for Decision-Making

Gabriel A. Bernal, Omar-Darío Cardona, Mabel C. Marulanda, and Martha-Liliana Carreño

Abstract Risk identification is the first step on a comprehensive disaster risk management strategy, and nowadays, when new open-source tools to conduct those analyses are becoming widely available, the interest and need to increase their transparency has increased. Catastrophic risk due to natural hazards should be considered in a prospective way quantifying the damages and losses before the real event occurs, and for that task, it is necessary to consider events that have not yet occurred. Since there are uncertainties related to when and where the next hazardous event will happen, how severe will it be, and how can it affect the exposed elements, it is important to adopt a probabilistic approach that considers those uncertainties and propagates them through the damage and loss calculation process following a rigorous methodology. This chapter develops the theoretical catastrophe risk model considering both retrospective and prospective analyses. In addition, it summarizes the methodology for the inclusion of second-order effects (nonphysical risk drivers), the approach to rationally incorporate background trends (e.g., climate change), an extension of the model to incorporate non-probabilistic uncertainty, and a methodology to define management actions that fit resilience targets. The work presented herein serves to provide a ground base for the minimum requirements of probabilistic risk assessment models.

Keywords Probabilistic risk assessment · Risk modeling · Uncertainty treatment · Risk management · Decision-making

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1 Introduction

A fully probabilistic approach to the risk problem, from an actuarial point of view, was first proposed by Filip Lundberg in his famous doctoral thesis of 1903 (Lundberg 1903). Around 1930, Harald Cramér formalized Lundberg's theory into what today is known as *ruin theory* (Cramér 1930). Lundberg defined an income-outcome model in which an insurance company starts its operation with a certain capital amount, which increases over time as premiums are collected. Moreover, losses (that the company must cover) occur randomly in time. If due to the payment of claims, the capital falls below zero, then the company faces bankruptcy.

Certainly, ruin theory considers (as it is natural) that the occurrence of claims is not deterministic. Lundberg proved that the occurrence of losses in time can be modeled as a *Poisson process*. In fact, any renewal process[1] is valid within ruin theory (Sparre Andersen 1957). A Poisson process is a stochastic point process, widely used in multiple applications in science and engineering, which sets the occurrence of events in a totally random way. The events, within this context, do not refer to hazardous events but to the occurrence of losses, independent from their origin. This is the reason why ruin theory is suitable for any phenomenon, natural or not.

The Poisson process is defined in terms of a unique parameter, its intensity, or rate. In risk assessment, this parameter is the *loss exceedance rate*. It is the inverse value of the average time between the occurrences of events that exceed a loss amount p. Therefore, when calculating risk on a portfolio of exposed elements (i.e., the probability that a certain loss p is exceeded within a time window), its exceedance rate $v(p)$ must be calculated as a function of the probability of occurrence of any of the possible hazardous events that will cause the exceedance of p. This configures a Poisson process which enables the estimation of the probability of exceedance of loss p in any time frame.

As expected, the assessment of the exceedance rates $v(p)$ is not limited to a unique value of p. Therefore, the *loss exceedance curve* (LEC) is calculated (i.e., $v(p)$ is calculated for any p). The LEC provides an exhaustive quantification of the risk problem, in terms of probability. It will never be possible to know the exact magnitude of a future disaster (in terms of the loss and consequences that will cause), but it is possible with the LEC to know the probability that any loss amount will be exceeded within any time frame and use this information to support the decision-making process for risk reduction. The LEC is recognized to be the most robust tool for representing catastrophe risk (Cardona 1986; Ordaz 2000).

The LEC exhibits well-known limitations, such as implicit stationarity, lack of flexibility to incorporate non-probabilistic uncertainty models, description of physical and economic impact only, and increased difficulty in communicating risk

[1] A renewal process is a type of time-continuous, increasing, point process in which the inter-event times are mutually independent and identically distributed random variables, with an expected value equal to the inverse of the mean occurrence rate.

to nontechnical stakeholders. This chapter provides insights on the way to overcome some of these limitations, except for the communication issue. Nowadays there is still a severe bias to calculate and communicate disaster risk in deterministic terms, through the definition of one or a few large events, for easiness in understanding the simulated impacts. This, however, contradicts the very definition of risk in which uncertainty plays a major role. Therefore, there is no treatment to deterministic analysis of disasters in this chapter.

2 Assessment of the Loss Exceedance Curve

There is a well-known differentiation between *extensive* and *intensive* risk. High-frequency, low-severity disasters, usually distributed along a wide portion of the territory, account for an important segment of the LEC. This segment is best estimated by *retrospective* analysis, given the impossibility to analytically model many complex phenomena when large territories must be covered. On the other hand, there are limitations on the amount of data available on previous disasters, leading to important underestimations of the impact of high-severity, low-frequency events. *Prospective* risk assessment complements the historical information by the simulation of future disasters which, based on scientific evidence, are likely to occur but have not occurred yet. A hybrid model, formed by both retrospective and prospective analyses, accounts for both extensive and intensive risk (Velásquez et al. 2014). As an example, Fig. 14.1 shows a hybrid loss exceedance curve for Nepal.

2.1 Retrospective Assessment

The purpose is to obtain the best estimation for λ, the parameter of the Poisson process associated with a loss amount. The value of λ is equal to the loss exceedance rate, for a reference loss amount. For an overview of the Poisson point process, the reader is referred to Kirgman (1992) or Soong (2004).

When performing retrospective probabilistic risk assessment, all historical valuated disasters (n in total) are usually arranged in a *time-loss* plot as shown in Fig. 14.2. By setting an arbitrary loss amount p, all the events that exceed p can identify from the plot (see Fig. 14.2). Inter-event times are now evident for p. The set of observed values (T_1, T_2, …, T_n) will be used to estimate the parameter λ of the exponential distribution that describes the inter-event times, taking advantage of the fact that it is the same λ of the Poisson process of interest.

A good estimator for λ is:

$$\Lambda = \frac{n-1}{\sum_{i=1}^{n} T_i} \tag{14.1}$$

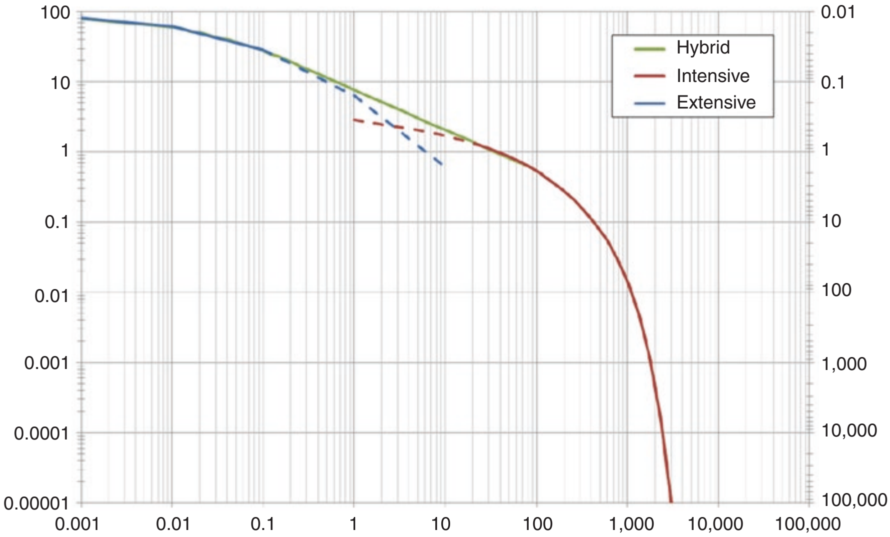

Fig. 14.1 Hybrid, intensive, and extensive loss curves for Nepal. (From Velásquez 2015)

It is unbiased ($E\{\Lambda\} = \lambda$), consistent ($\Lambda \rightarrow \lambda$ as $n \rightarrow \infty$), and sufficient. Though it is not of minimum variance,[2] it is a good-enough estimator. However, different estimators may be proposed by fitting the variance to the Cramér-Rao lower bound. As expected, the coefficient of variation (CoV) of Λ decreases with increasing n. This means that high and infrequently exceeded loss amounts will be related to more uncertain estimations of λ. For losses exceeded many times in the historical period, the assessment of λ will be more precise:

$$\mathrm{CoV}\{\Lambda\} = \frac{1}{\sqrt{n-2}} \tag{14.2}$$

With the appropriate estimator for the loss exceedance rates, the assessment of the LEC is straightforward. The process consists of setting different amounts for the reference loss p and computing Λ as an estimator for λ using Eq. 14.1 and the observed inter-event times. Figure 14.3 shows a diagram that summarizes this process.

As mentioned, the uncertainty of the estimation of the loss exceedance rates depends on the number of observed inter-event times from the historical information. This translates into a sort of "uncertainty band" that gives information on the quality of the assessment. As can be seen in Fig. 14.4, for small losses the assessment is good enough and is logical to rely on the retrospective approach. However, for higher losses, the quality of the assessment rapidly decreases. In addition, there is a limitation in the historical information related to the maximum observed loss.

[2] $\mathrm{Var}\{\Lambda\} = \lambda^2/(n-2)$. The Cramér-Rao Lower Bound $\mathrm{CRLB}\{\Lambda\} = \lambda^2/n$.

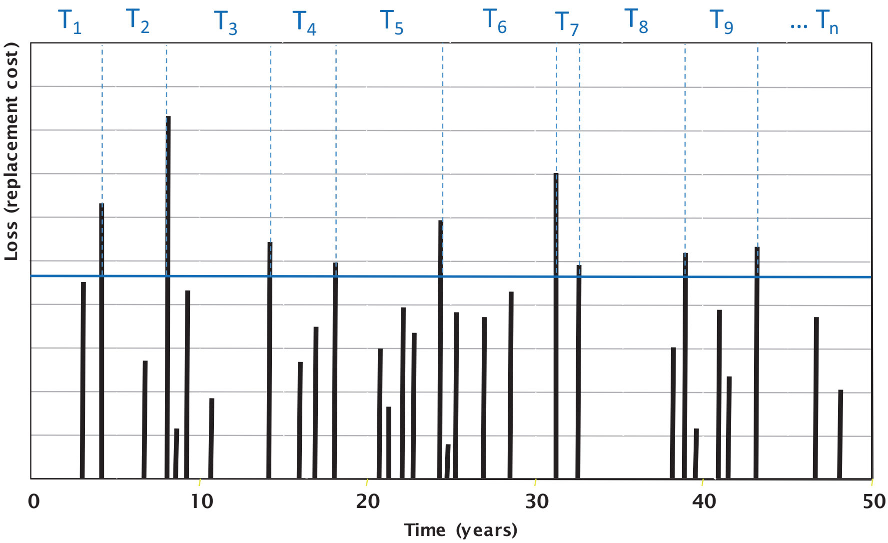

Fig. 14.2 Hypothetical history of valuated disasters

This is the reason why, for large losses, the exceedance rates cannot be estimated statistically.

2.2 Prospective Assessment

When undertaking a probabilistic catastrophe risk analysis, the relevant components of risk, which include the exposed assets, their physical vulnerability, and the hazard intensities, must be represented in such a way that they can be consistently estimated through a rigorous and robust procedure, in both analytical and conceptual terms. The probabilistic risk model is comprised of three components:

- *Hazard assessment*: For each of the natural phenomena considered, a set of events is defined along with their respective frequencies of occurrence, forming an exhaustive representation of hazard. Each scenario contains the spatial distribution of the probability parameters to model the intensities as random variables.
- *Exposure assessment*: An inventory of the exposed assets must be constructed, specifying the geographical location of the asset, its replacement value or fiscal liability cost, and its building class.
- *Vulnerability assessment*: For each building class, a vulnerability function is defined, for each type of hazard. This function characterizes the structural behavior of the asset during the occurrence of the hazard event. Vulnerability functions provide the probability distribution of the loss as a function of increasing hazard intensity.

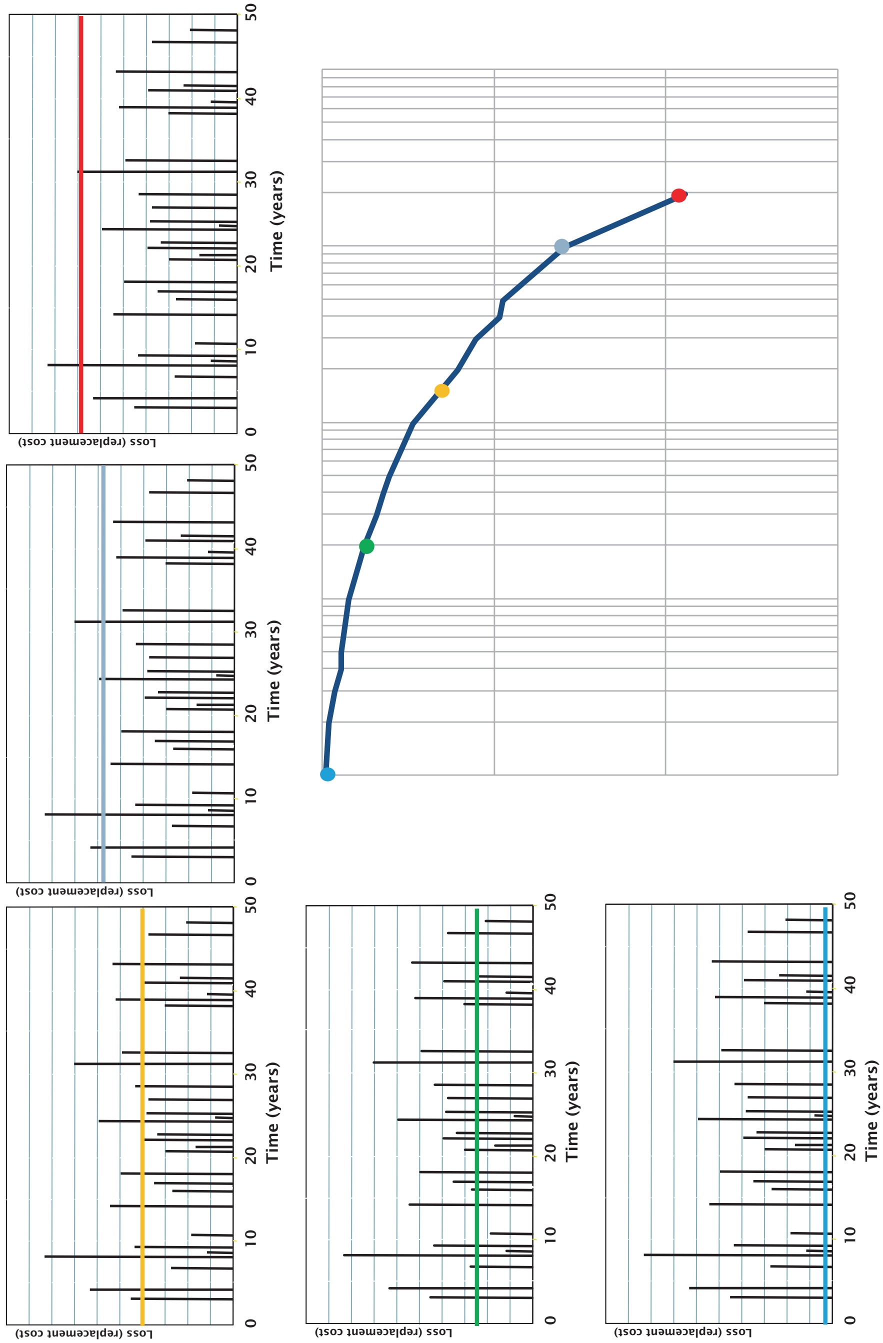

Fig. 14.3 Graphical representation of the calculation of the loss exceedance curve

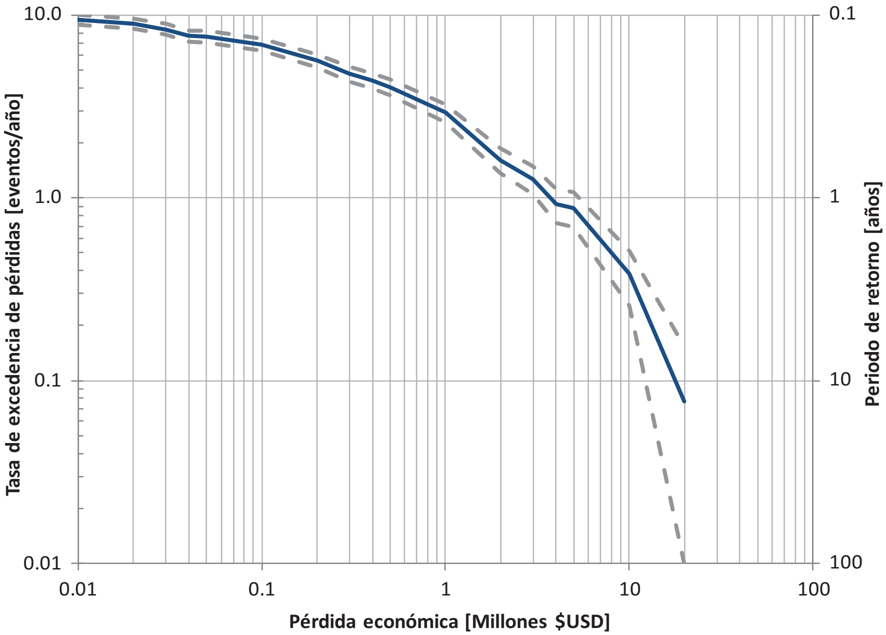

Fig. 14.4 Retrospective loss exceedance curve. The blue line is the mean estimation of λ and the gray dashed lines are +/− one standard deviation

Because the occurrence of hazardous events cannot be predicted, it is common practice to use sets of scenarios, obtained as an output of the hazard model. The set of scenarios contains all the possible ways in which the hazard phenomenon may manifest in terms of both frequency and severity. Event-based probabilistic risk assessments have been extensively applied in the past for different hazards at different scales (see, for example, Bernal et al. 2017a, b, Salgado-Gálvez et al. 2017; Salgado-Gálvez et al. 2015; Cardona et al. 2014; Salgado-Gálvez et al. 2014; Wong 2014; Niño et al. 2015; Quijano et al. 2014; Torres et al. 2013; Jenkins et al. 2012).

2.2.1 Hazard Representation

Consider a loss event, A, defined within the universe of all possible losses (or sampling space) S (Fig. 14.5). Event A is a subset of S, and it is defined in a completely arbitrary way (its definition depends exclusively on what question needs to be answered). Once defined, what is required to know about event A is its probability of occurrence, denoted $P(A)$.

Consider now a subdivision of the sampling space S into a finite number of mutually exclusive and collectively exhaustive base events, denoted B_i, as shown in Fig. 14.6.

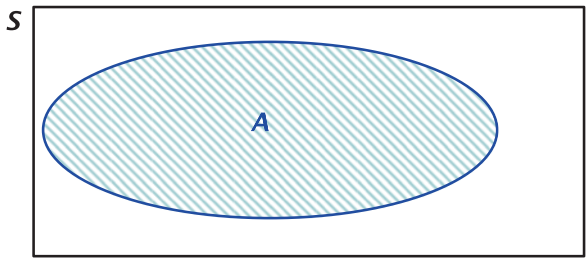

Fig. 14.5 Arbitrary event *A* within the sampling space *S* of the loss events

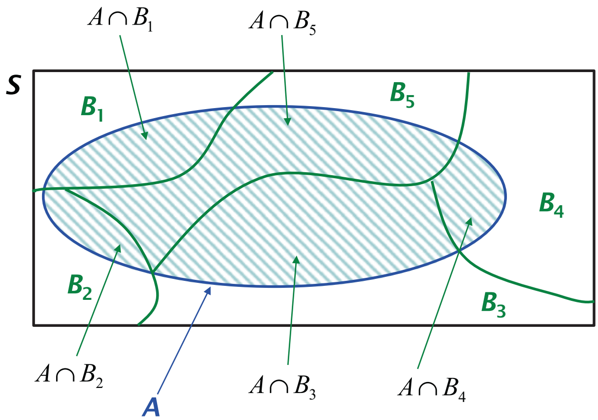

Fig. 14.6 Subdivision of the sampling space *S* into base events B_i

Given that event *A* can be defined as the union of its intersections with the base events B_i, and making use of the third axiom of probability theory, $P(A)$ can be calculated as:

$$P(A) = \sum_{i=1}^{n} P(A \mid B_i) \cdot P(B_i) \tag{14.3}$$

which is one of the simplest expressions of the *total probability theorem*. In summary, the definition of the events of interest *A* is completely arbitrary, so $P(A)$ is calculated as a function of the probability of loss base events *B*. This implies that the base events *B* cannot be defined arbitrarily.

The collection of base events *B* is constructed from the definition of hazard scenarios. Each base event *B* in the loss dominium corresponds to the loss caused by each hazard scenario. These scenarios must be mutually exclusive (i.e., cannot occur simultaneously) and collectively exhaustive (i.e., they are all the ways in which the hazard may manifest). In addition, each scenario has an annual frequency of occurrence (analogous to its probability of occurrence $P(B)$) and a spatial distribution of the random intensity (i.e., the distribution of its probability moments). The intensity corresponds to the physical variable representing the local severity of the phenomenon. For example, in the case of earthquakes, spectral accelerations are commonly used. As will be explained later, a spatial correlation coefficient for the intensity is not needed.

Failing to represent mutually exclusive hazard scenarios leads to an incongruence when adopting the Poisson point process to model the occurrence of loss in time.[3] In the case of hazards that can generate simultaneous intensities associated with different effects (i.e., tropical cyclones), a totalizing approach as the one proposed by Ordaz (2014) and Jaimes et al. (2015) is applied to each scenario. On the other hand, being the hazard scenarios collectively exhaustive has nothing to do with the total number of them. For example, two scenarios may be enough to represent some hazard in an exhaustive way, if they are known to be the only ones that can occur. Similarly, a million scenarios, although seeming like an exceptionally large representative number, do not necessarily guarantee the fulfillment of this requirement.

Hazard is commonly represented as maps of uniform return period (i.e., uniform hazard maps). These maps are obtained by the calculation of the *intensity exceedance rates*, which are analogous to the *loss exceedance rates* but provide information only about the intensity at a location. The exceedance of intensity a, denoted $v(a)$ is calculated as follows:

$$v\left(a\right)=\sum_{i=1}^{N}P\left(A>a\mid \text{Event}_i\right)\cdot F_A\left(\text{Event}_i\right) \tag{14.4}$$

where N is the total number of hazard scenarios and $F_A(\text{Event}_i)$ is the annual frequency of occurrence of event i while $P(A > a \mid \text{Event}_i)$ is the probability of exceeding a, given that event i occurred. Note that Eq. 14.4 is another form of the total probability theorem. By performing this calculation for different intensity levels, it is then possible to obtain the *intensity exceedance curve* (also known as hazard curve) that relates different hazard intensities with their associated exceedance rate on each calculation site (see Fig. 14.7). If this curve is calculated for several nodes on a grid arrangement, by selecting any fixed exceedance rate (or its inverse value, the return period), it is possible to obtain hazard maps. Note that, even though hazard maps can be obtained from the set of scenarios, the process is not reversible, which means that it is impossible to define the scenarios from uniform hazard maps.

2.2.2 Exposed Elements

An exposed element is any object susceptible to suffer damage or loss because of the occurrence of hazard events. Furthermore, exposed elements have an implicit component associated with loss liability. If, for example, the exposed elements are

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[3] In particular, the increments of the process will not be independent.

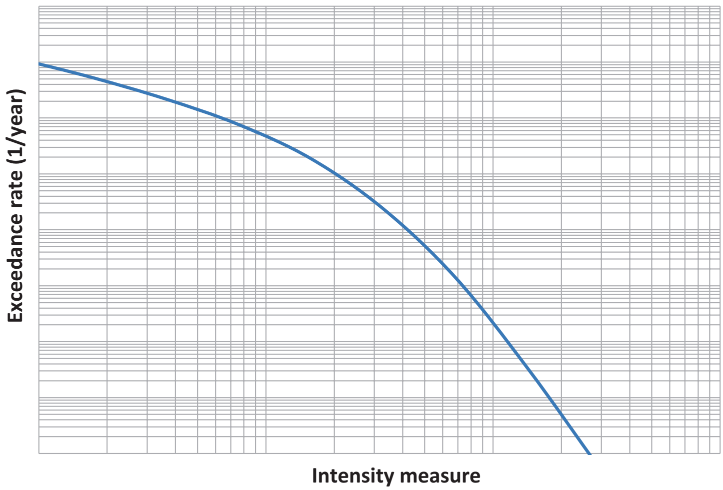


Fig. 14.7 Example of a hazard curve. Both axes are in logarithmic scale

dwellings of low socioeconomic income, then the losses add to the fiscal responsibility of the State, given the inability of the homeowners to cope with the situation. It is important to determine the liability of losses directly into the definition of the exposed elements. For this reason, the exposed elements are grouped in portfolios.

The exposure model is the collection of portfolios of assets (buildings and infrastructure) that can be affected by the occurrence of natural hazards. It is an essential component in risk analysis that determines the resolution (or scale) of the results. Highly detailed exposure data is always desirable; however, when detailed information is not available, or an estimation over a wide region is intended (e.g., a full country), it is necessary to carry out approximate estimations that account for the inventory of exposed elements. This is usually referred to as the *proxy* exposure model (see Fig. 14.8).

The description, characterization, and appraisal of the physical inventory of exposed elements for a probabilistic risk assessment always present serious challenges for modeling regardless of scale. Several assumptions are usually made which naturally increase the epistemic uncertainty in the risk modeling, even in those cases where detailed information is available (e.g., a building-by-building inventory; see Fig. 14.9). Fortunately, when quantifying losses for hazard scenarios, the aggregation of the losses at individual elements (e.g., buildings) results in a progressive reduction of the uncertainty in the total loss (*law of large numbers*). In any case, there are always doubts regarding the accuracy and reliability of exposure data. This highlights the importance of modeling the loss as a random variable.

Fig. 14.8 Example of a low-resolution exposure model for Bogotá, Colombia

2.2.3 Vulnerability

The vulnerability of exposed elements is defined using mathematical functions that relate the intensity to the direct physical impact. Such functions are called *vulnerability functions*, and they must be estimated and assigned for each one of the construction classes identified in the exposure database. Vulnerability functions provide the variation of the probability moments of the *relative loss* with increasing intensity (see Fig. 14.10).

Vulnerability functions are useful to describe the expected behavior of the different construction classes. Aspects such as construction quality and the degree to which builders complied with local or regional building codes must be considered for the different classes of buildings. Figure 14.11 presents an example of flood vulnerability functions, showing how the expected damage increases as a function of the water depth for each building class.

It is worth mentioning that this type of vulnerability modeling aims to capture the general characteristics compatible with the level of resolution used in the exposure database; no specific considerations should be made for any structural system. Every single asset identified and included in the database must be associated with a vulnerability function.

2.2.4 Risk Assessment (Calculation of the LEC)

The calculation of the LEC follows the next sequence of steps:

Step 1: Loss in a single exposed element

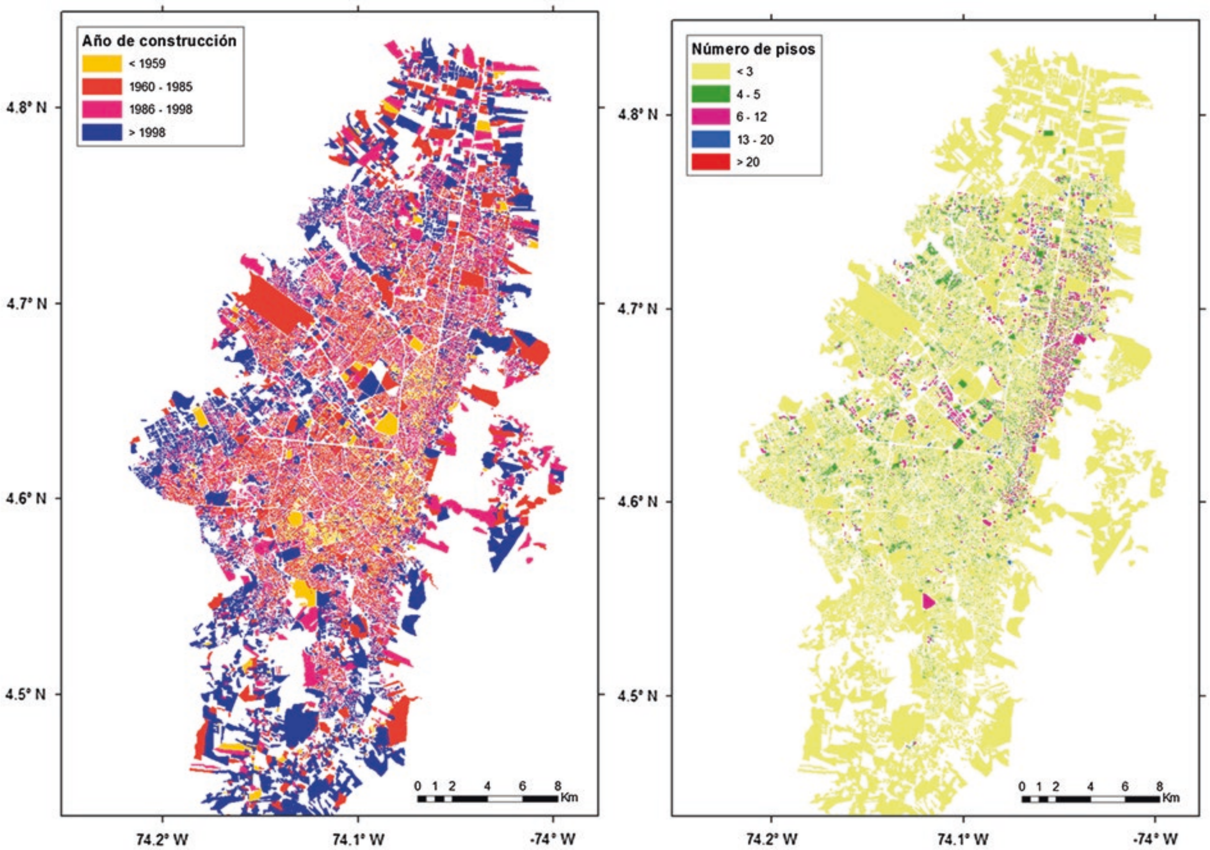


Fig. 14.9 Example of a high-resolution exposure model for Bogotá, Colombia

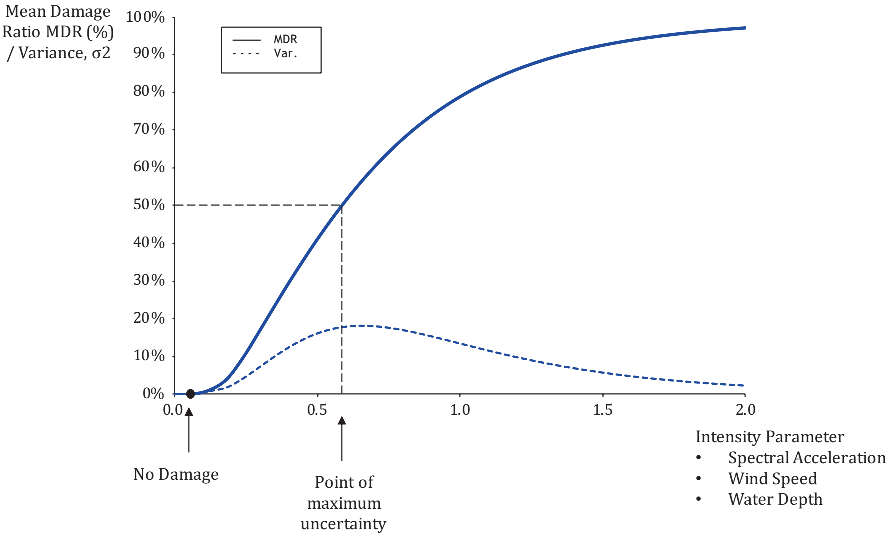


Fig. 14.10 Example of a vulnerability function

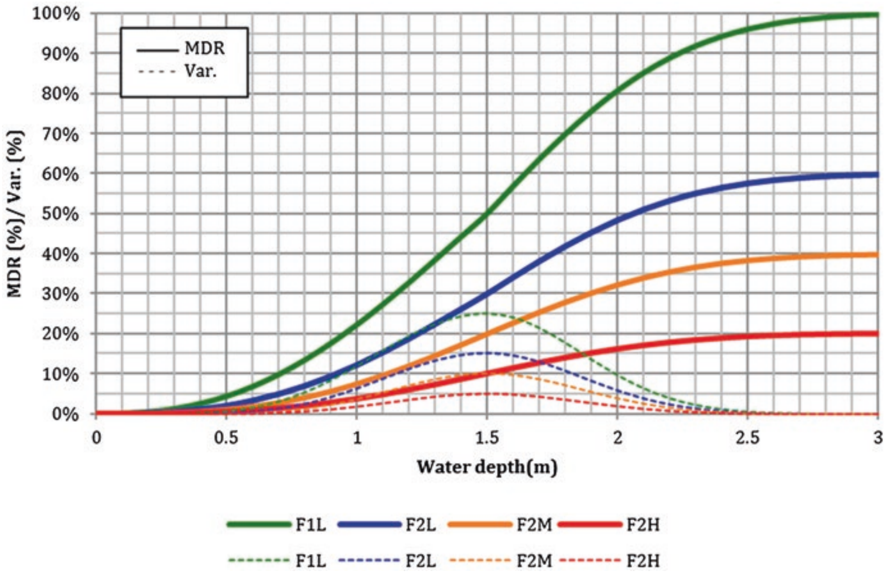


Fig. 14.11 Example of flood vulnerability functions for different building classes

The intensity occurring at the location of an exposed element and the loss caused are both random variables. The relationship between hazard (intensity a) and vulnerability (loss p given intensity a), for a single exposed element, is modeled by applying the total probability theorem, integrating for the complete dominium of the intensity:

$$f_P\left(p\right)=\int_0^{\infty} f_A\left(a\right)\cdot f_P\left(p\mid a\right)\cdot da \tag{14.5}$$

where $f_P(p)$ is the probability density function (pdf) of the loss, $f_A(a)$ is the pdf of the intensity at the location of the exposed element, and $f_P(p|a)$ is the intensity-dependent pdf of the loss at the exposed element. Note that the integral covers the full dominium of the intensity, so there is no need to perform simulations of the intensity field for each scenario.

Step 2: Scenario loss

Step 1 is repeated for all the elements in the portfolio. If the individual losses of the exposed elements were independent, then the pdf of the total loss would simply be the successive convolution of the individual loss pdfs (rendering a normal distribution according to the central limit theorem). However, it is recognized that there is a certain amount of correlation between the losses for the same scenario. Under this condition, the total loss is modeled by adding the probability moments of the individual losses:

$$m_P=\sum_{j=1}^{NE} m_{Pj} \tag{14.6}$$

and,

$$\sigma_P^2=\sum_{j=1}^{NE}\sigma_{Pj}^2+2\sum_{\substack{k=1\\k<j}}^{NE-1}\sum_{j=2}^{NE}\rho_{k,j}\sigma_{Pk}\sigma_{Pj} \tag{14.7}$$

where m_{Pj} and σ_{Pj}^2 are the mean and variance of the jth exposed element, $\rho_{k,j}$ is the correlation coefficient of the loss in elements k and j, NE is the total number of exposed elements, and m_P and σ_P^2 are the mean and variance of the total scenario loss. There is no general methodology to determine the value of ρ. In practice, each modeler chooses its value by observing the coherence of the results. A commonly used, blanket value is 0.3. From the probability moments of the total scenario loss, a *beta* distribution is parametrized (see, e.g., ATC-13 1985). The choice to use a beta distribution to describe the loss, however arbitrary, is based on three properties that make it very convenient for this purpose:

- Its dominium is the interval [0,1], i.e., it directly fits into the description of a relative loss.

- It accommodates multiple shapes, showing different mode locations (left-sided, symmetrical, right-sided) and even adopting an exponential-like form (both increasing and decreasing).
- It is characterized by only two parameters.
- *Step 3: Totalize the loss*

Step 2 is repeated for all hazard scenarios so that a set of loss pdfs is obtained, each corresponding to the total loss for a single scenario. To totalize the effect of all scenarios, the total probability theorem is used in the same way as Eq. 14.4:

$$v\left(p\right)=\sum_{j=1}^{N}P(P>p\left|\text{Event}_i\right.)\cdot F_A\left(\text{Event}_i\right) \tag{14.8}$$

where $v(p)$ is the rate of exceedance of loss p, N is the total number of hazard scenarios, $F_A(\text{Event}_i)$ is the annual frequency of occurrence of the ith hazard event, and $\text{P}(P > p \mid \text{Event}_i)$ is the probability of exceeding p, given that event i occurred. The

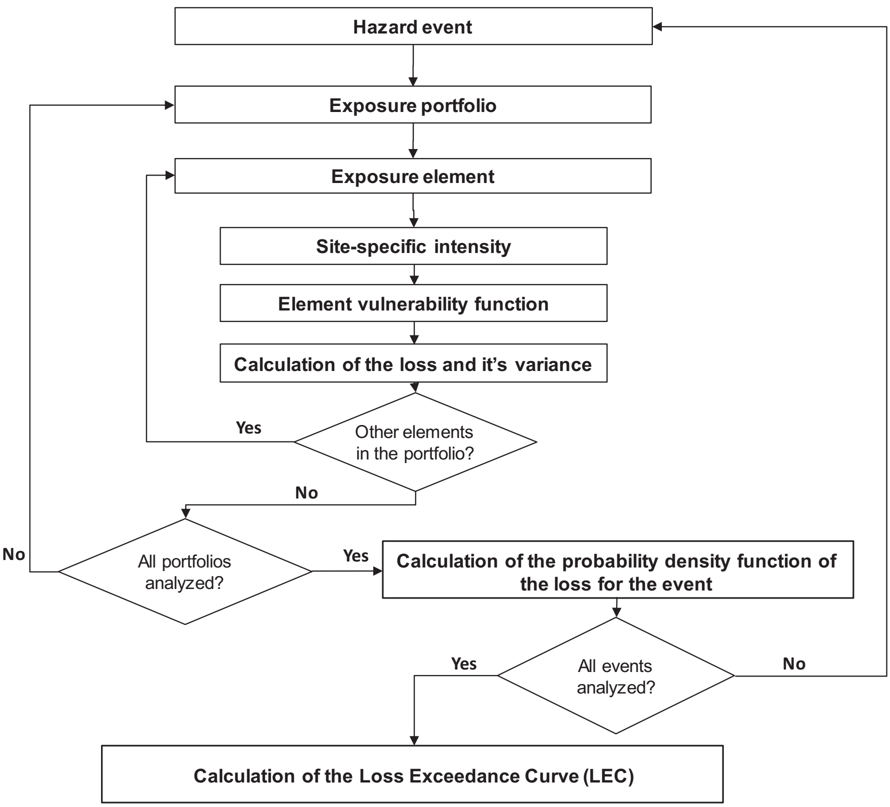


Fig. 14.12 Flowchart of the risk assessment process

sum of the equation is made for all hazard scenarios. Figure 14.12 summarizes the calculation process.

3 Risk Metrics

As indicated above, the LEC contains all the information required to characterize the process of occurrence of losses. However, it is sometimes impractical to use the complete curve. Instead, it is convenient to use specific metrics that allow the risk to be expressed by a single number. The most used metrics are described next.

3.1 Probable Maximum Loss (PML)

This is a loss that does not occur frequently, that is, a loss usually associated with long return periods (or, alternatively, a low exceedance rate). The *return period* is the inverse of the exceedance rate (i.e., is the expected value of the inter-event times):

$$Tr(p) = \frac{1}{\nu(p)} \tag{14.9}$$

There is not a single PML value, but a complete curve which is analogous to the LEC. However, it is common practice to define a PML value by fixing a return period. There are no universally accepted standards to define what is meant by "not very frequently." In the insurance industry, for example, the return periods used to define the PML range from 200 up to 2500 years (Fig. 14.13).

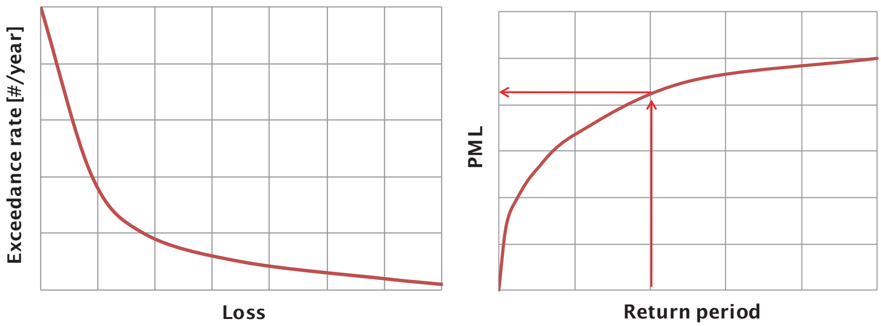


Fig. 14.13 Risk curves. Left: in terms of the exceedance rate (loss exceedance curve). Right: in terms of the return period (PML curve). Note that the value of the PML requires an arbitrary selection of the return period

3.2 Average Annual Loss (AAL)

The average annual loss (AAL) is an important indicator because it integrates into a single value the effect, in terms of loss, of the occurrence of hazard scenarios over vulnerable exposed elements. It is considered as the most robust risk indicator, not only for its ability to resume the loss-time process in a single number but for having low sensitivity to the uncertainty.

The AAL corresponds to the expected value of the annual loss and indicates the annual value to be paid to compensate in the long term all future losses. In a simple insurance scheme, the AAL would be the annual pure premium. It is calculated as the integral of the loss exceedance curve:

$$\text{AAL} = \int_0^\infty v\left(p\right)dp \tag{14.10}$$

From the set of loss events, AAL can be calculated as:

$$\text{AAL} = \sum_{i=1}^{N} E(p\left|\text{Event}_i\right.)\,F_A\left(\text{Event}_i\right) \tag{14.11}$$

where $E(p|\text{Event}_i)$ is the expected value of the loss given the occurrence of the event i. Furthermore, in those cases in which the hazard is not expressed as a set of scenarios, but as a collection of uniform hazard maps, despite the impossibility to fully assess risk, it is possible to calculate the AAL as:

$$\text{AAL} = \sum_{i=1}^{NE}\int_0^\infty -\frac{1}{v\left(0\right)}\frac{dv\left(a\right)}{da}E\left(p\mid a\right)da \tag{14.12}$$

where the quantity $E(p|a)$ is obtained from the vulnerability functions of the exposed elements. The AAL is the only mappable risk metric. Risk maps are a remarkably effective communication tool. High-resolution AAL maps, both absolute and relative (to the exposed value of each asset), are highly desirable outcomes to orient risk management. Figure 14.14 presents an example of AAL maps for Bogotá, Colombia.

3.3 Other Metrics

In addition to the abovementioned metrics, many results may be obtained from the LEC by the direct application of the Poisson point process that describes the loss occurrence in time.

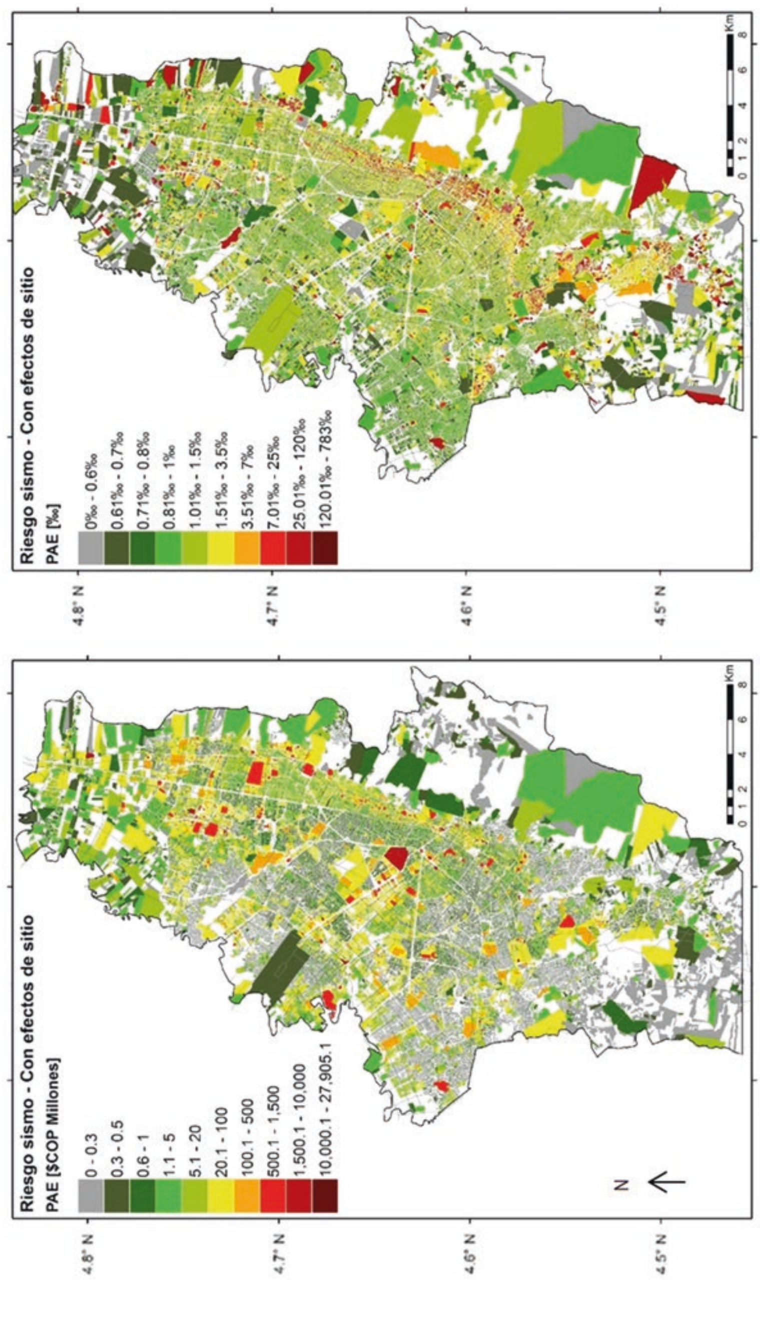


Fig. 14.14 Maps of multi-hazard (earthquake and landslide) AAL for Bogotá, Colombia. Left, absolute; right, relative. The exposure database has more than 1 million buildings. (From Cardona et al. 2016)

3.3.1 Probability of Ruin

A commonly used metric in insurance is the probability of ruin. It is defined as the probability of exceeding a reference PML in an operational period. In general, the probability of exceeding a loss amount p at least once in T years is:

$$P(P > p) = 1 - e^{-\nu(p)\cdot T} \tag{14.13}$$

Equation 14.13 has the advantage of being a standard formula. Only by knowing the return period of the loss and the operational time window (or exposure time) is it possible to calculate its exceedance probability.

3.3.2 Inter-Event Times

In many risk applications, it is necessary to make inferences on the time between loss events. The pdf of the inter-event times is:

$$f_T(t) = \nu(p) e^{-\nu(p)t} \tag{14.14}$$

This is particularly useful when testing the effectiveness of land use or risk management plans which are usually executed gradually in the short and medium term.

3.3.3 Number of Events

In many risk applications, it is necessary to make inferences on the number of loss events expected to occur in a fixed time window. The probability mass function of the number of events in time window T is:

$$p_N = \frac{\left(\nu(p)\cdot T\right)^N e^{-\nu(p)\cdot T}}{N!} \tag{14.15}$$

This is particularly useful when designing risk management instruments that require reinstallations. For example, some financial protection instruments, as well as some structural protection devices, are commonly designed considering reinstallations.

3.3.4 Next Event

It is possible to estimate the probability of exceeding loss p in the next event (or any randomly selected event):

$$\Pr\left(P > p\right) = \frac{v\left(p\right)}{v\left(0\right)} \tag{14.16}$$

This result is quite useful for emergency preparedness activities, as well as for quantifying the cost of financial instruments and mitigation strategies.

4 Incorporating Background Trends

The stationarity of the Poisson point process implies that the mean rate is constant in time. Although this is hardly the case, it is widely accepted as the best approximation due to the difficulty to incorporate time-dependent hazard, exposure and vulnerability models, and the large uncertainty arising from incorporating them. Nevertheless, in cases in which, to the extent of knowledge, the stationarity condition is far too unrealistic, and the future dynamics of the risk components are known or can be approximated reasonably, it is possible to extend the model to a nonstationary process.

Consider a LEC resulting from a probabilistic risk assessment. This result is expressing the possibility of loss given the incidence of hazard, exposure, and vulnerability, as modeled for a specific moment in time. If there is a reasonable way to model the future changes of these risk components, it is possible to calculate new LECs for different, future dates. Therefore, the loss exceedance rates now exhibit a time dependency, transforming the LEC into a loss exceedance surface (LES, see Fig. 14.15). The LES, constructed from the LECs of future conditions, contains all the $v(p,t)$ functions required to define the occurrence in time of losses greater than p as a *nonhomogeneous Poisson process*.

A nonhomogeneous Poisson process satisfies the same basic properties of a homogeneous one, i.e. independent and Poisson distributed increments. The main difference is that the rate of the process is a function of time, $\lambda(t)$. For an overview of the nonhomogeneous Poisson process, the reader is referred to Kirgman (1992). Note that when assessing disaster risk as an LES, the following properties hold:

- The loss occurrence process is still stochastic.
- The mean rate of the process changes in time.
- All risk metrics (AAL, PML, etc.) are functions of time.

The latter means that single-valued metrics, as the AAL, are no longer single-valued. This implies losing some of the desirable characteristics of condensed, comprehensive metrics. To obtain single-valued metrics, a simple time average is required, with an arbitrary choice of its limits.

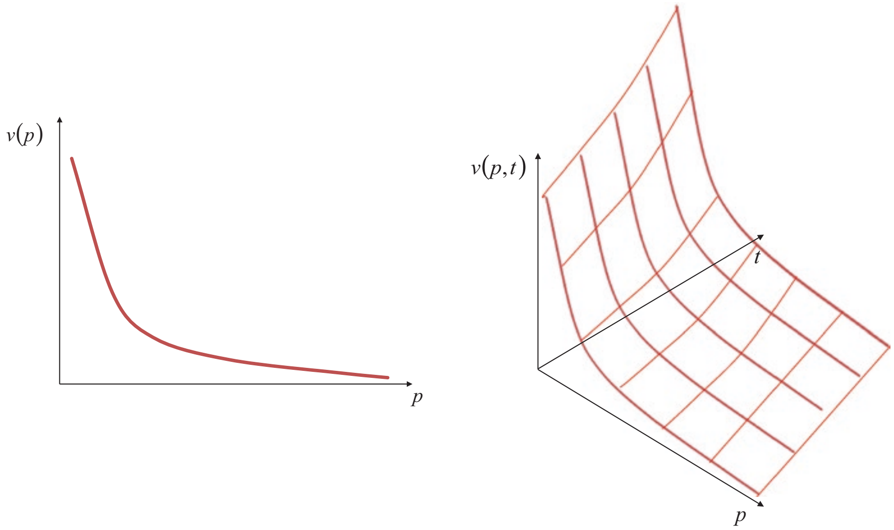
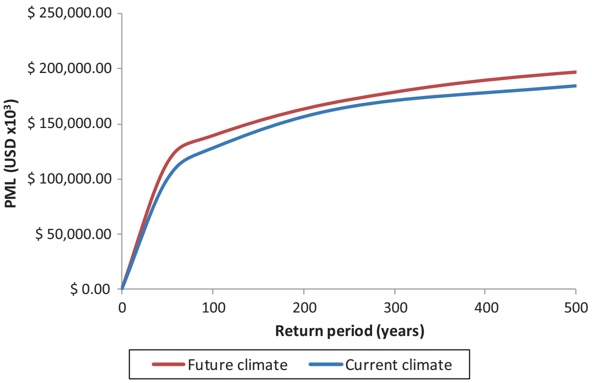


Fig. 14.15 Time dependency added to the loss exceedance rates. Left, loss exceedance curve; right, loss exceedance surface

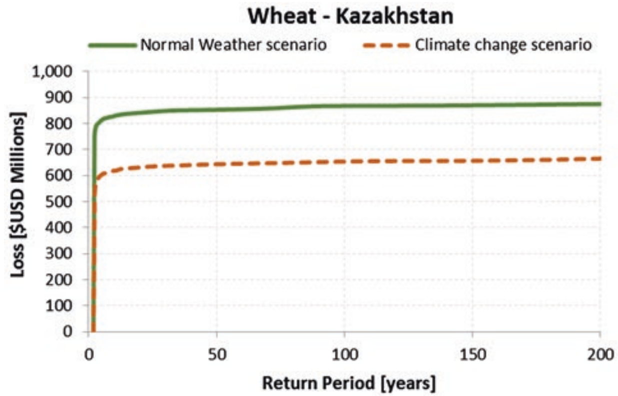
Fig. 14.16 Time-dependent PML curves for Puerto Barrios, Guatemala, due to tropical cyclones and the effect of climate change. (From Cardona et al. 2013)



4.1 Incorporating Climate Change

This approach works very well when incorporating climate change into risk calculations. For example, Figs. 14.16 and 14.17 show time-dependent risk metrics, calculated from probabilistic risk assessment to Puerto Barrios, Guatemala (due to tropical cyclones), and to the wheat stock of Kazakhstan (due to droughts), and including the effect of climate change (up to 2050).[4] In both cases, the time-dependent loss exceedance rates $v(p,t)$ were calculated for different moments in

[4] In both cases for RCP 8.5 and selecting the climate model that best fits the historical observations.



Results		Normal Weather	Climate Change
Exposed value	USD Millions	$1,621	
Annual Average Loss	USD Millions	$361	$260
	%	22.3%	16.0%

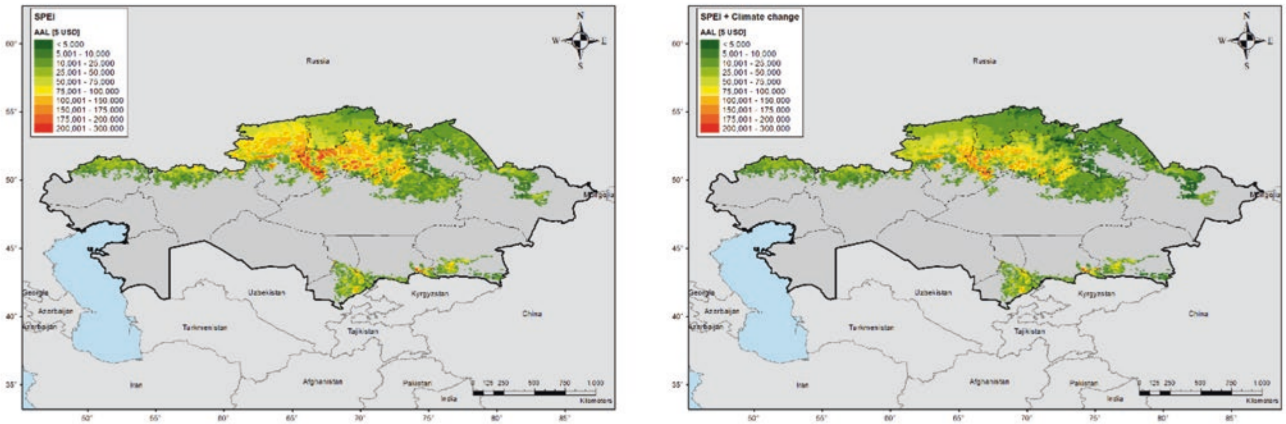


Fig. 14.17 Time-dependent risk metrics for wheat in Kazakhstan due to droughts and the effect of climate change. (From Maskrey et al. 2019)

time, allowing for an estimation of the time dependency of λ and therefore increasing the applicability of the risk assessment methodology. Furthermore, the inclusion of climate change as a background trend of the risk process provides a unique mathematical framework for both risk management and climate change adaptation.

Introducing background trends into probabilistic risk assessment requires complex models of the future dynamics of hazard, exposure, and vulnerability. Even though these models may exist, they should be introduced with care, keeping in mind the additional uncertainty brought into. Such uncertainty is extremely difficult to model from the probabilistic point of view, being commonly referred to as *deep uncertainty*. An overview of the treatment of deep uncertainty is presented in the next section.

5 Dealing with Deep Uncertainty

The future characteristics of the built environment, the dynamics of the socio-technical systems, or the exact conditions of the future climate are desirable inputs for risk modeling, useful for designing the actions and policies to anticipate the materialization of risk. However, knowing with arbitrary precision how nonstationary natural phenomena, exposed elements, and their vulnerability will change in the far, or even near future, is practically impossible. Furthermore, assigning any kind of probability model to such dynamic and complex behavior is extremely difficult without arbitrariness.

Most of the variables involved in probabilistic risk assessment fit well into probability models. It is even possible to insert background trends into the calculation, keeping the problem within the reach of probability theory. Nevertheless, it must be recognized that in the process of building a risk model, many assumptions are made, based on expert criteria and common sense, but inevitably rendering a model that is not truly "fully probabilistic." However, within good modeling practice, all the assumptions made are sufficiently trustworthy, so, again, the problem fits into a fully probabilistic approach.

But what happens when incorporating a new variable from which there cannot be made any reasonable point assumptions, there is no observed data (or not enough), it is not possible to truly predict its behavior from physical models, and there is no bounded consensus on how it will perform? This configures a problem with *deep uncertainty*.

In a broad sense, uncertainty is inherent in any approach to model complex dynamical systems. It can be understood as the gap between the outcome of the model and the real behavior of the system. This gap is composed by the uncertainty on the available observations, the estimation of model parameters, the functional form of the model itself (typically simplifying the phenomena), the value of model inputs, the transformations of scale (commensurability), and the natural randomness. The latter is usually referred to as *aleatory* uncertainty. All the other mentioned sources compose the *epistemic* uncertainty. It is widely recognized that epistemic uncertainty is reducible as more data or knowledge is added to the problem. However, deep uncertainty, which holds both aleatory and epistemic uncertainty, is exceedingly difficult to reduce. In practice it would require, for example, waiting until the future conditions of the assets at risk are known, which invalidates the purpose of risk assessment and overthrows any planning attempt.

Dealing with deep uncertainty in risk assessment requires an expansion of the methodological approach. Recently, several authors have proposed innovative approaches to deal with problems with deep uncertainty and orient decision-making, grouping them under the name *Decision Making Under Deep Uncertainty* (DMDU). For further details, the reader is referred to Marchau et al. (2019). All DMDU approaches share key methodological steps: (1) framing the analysis, (2) simulation, (3) exploration of results, (4) analysis of compensations (trade-offs) of strategies, and (5) iteration and reexamination. In short, DMDU methods recognize that it is not possible to achieve robust decision-making without considering the multiple ramifications that define the domain of the future possibilities. But how do we reasonably define those ramifications or paths of the risk problem?

Step 2 of DMDU approaches (simulation) is strongly related to risk assessment. Its purpose is to explore possible unforeseen or uncertain futures. In other words, robust decision-making must be based on the universe of all possible outcomes that a problem with deep uncertainty can evolve into, to consider them all when deciding. Probabilistic risk theory follows a similar approach, seeking to quantify the consequences of all possible future catastrophic events (without the need to know which will be next) to consider those consequences in the decision-making process. Therefore, as far as disaster risk management respects, probabilistic risk assessment is the most appropriate way to approach step 2, although some expansion of its analytical potential is required.

The main limitation of probabilistic risk assessment is precisely that of being probabilistic. Nonetheless, regardless of that limitation, it is a robust approach, good enough in most risk assessment applications. As models evolve and gain complexity, more variables are added that not necessarily fit into a probabilistic representation. In the past decades, many mathematical theories have arisen as an attempt to formally conceptualize the treatment of *non-probabilistic* uncertainty problems. In the 1960s, Zadeh proposed the *fuzzy set theory* (Zadeh, 1965) as an approach to deal with epistemic uncertainty, allowing the representation of concepts expressed by linguistic terms. A few years later, Dempster (1967) develops what today is known as *Dempster-Shafer evidence theory* (formalized by Shafer 1976), seeking the representation of epistemic knowledge on probability distributions and, in the process, relaxing some of the strong rules of probability theory. In parallel, and within the context of stochastic geometry, Kendall (1974) and Matheron (1975) developed the foundations of what is nowadays known as the *random sets theory*. In short, random sets theory deals with the properties of set-valued random variables (in contrast to point-valued random variables in probability theory). In 1991, Peter Walley introduces the *theory of imprecise probabilities*, in which sets of probability measures are explored as a more general case of the classical probabilistic approach to random variables. Other theories to give formal treatment to non-probabilistic uncertainty have appeared recently. It is worth mentioning the *theory of hints* (Kohlas and Monney 1995), the *info-gap theory* (Ben-Haim 2006), and the *theory of fuzzy randomness* (Möller and Beer 2004).

From the abovementioned approaches, random sets theory excels as the most general approach to uncertainty to date, allowing many different types of uncertainty structures (e.g., Dempster-Shaffer bodies of evidence, info-gap structures, probability boxes, raw intervals, fuzzy sets, probability distribution functions, among others) to be represented as random sets. Alvarez (2008) proved that *infinite random sets of the indexable type* can accommodate all these uncertainty structures. Furthermore, he developed a general method to sample values from all these types of uncertainty structures indistinctively. Therefore, the theory of random sets, and particularly the methods developed by Alvarez (2008) for infinite random sets, provides a mathematically sound framework for the simulation of the ramifications or unforeseen futures in problems with deep uncertainty.

5.1 Random Sets

Consider the probability space $(\Omega, \sigma_\Omega, P_\Omega)$ and a universal non-empty set X with a power set $\wp(X)$. Let $(\mathcal{F}, \sigma_\mathcal{F})$ be a measurable space such that $\mathcal{F} \subseteq \wp(X)$. A random set Γ is a $(\sigma_\Omega - \sigma_\mathcal{F})$ – measurable mapping such that $\Omega \to \mathcal{F}, \alpha \to \Gamma(\alpha)$. Every $\Gamma(\alpha)$ is a *focal element* in the *focal set* $\mathcal{F}$.

If all elements in $\mathcal{F}$ are singletons (points), then Γ is a random variable, and therefore the probability of any event F in $\mathcal{F}$ is calculable via classic probability theory. Such focal set $\mathcal{F}$ is called *specific*. However, when $\mathcal{F}$ is *nonspecific*, the probability of event F cannot be precisely calculated, but only its upper and lower bounds, giving as result an *imprecise probability* measure. Upper (UP) and lower (LP) probabilities for event F are given by:

$$\mathrm{LP}(F) = P_\Omega\{\alpha : \Gamma(\alpha) \subseteq F, \Gamma(\alpha) \neq \varnothing\} \tag{14.17}$$

$$\mathrm{UP}(F) = P_\Omega\{\alpha : \Gamma(\alpha) \cap F \neq \varnothing\} \tag{14.18}$$

which means that the lower probability LP is the totalization of the probability or mass assignments of all the elements in $\Gamma(\alpha)$ contained in F, i.e., those that imply the occurrence of F. Upper probability UP is the total probability of the elements in $\Gamma(\alpha)$ that share at least one element with F, i.e., those that may or may not imply the occurrence of F. A complete overview of random sets can be found in Molchanov (2005).

5.2 Simulation

The process of simulation is performed by means of a Monte Carlo approach. Every variable is represented as a random set in the real line. Each may have a different treatment of the uncertainty, enabling the combination of random variables, fuzzy sets, bodies of evidence, intervals, etc. This may be the more general simulation approach to date.

Sampling from a random set is to randomly obtain focal elements from it, regardless of the type of uncertainty. To enable this process, an indexing procedure must be applied previously, so that the diversity of mathematical structures can be treated equally (α-*indexation*; see Alvarez 2008). Once indexed, it is possible to sample focal elements. Figure 14.18 shows an illustration of this process.

Note that $\Gamma(\alpha)$ is an interval in the dominium of *X*. If there are many variables involved in the problem, the same process can be applied to a coupled combination of the variables. Let *X* be the vector of all variables, and then α becomes a space (the α-space). In such space, the dependence between variables is modeled by a couple, and the quasi-inverse sampling methods for couples can be used to sample the multidimensional focal elements (see Nelsen 1999 for a comprehensive guide of coupled simulation techniques). Figure 14.19 shows an illustration of sampled focal elements in both the *X*-space and the α-space for the two-dimensional case (two variables). Note that in the *X*-space, the focal elements are multidimensional boxes,

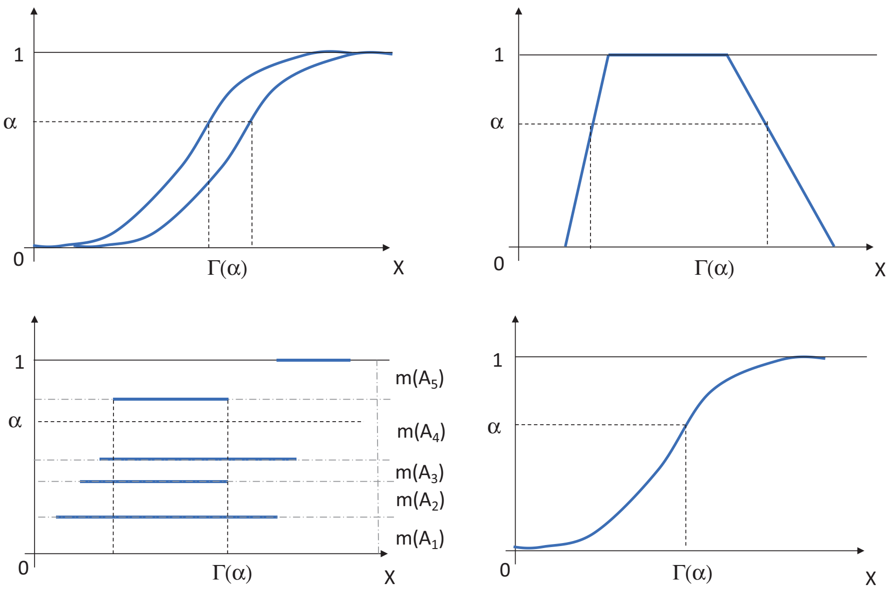


Fig. 14.18 Sampling from α-indexed random sets. Upper left: probability box. Upper right: possibility distribution. Lower left: Dempster-Shafer body of evidence made of raw intervals. Lower right: cumulative distribution function. (Reproduced from Alvarez 2008)

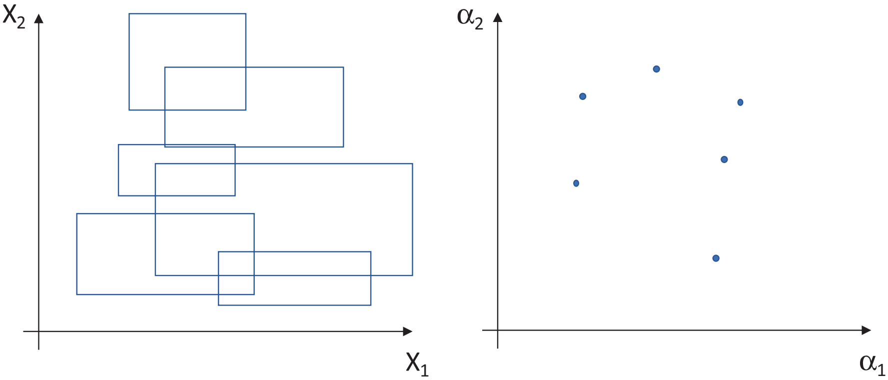


Fig. 14.19 Focal elements for the two-dimensional case in the X-space and in the α-space. (Reproduced from Alvarez 2008)

while in the α-space they are always points, regardless of the number of variables (dimensions).

5.3 Functional Propagation

Once the full set of focal elements is sampled, the response of the system must be evaluated. This is to calculate the image of the focal elements by applying on them a function describing the system response, i.e., to propagate the random focal set. This is achieved by applying the *extension principle*[5] which states that given a function $g : X \rightarrow Y$ (the system response) and a random set $(\mathcal{F}, m)$, the image of $(\mathcal{F}, m)$ through g, denoted here as $(\Re, \rho)$, is:

$$\Re = \left\{ R_j = g(A_i) : A_i \in \mathcal{F} \right\} \tag{14.19}$$

$$\rho(R_j) = \sum_{i=1}^{n} I\left[R_j = g(A_i) \right] m(A_i) \tag{14.20}$$

where $I[\bullet]$ is the *indicator function.*[6] A_i is a d-dimensional box in R^d with 2^d vertices obtained as the Cartesian product of the finite intervals sampled from each variable in the X-space. For those systems in which there is not an explicit functional form for g (e.g., risk assessment), the extension principle can be sequentially applied as the process of calculation moves forward.

[5] See Alvarez (2008) for a summary of techniques to practically apply the extension principle.

[6] $I[\bullet] = 1$ if $\bullet$ is true and $I[\bullet] = 0$ if $\bullet$ is false.

5.4 Calculation of the Loss

Each focal element contains a sampling of the input variables in a stage of the calculation. Getting to assess the loss requires a series of steps that are presented here. Note that these steps are the most general sequence for risk assessment. None of the particularities of, for example, hazard modeling, are included here because they are different for each hazard for obvious reasons. Nonetheless, each hazard model (and in general each component of the risk problem) would require similar approaches for the whole process to be consistent.

1. Sample the occurrence of the event.
2. Sample the intensity field. In some cases (e.g., earthquake hazard), this would require the definition of correlation parameters.

    2.1. At the location of the exposed elements, sample the focal elements of the local intensity.

    2.2. From the vulnerability function of each element, sample the loss caused by each focal element of the intensity.

    - *This requires coupled sampling of the intensity and loss (steps 2.1 and 2.2). An independence couple should suffice in most cases.*

    2.3. Repeat for all exposed elements and add their individual losses using the extension principle.

3. Repeat for all the intensity field simulations.
4. Repeat for all events.

Note that this approach requires many simulations, making it costly in terms of computational resources. It is recommended to apply any of the many sampling optimization techniques usually implemented when performing Monte Carlo simulations.

Let $(\mathcal{L},\ell)$ be the random set containing all the images of the loss calculations. Then $\mathcal{L}$ is the collection of loss focal elements (intervals), and $\ell\,(L_i)$ for $L_i \in \mathcal{L}$ is the mass assignment, i.e., the probability of occurrence of the event that generated the loss focal element. This representation requires a relaxation of the rules applied to mass assignments (rules established in evidence theory and usually transferred to random sets). Given that $\ell\,(L_i)$ is representing the annual occurrence frequency of the event that generated the focal element L_i, then the sum of mass assignments is not necessarily 1. In practice, this condition can be forced into $\ell\,(L_i)$ if required and for the sake of coherence; however, it seems unnecessary and may have no practical effect on the final outcomes. In any case, this is an issue that requires further analysis.

Let F be the event where the loss P exceeds the amount p (i.e., $F = \{P : P \geq p\}$), and then by rewriting Eq. 14.8, upper and lower loss exceedance rates are obtained, i.e., the LEC is transformed into two complementary curves $\mathrm{LEC_L}$ (Eq. 14.21) and $\mathrm{LEC_U}$ (Eq.14.22) that may be interpreted as an *imprecise loss exceedance curve*:

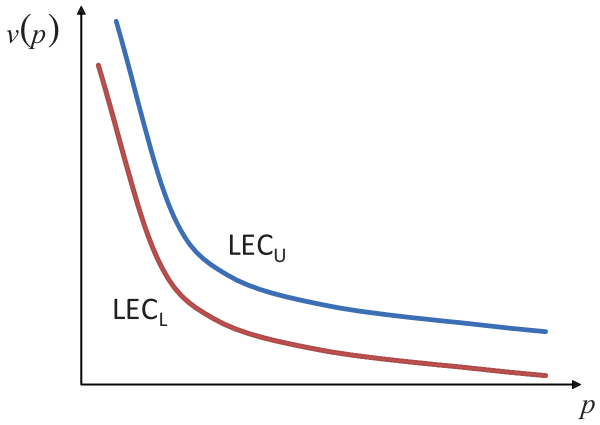


Fig. 14.20 Illustration of an imprecise loss exceedance curve composed by curves LEC_L and LEC_U

$$\nu(p)_L = \sum_{j=1}^{n} I\left[L_j \subseteq F\right] \cdot \ell\left(L_j\right) \tag{14.21}$$

$$\nu(p)_U = \sum_{j=1}^{n} I\left[L_j \cap F \neq \varnothing\right] \cdot \ell\left(L_j\right) \tag{14.22}$$

where n is the total number of focal elements in $\mathcal{L}$. Figure 14.20 shows an illustration of an imprecise loss exceedance curve. Note that all risk metrics now become imprecise. Background trends can still be incorporated by obtaining for every moment in time both LEC_U and LEC_L curves, i.e., rendering an *imprecise loss exceedance surface*.

6 Incorporating Second-Order Effects

Risk addressed from a physical point of view is the starting point to analyze the subsequent impacts of a disaster on society. Disasters resulting from natural events damage the built environment, affecting people and their activities in different ways. It is widely recognized that the development level of the society usually determines the severity of the consequences derived from disasters. Cardona (2001) developed the *Holistic Risk Assessment* methodology, as an attempt to incorporate context variables into risk assessment, with the objective to account for social, economic, institutional, environmental, governance, and cultural issues, among others, that set the foundations for underdevelopment, unsafety, poverty, social injustice, and many other problems widely recognized as risk drivers.

Holistic evaluations have been performed in recent years for different cities worldwide (Birkman et al. 2013; Carreño et al. 2007; Jaramillo et al. 2016;

Marulanda et al. 2013; Salgado-Gálvez et al. 2016) as well as at country level (Burton and Silva 2014) and have proven to be a useful way to evaluate, compare, and communicate risk while promoting effective actions toward the intervention of vulnerability conditions measured at its different dimensions. It has also been integrated into toolkits, guidebooks, and databases for earthquake risk assessment (Khazai et al. 2014, 2015; Burton et al. 2014).

The holistic evaluation approach states that to reduce existing risk or to prevent the generation of new risk, it is required a comprehensive risk management system, based on an institutional structure accompanied by the implementation of policies and strategies to intervene vulnerable elements and also diverse factors of the society that create or increase risk. In the same way, in the case a hazard event is materialized resulting in a disaster, emergency response and recovery actions should be conducted as part of the risk management framework. Figure 14.21 shows the conceptual framework of the holistic risk approach.

The physical component in the evaluation is provided by the probabilistic risk assessment as presented in the previous section. The aggravating factors are chosen considering their capability to capture important dimensions of society, as well as the coverage and availability of the data. Furthermore, these variables are sought to cover a wide spectrum of issues that underlie the notion of risk in terms of predominating vulnerability conditions beyond the physical susceptibility, that is, factors related to *social fragility* and *lack of resilience* that favor indirect and intangible impacts, affecting the capacity of the society to cope with disasters, increasing the incapability to absorb consequences, to respond efficiently, and to recover from the impact. Figure 14.22 shows, as an example, the aggravating factors used in the global holistic evaluation of disaster risk for the UNISDR GAR ATLAS (2017).

6.1 Holistic Risk Assessment Methodology

According to Cardona (2001) and Carreño et al. (2007), the holistic risk assessment index or total risk (RT) is calculated as:

$$\mathrm{RT} = \mathrm{RF}\left(1 + F\right) \tag{14.23}$$

This expression, known in the literature as *Moncho's equation*, is defined as a combination of a physical risk index, RF, and an aggravating coefficient, F, both being composite indicators (Carreño et al. 2007). RF is obtained as a nonlinear normalization of a probabilistic risk metric (commonly a robust metric such as the AAL, whether precise, imprecise, or time-dependent), while F, which accounts for the socioeconomic fragility and lack of resilience of the area under analysis, is obtained from available data regarding political, institutional, and community organization.

It is assumed that total risk (RT) can be, at most, two times the physical risk of the affected area. It means that, in a hypothetical case where socioeconomic characteristics are optimal and there is neither fragility nor lack of resilience, the

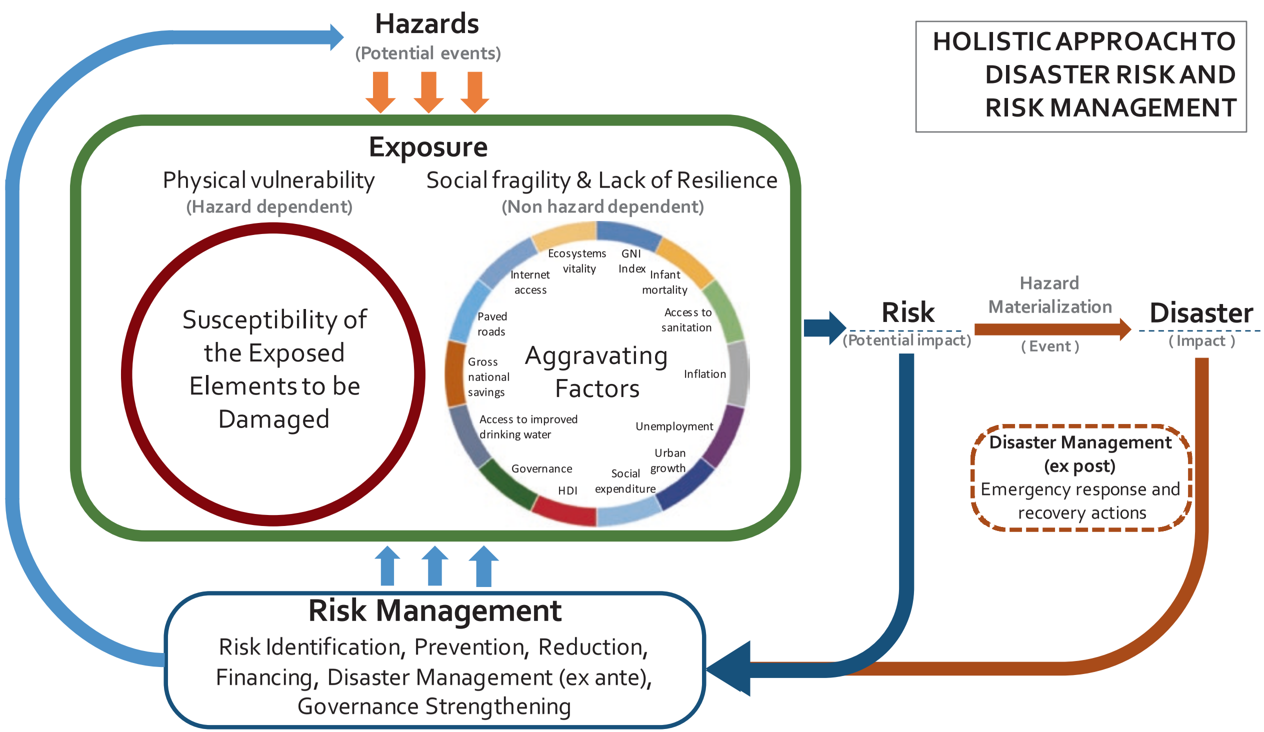


Fig. 14.21 Conceptual framework of the holistic approach to disaster risk

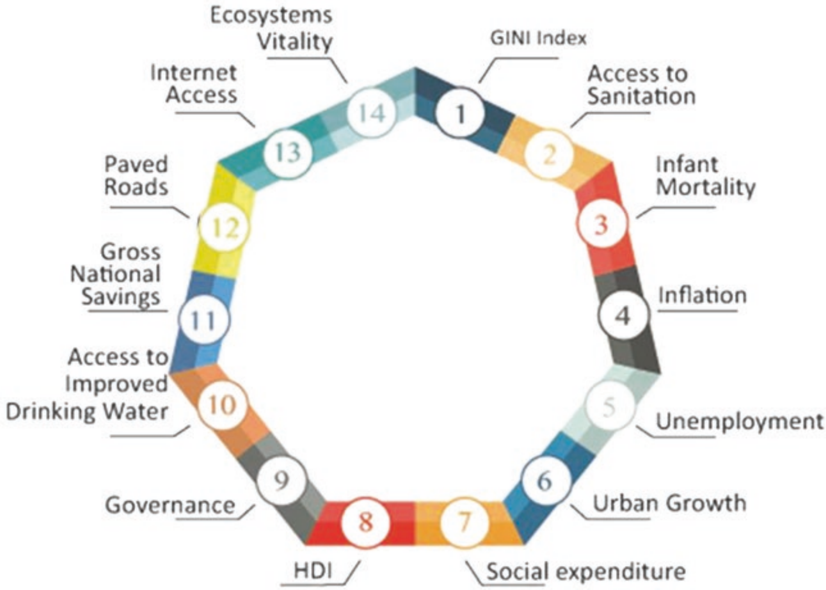


Fig. 14.22 Structure of indicators used in the holistic evaluation of risk at a global scale

aggravating factors would be zero and then the total risk would be the same as the physical risk. However, if the societal characteristics render the maximum value of the aggravating coefficient (1.0), the total risk would be twice the physical risk value. This assumption, though arbitrary, is made to reflect how socioeconomic characteristics can influence the impact of a disaster. The aggravating coefficient, F, is calculated as follows:

$$F = \sum_{i=1}^{m} F_{SF_i} \cdot W_{SF_i} + \sum_{j=1}^{n} F_{LR_i} \cdot W_{LR_i} \tag{14.24}$$

where F_{SFi} and F_{LRj} are the aggravating factors, W_{SFi} and W_{LRj} are the associated weights, and m and n are the total number of factors for social fragility and lack of resilience, respectively. Weights W_{SFi} and W_{LRj} are defined to set the importance of each of the factors on the index calculation, i.e., the contribution of each indicator in the characterization of the dynamics of the society.

The factors used in the calculation of the total risk (*RT*) capture different aspects of society, usually quantified and reported in different units. For this reason, normalizing procedures are needed to standardize the values of each descriptor and ensure commensurability. A common practice is to standardize them by using transformation functions (see Fig. 14.23). The shape and characteristics of the functions vary depending on the nature of the descriptor. Functions related to descriptors of social fragility have an increasing shape, while those related to resilience have a decreasing one. Thus, in the first case, a high value of an indicator means a greater

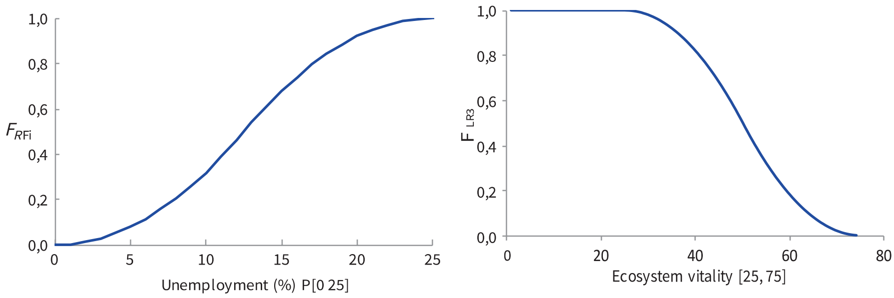


Fig. 14.23 Examples of transformation functions

contribution to aggravation (e.g., corruption: if high, it will contribute more to aggravate conditions to cope with an adverse situation). In the second case, a high value of the indicator means a lower negative influence on the aggravation (e.g., access to education: a high value is a positive characteristic for more resilient societies; therefore, it will contribute less to aggravate risk). The transformation functions can be understood as fuzzy membership functions of the linguistic benchmarking ("high," "low") of aggravation.

In all cases, the transformed variables have as dominium the interval [0,1]. Given that transformation functions are fuzzy membership functions, a value of 0.0 means no contribution, while the value of 1.0 means a full contribution to the aggravating coefficient.

7 Incorporating Risk Management Strategies

There is a wide range of possibilities to reduce risk. For example, in flood risk problems, the use of flood defenses is common practice. Nevertheless, it is not the only available possibility (see, e.g., Yousefi et al. 2015). The best combination of risk reduction alternatives is, in general, quite difficult to obtain without arbitrariness.

The LEC, among many interesting properties, can be stratified to define a set of interventions to reduce risk (Fig. 14.24). Each intervention affects the curve in a different way, building up a risk management strategy. The risk landscape is modified when a mitigation strategy is applied. The best way to define if a strategy is good enough to reduce risk is to perform the risk assessment including its effect. The objective is to identify a set of risk management alternatives that are highly efficient in reducing risk. This is achieved by applying *risk control engineering* (RCE).

RCE is a methodological framework specifically designed to help governments, institutions, and private sector stakeholders meet resilience targets by identifying the set of risk management alternatives that are more efficient in reducing risk up to a predefined expected level. The RCE process is summarized in Fig. 14.25. Note that RCE can be applied indistinctively on LECs, LESs, or imprecise LECs, even

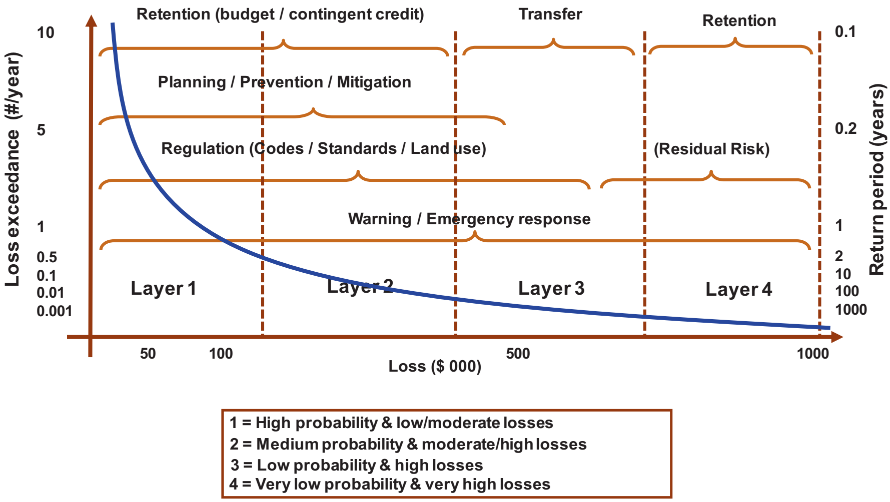


Fig. 14.24 Loss exceedance curve stratified to define actions to reduce risk

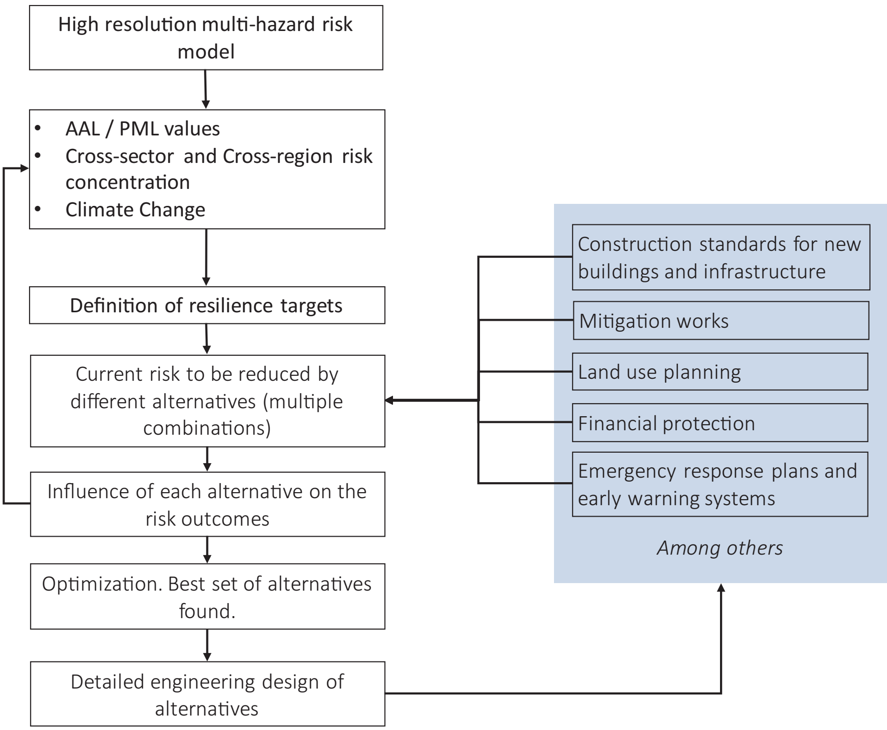


Fig. 14.25 RCE process

incorporating second other effects. The RCE process is illustrated with a single LEC for easiness. In addition, it is worth mentioning that RCE matches the purpose of steps 3, 4, and 5 of DMDU.

The resilience target is defined as the expected reduction of risk after the application of several risk management alternatives. This means that a resilience target is a new LEC, reduced from the real risk result to an acceptable risk level (see Fig. 14.26).

A resilience target may be achieved by a combination of many risk management alternatives. The available alternatives include, among others, definition of construction standards for new buildings and infrastructure, implementation of hazard-control or vulnerability-reduction mitigation works, risk-based land-use planning, financial protection, emergency response plans, and early warning systems. The implementation of any of these alternatives will modify the risk, in a way that can only be known by incorporating it into the hazard and risk models and obtaining the results again. For example, Fig. 14.27 shows risk maps (in terms of building-by-building AAL) for Santa Fe, Argentina, with and without any retrofitting of the city perimeter flood defenses. The black lines in the figure show the location of the defense dikes.

A combination of alternatives is defined in terms of (i) the alternatives considered, (ii) the risk reduction capabilities of each alternative, (iii) the cost of implementation of the combination, and (iv) the impact it has on reducing risk. Figure 14.28 exemplifies a combination of alternatives over a LEC.

Many combinations are created to identify possible strategies that meet the same target at different costs. The best alternatives are selected from an optimization process in which the combinations that best meet the resilience target, at the lowest cost (i.e., best cost/benefit ratios), are selected as champions. The optimization process implemented within the RCE framework, which is based on evolutionary programming (genetic algorithms), is summarized next.

1. Combinations of alternatives are randomly created to populate the *first generation*. Each combination is considered an *individual*. The *genotype* of an individual is the set of alternatives (see Fig. 14.29). Note that each individual has a

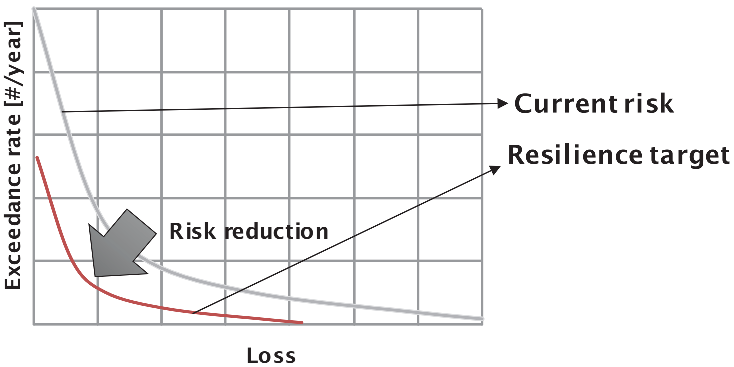


Fig. 14.26 Definition of a resilience target

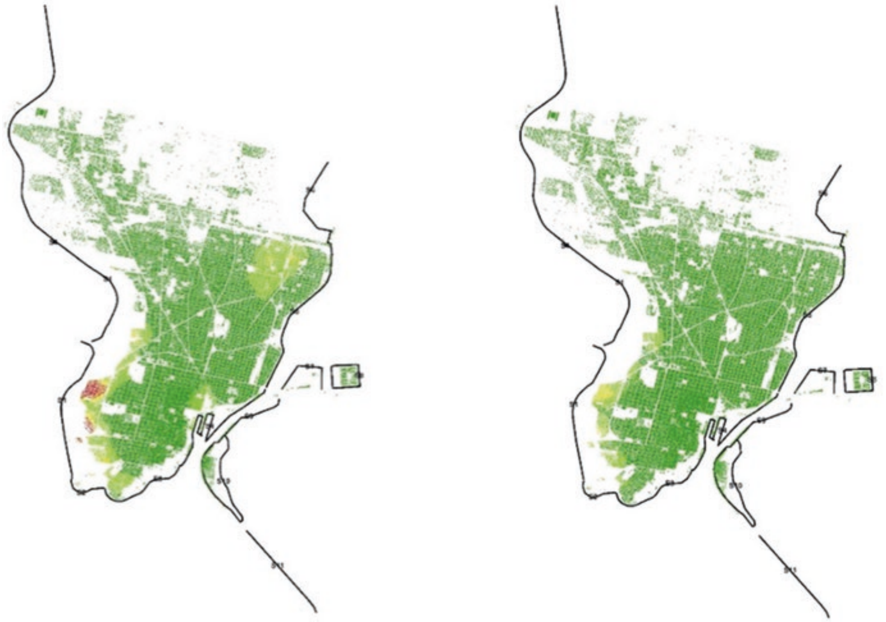


Fig. 14.27 Illustration of the effect of retrofitted flood dikes in central Santa Fe, Argentina. Left: AAL map with current-state dikes. Right: AAL map with retrofitted dikes

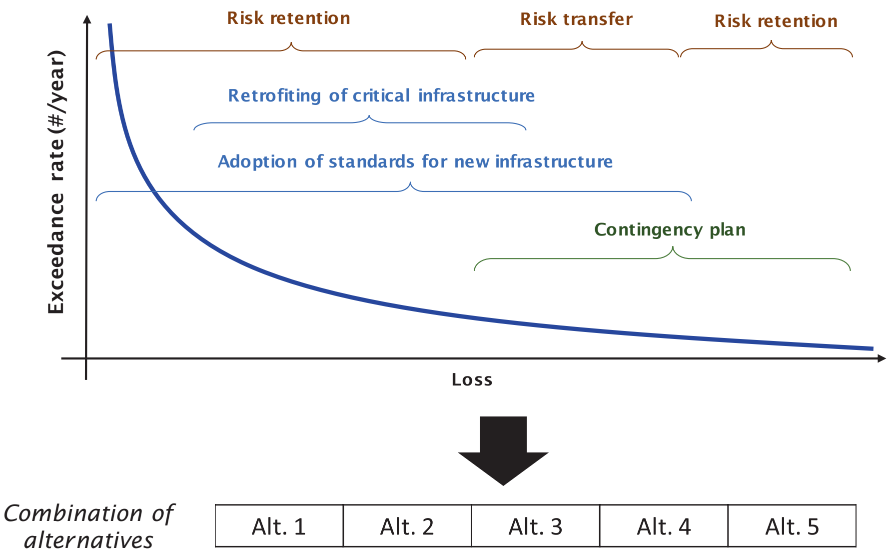


Fig. 14.28 Example of a combination of alternatives. Note that each alternative has a risk reduction domain in terms of the loss range it targets

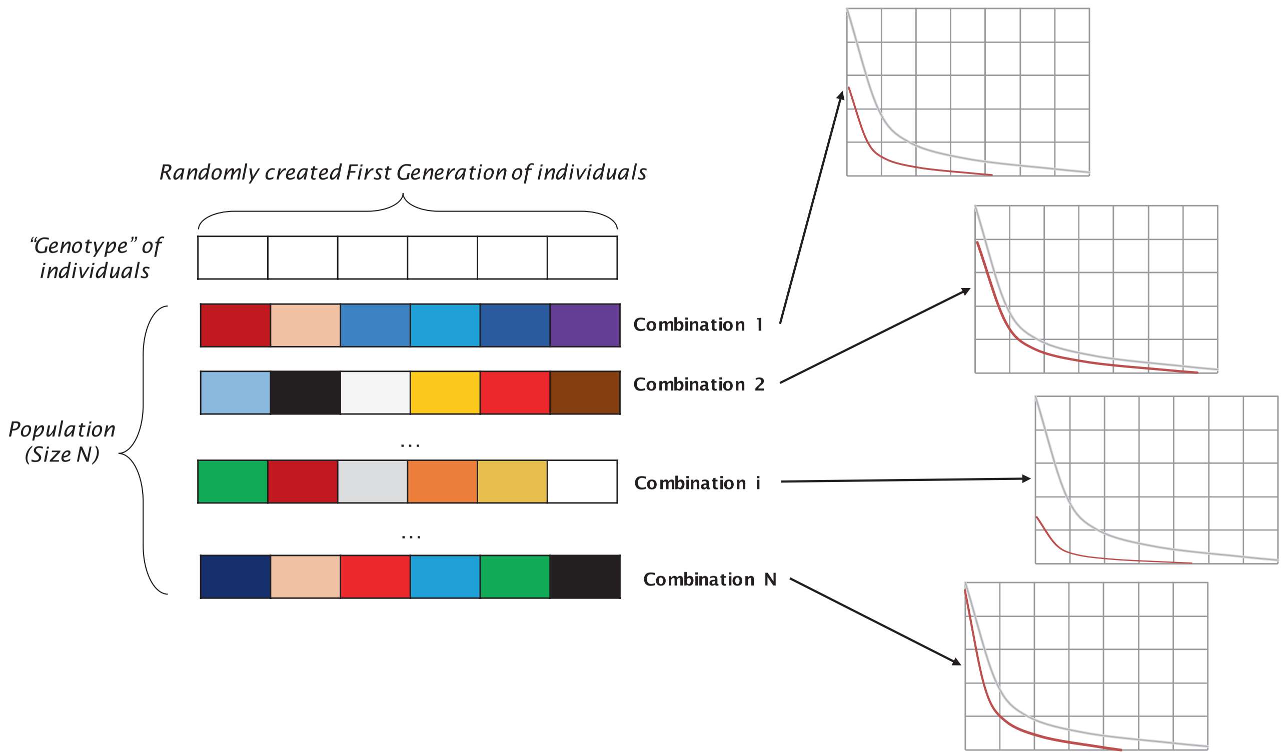


Fig. 14.29 Illustration of the creation of the first generation of combinations. The colors in the boxes are to illustrate different characteristics within each alternative (box)

different capacity to meet the resilience target. The one that best meets the target is considered the *champion*.

2. The evolutionary process starts so that new combinations of alternatives are created randomly as a result of *crossing* and *mutating* the individuals of the previous generation (Fig. 14.30).

The champion of the last generation holds the combination of risk reduction alternatives that best fit the resilience target. This combination is a strong candidate to become the risk reduction strategy to be undertaken.

8 Summary and Conclusions

A first step toward building a solid political and economic imperative to manage and reduce disaster risk is to estimate probable future disaster losses. Unless governments can measure their levels of risk, they are unlikely to find incentives to manage disaster risk. Risk estimations can provide those incentives and, in addition, allow governments to identify what are the most effective strategies to manage and reduce risks. Effective public policies in disaster risk reduction and sustainable development, ranging from financial protection, risk-informed public investment, resilient infrastructure, territorial planning, and impact-based early warning, all can benefit from appropriate estimations and layering of risk.

Probabilistic risk assessment provides a robust mathematical framework for estimating the consequences of future disasters considering the random nature of both hazard and vulnerability and rationally incorporating that uncertainty into the result. It provides a set of metrics that fully represent the loss occurrence process and allows the incorporation of risk management strategies, second-order effects, background trends, and modeling under deep uncertainty into a sound mathematical framework, making it a versatile tool for decision-making.

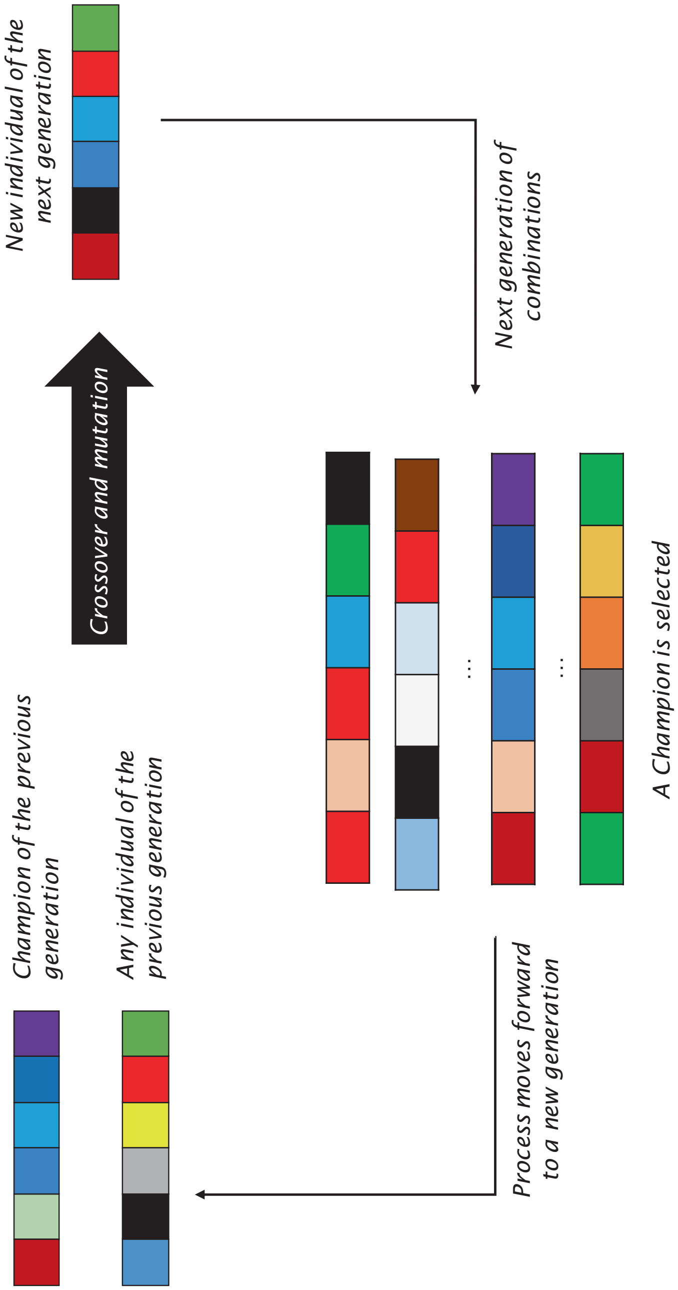


Fig. 14.30 Illustration of the evolutionary process for the optimization of the combination of alternatives

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Chapter 15
A Conceptual Unified Model for Assessing Improvements in Sustainability and Resilience in Water Distribution Systems

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Abstract Communities around the world are looking for ways to provide reliable and cost-effective infrastructure services to end users. Sustainable and resilient infrastructures are the demands of the day. Both public and private sectors demand resilient and sustainable infrastructure to satisfy the rising consumer demands and foster economic development. While a resilient infrastructure fares well under a catastrophic disaster event by withstanding strongly and recovering quickly, a sustainable infrastructure can function effectively over the lifetime without placing excessive demands on limited resources. There is increased awareness among government entities, municipalities, and communities about the necessity for considering both sustainability and resilience in the decision-making process. There have also been attempts within the research community to develop a common framework for sustainable and resilient infrastructures. However, the studies remained too general and limited to expressions of the need only and not often relevant to water distribution system (WDS). The objective of this chapter is to present a conceptual decision model based on the life cycle thinking (LCT) approach. The WDS from Sharjah Electricity and Water Authority (SEWA) is used as an example to illustrate the use of the model. The proposed model takes into account relevant metrics and parameters to help unify the impacts of sustainability and resilience improvements in a WDS. Improvement measures (scenarios) in the model are considered as decision alternatives. The conflicting aspects of sustainability and resilience are examined using a combination of life cycle assessment (LCA) and life cycle-based global resilience analysis (GRA) of the infrastructure. LCA includes the evaluation of sustainability using appropriate metrics. GRA is conducted to determine the resiliency of the WDS. Unified evaluation of both resilience and sustainability for the WDS provides the basis of a model for realistic assessment and critical decision-making.

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The study develops a LCT-based model to help determine the course(s) of action necessary to achieve sustainability and resilience goals, including the necessary trade-offs, while continuing to provide reliable service to consumers.

Keywords Sustainability · Resilience · Life cycle assessment · Global resilience assessment · Life cycle thinking · Water distribution system

1 Introduction

Increasing environmental threats originating from intense drought, flood, earthquake, food shortages, and climate change underscore the importance of building resilient infrastructure (Marchese et al. 2018). This is in addition to the growing significance of ensuring development of sustainable infrastructure. Many emergency response agencies (Ward et al. 2017) and nongovernmental organizations (NGOs) (Dynes and Quarantelli 1975) were established to build infrastructure resistant to the disaster events. Although considerations of both sustainability and resilience are important, their conflicting objectives in the context of municipal infrastructure at times pose challenges that need to be resolved prior to any critical decision-making. While resilient cities might require increased amount of resources to withstand against disaster events, sustainability promotes the conservation of resources for future generations (Shahidehpour et al. 2018; Timashev 2017). For this reason, among others, an integrated approach of developing both sustainable and resilient city is necessary (Thomas Ng et al. 2017; Makhoul 2015; De Jong et al. 2015).

Research in sustainable urban infrastructure so far has been limited (Ferrer et al. 2018). Among various civil infrastructures, sustainability of buildings received much attention, as assessment of buildings helps to improve environmental performance (Haapio and Viltaniemi 2008). Apart from buildings, there were several studies conducted on distributed infrastructure and transportation systems (Rijsberman and Van De Ven 2000; Balkema et al. 2002; Afgan and Carvalho 2004; Mihyeon Jeon and Amekudzi 2005). There were also studies focused on evaluating sustainability of urban infrastructure based on environmental, economic, social, and engineering impacts (Liang et al. 2018; Eslamian and Motevallian 2014; Sahely et al. 2005).

Cities are interdependent and complex systems, generating a large amount of vulnerability due to natural and artificial threats (Ali et al. 2016; Godchalk 2003). Resilience can be defined as the ability of any system to withstand from a disaster and recover quickly and smoothly. Resilience is very important factor for infrastructures that can be impacted by a system failure (McDaniels et al. 2008). Resilient systems, especially in critical infrastructures, involving power, water, and healthcare can protect against external shocks in extreme events in addition to protection against cascading failure events (failure in one infrastructure leading to failure in others) (Mortula et al. 2020).

1.1 Life Cycle Thinking (LCT)

Life cycle thinking (LCT) paradigm uses life cycle management approaches to evaluate infrastructure. Impacts on triple-bottom line of sustainability (i.e., environment (environmental impact assessment (EIA), life cycle inventory (LCI), strategic environmental assessment (SEA)), economy (cost benefit analysis (CBA)) and social (multi-criteria analysis (MCA)) aspects) for any product (e.g., infrastructure) and/or a process (e.g., services) can be investigated by incorporating LCT (Fig. 15.1). A typical life cycle of a product includes different stages from the resource extraction to the end-of-life waste disposal scenarios. It is a holistic way of considering human interactions with the physical, economic, and social aspects of a global system (Frostell 2013). The use of LCT has drawn a lot of attention for sustainability assessment of infrastructure systems (Saleem et al. 2018; Taborianski and Prado 2012). Life cycle assessment (LCA) is one type of environmental assessment method to evaluate environmental sustainability of different types of infrastructures. Numerous studies on environmental sustainability assessment of civil infrastructure systems using LCA have been reported (Gharzeldeen and Beheiry 2015; Arif et al. 2013; Reza et al. 2011; Sadiq and Khan 2006). S-LCA (social LCA) can be used to evaluate the social impacts of various products or services, and LCC (life cycle costing) is used to study the economic impacts of a project/product. The LCT paradigm can also be useful for assessing resiliency of infrastructure systems. Moreover sometimes, risk-based life cycle assessment is also developed to evaluate vulnerability and risks related to infrastructure systems (Sadiq and Khan 2006). It has been an active research area among the researchers on how to combine risk analysis and LCT-based approaches for studying the risks and resiliency of infrastructure systems over their life spans, which may guide decision- and policy-making (Wilkinson and Osmond 2018). It is very critical in the context of resource management. In practice, it is almost impossible for a complete implementation due to lack of available data.

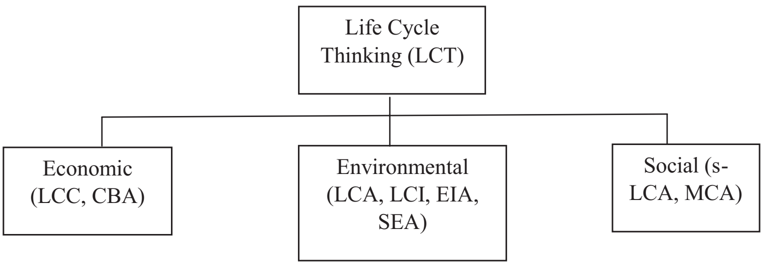


Fig. 15.1 Life cycle thinking. (Adapted from Frostell (2013))

1.2 Integration of Sustainability and Resilience

In many contemporary literature, the terms “sustainability” and “resilience” have been used together or interchangeably to imply the same or similar meaning. Yet, the two concepts are markedly different and have different implications. Marchese et al. (2018) classified the approaches to linking sustainability and resilience in environmental management applications into resilience as a subset of sustainability, sustainability as a subset of resilience, and sustainability and resilience as distinct objectives. Al-Tekreeti and Beheiry (2016) indicated that sustainability is a broad concept upon which systems can be assessed and evaluated to balance economic efficiency, environmental prudence, and social equity. Biggs et al. (2015) explain the principles of resilience in the context of socio-ecological systems and the ecosystem services they provide. They also synthesize insights from across natural and social sciences to provide a comprehensive interdisciplinary overview on building resiliency through in-depth analysis of different case studies.

As argued, sustainability and resilience are distinct but interconnected concepts (Grafakos et al. 2016). There are similarities between sustainability and resilience in the civil infrastructure. They have differences in origin, concept, and context. However, the literature exploring the interconnections, dependence, and distinctions between these two concepts (sustainability and resilience) is scant.

1.3 Development of the Unified Model

Bocchini et al. (2014) were one of the first to recognize the importance of building a unified approach for resilience and sustainability. They discussed the importance of both resilience and sustainability through discussion of historic perspective. However, there is no specific model demonstrated as a means of building the unification. Minsker et al. (2015) discussed the importance of developing performance-based evaluation of sustainable and resilient infrastructure design. They evaluated the emerging infrastructure rating systems and recommended the necessity of developing new technologies and policy changes. However, the study showed little details on the unification of resilience and sustainability. Reiner and Ramaswami (2016) also discussed the necessity of similar model for remedial secondary infrastructure. However, the study mostly focused on the remedial secondary infrastructure and didn’t involve the combination of both resilience and sustainability. Grafakos et al. (2016) investigated the development of a combined benefit assessment framework for green growth interventions. The study developed a common framework for all the different services provided by the municipalities. However, the study lacked the context of sustainability and resiliency for individual infrastructures. Bignami (2017) explored multi-disaster building’s certification based on sustainability and resilience. However, the study mostly focused on the sustainable land use and resilience for urban planning, lacking the context of sustainable and resilient infrastructure. Liang et al. (2018) explored the use of an index-based unified assessment approach for urban infrastructure sustainability and resilience. The study used the context of life cycle approach. However, the study is quite broad based on the urban planning perspective. The context of civil infrastructure and its sustainability and resilience was missing in the study. Yang et al. (2018) discussed the importance of infrastructure integration as a means of developing a common platform. Similar to most other literatures, the study mostly focused around urban planning perspective, lacking the context of individual infrastructures. The study also lacked specific models to evaluate civil infrastructures. Marchese et al. (2018) reviewed the different literatures on a common platform for sustainability and resilience and discussed the necessity for interconnection between them. The study mostly revolved in the context of environmental management, lacking the focus on individual civil infrastructure. All these studies have limitations of the applicability of sustainability and resilience on individual civil infrastructures. In addition, the application of the LCT approach in the context of a common framework (unified model) was not evident.

1.4 Unified Models for WDS Relevant to This Study

In this chapter, the concept of the common framework in the context of the water infrastructure is discussed. Santora and Wilson (2008) were one of the first to emphasize the importance of integrating resilience and sustainability in water infrastructures. However, the paper didn't quite elaborate any specific plan on achieving the integration. Clements et al. (2010) developed a framework for sustainable water infrastructure. However, the appropriate integration of resilience in the process was overlooked. Pandit (2014) discussed a framework to identify sustainable and resilient zones in a water infrastructure system. However, the study mostly focused on the planning and design of infrastructure ecology in broader perspective, lacking some details of water distribution system. Boulos (2017) developed a "smart water network model" for sustainable and resilient infrastructure. The study focused on a combination of different software models for rainfall-runoff prediction, asset integrity and capital planning model, and urban storm water model. The study didn't include much details on the water infrastructure system. Dong et al. (2017) developed a new formulation of resilience for urban drainage system. However, the study didn't include sustainability.

WDS consists of a network of pipes interconnected with tanks and pumps to supply drinking water to the individual consumers (Fig. 15.2). There have been a limited number of studies conducted on the resilience of water supply system (Jung, 2013; Diao et al. 2016). Fattah and Mortula (2020) and Mortula et al. (2019) concluded that WDS is one of the most vulnerable components of water supply system. Lansey (2012) discussed the importance of sustainable and resilient water distribution system (WDS). However, the paper falls short on development of any framework or model combining sustainability and resilience.

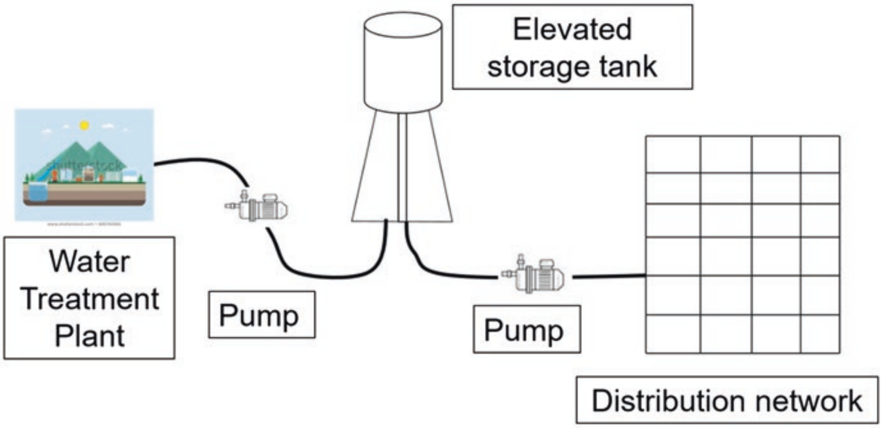


Fig. 15.2 A typical water distribution system

However, as in other infrastructures, there has not been any common model or framework including both sustainability and resilience in WDS. Understanding the sustainability and resilience of a modern water infrastructure is critical in order to provide good-quality services to the consumers consistently over a many years.

Having a unified model based on "life cycle thinking (LCT)" would provide a structured decision support system for municipalities. The aim of this chapter is to develop a conceptual model to assess sustainability and resilience in WDS infrastructures to improve them. In this chapter, the model to evaluate sustainability and resilience was demonstrated in a WDS using life cycle analysis (LCA) and global resilience analysis (GRA), respectively. The major contribution of this research is creating new knowledge and applying that to develop a decision model to improve both sustainability and resilience of urban infrastructures. The underlying principles of the model will be usable by infrastructure authorities irrespective of global regions.

The book chapter is limited to a hypothetical example. Appropriate implementation of data from a real water distribution system (WDS) can help improve the model and its implementation as a decision support system. Hypothetical scenarios or decision alternatives were used as improvement measures in sustainability and resilience of an infrastructure. These are mere examples and can be very different in a real-life WDS. For this reason, each water network needs to develop its own set of alternatives for improvements in sustainability and resilience. In addition to the alternatives, decision-making authorities need to develop a set of metrics or parameters to measure the impacts of sustainability and resilience, as explained, their respective weights, and scores of each metrics corresponding to the scenarios in order to use the model. The model is flexible and can be used very effectively to run "what-if" scenarios.

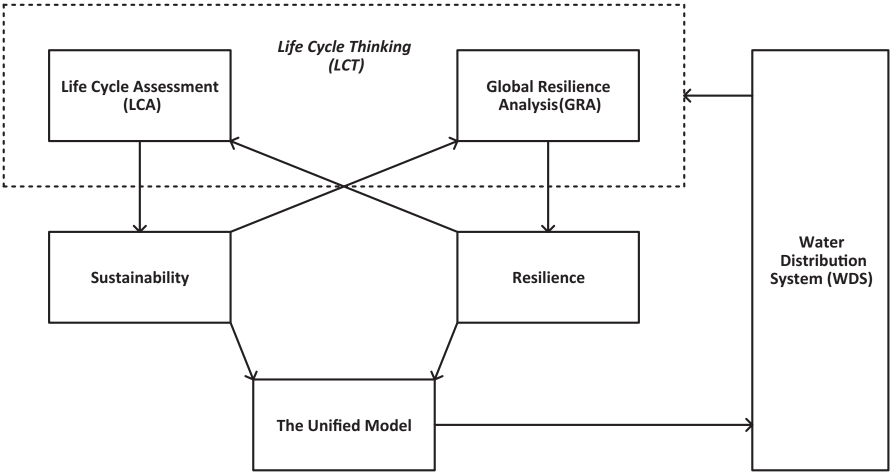


Fig. 15.3 Framework of the conceptual model

2 Development of the Conceptual Model

The model is developed based on LCT approach. LCT seeks to evaluate possible improvements of environmental impacts throughout the whole life of a product. However, it is not just a way of evaluating environmental impacts but also a way to visualize the broader implications of any development activities throughout the life cycle (Thabrew et al. 2009). Under the overall context of LCT, the model incorporates a combination of different methodologies. The interconnections between different approaches are demonstrated in Fig. 15.3. LCA is applied for sustainability assessment. The WDS is investigated throughout the life cycle on different aspects of environmental impacts. GRA is typically conducted on a networked infrastructure. GRA is used to conduct the resiliency assessment throughout the life cycle for the entire WDS. Thus, the unified model, integrating both sustainability and resilience, is based on the LCT combining both LCA and GRA approaches.

2.1 Life Cycle Assessment (LCA)

LCA is normally conducted to evaluate the environmental effects of a product, service, or process during their lives (Finnveden et al. 2009). In this model, LCA is used following the general framework used by Hajibabaei et al. (2018). However, their study was limited within the pipe materials, and the extent of life cycle was limited to production, transportation, and installation. This model can include tanks and pumps, in additions to pipes, as well. The rationale is to broaden the system

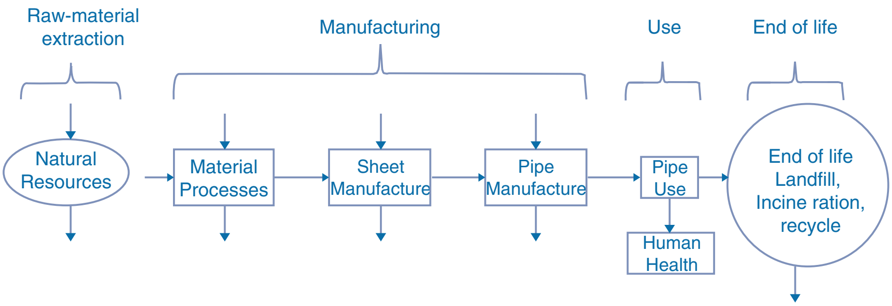


Fig. 15.4 Life cycle of water distribution pipe. (Adapted from Mihelcic and Zimmerman (2009))

boundaries and encompass the entire distribution system. In addition, in this study, life cycle is extended up to the end of life scenarios (Fig. 15.4).

The purpose of the LCA is to evaluate the various types of environmental impacts of different pipe materials, storage tanks, and pumps during their entire life cycle. All these impacts are used to develop a unified sustainability index for the WDS. Pipes constitute the major portion of the WDS. For this reason, the model focuses on the different kinds of pipes.

Life cycle inventories consist of collecting data to quantify the inputs and outputs of the system including consumption of resources, use of infrastructure services, and end-of-life data for waste management. A wide range of data including manufacturing plants (for pipe, tank, and pump) and literature review would be essential. Some of the data are available commercially. Once the life cycle inventory is available, appropriate LCA can be conducted. Impact assessments would depend on assumptions consistent with the previous literatures (Hajibabaei et al. 2018). LCA produces a wide range of indicators of sustainability. For illustration, only five indicators or metrics are considered in this study. They are material intensiveness, energy, air pollution, water pollution, and global warming potential. Each one of these metrics may have multiple dimensions and will most likely involve rigorous analyses for assessment. More importantly, it should be realized that they are measureable objectively with appropriate physical units. An additional assumption inherent is that these metrics are mutually exclusive allowing us to use an additive model. Indicators reflecting social, environmental, and economic impacts can and, in many cases, should be included in the model.

The model is based on a multiple criteria for assessing the LCA impacts of different alternatives. In this study, the five criteria (metrics) are used to estimate a sustainability index. These scores can be used to rank the considered alternatives. In other words, each alternative having an impact on sustainability (and resilience, as well) will be assessed against these metrics in order to assign a score. There are several methods available in the literature on multi-criteria decision modeling. The method chosen is a very simple one just to demonstrate the concept. However, advancement of modeling techniques using neural network and/or genetic algorithm can also be attempted.Sustainability index (Z_1) is computed based on a multivariable linear additive model, as presented in Eq. 15.1:

$$Z_1 = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_4 X_4 + \alpha_5 X_5 \quad (15.1)$$

where:

X_1 = Material intensiveness
X_2 = Energy
X_3 = Air pollution
X_4 = Water pollution
X_5 = Global warming potential

α_1, α_2, α_3, α_4, and α_5 are the relative weights representing relative importance of the metrics. They are percentages expressed in decimals (e.g., 0.2 for 20%) and add to a total of 1.0 or 100%.

The relative importance of different parameters (X) toward achieving sustainability is often debatable. For this reason, a reasonable estimate for the individual weights is often challenging. It can be estimated through a survey-based study relying on expert and professional opinion.

All five metrics or Xs (measures of impacts on sustainability) in Eq. 15.1 are subjective scores, assigned by the decision-making authority for each decision alternative, as described in the next section using a hypothetical case.

2.2 Global Resilience Analysis (GRA)

GRA is an assessment methodology to evaluate vulnerability of a series of infrastructure network (Mugume et al. 2015; Hokstad et al. 2013; Johansson 2007). However, the use of GRA in WDS is quite recent (Meng et al. 2018; Diao et al. 2016). GRA is used in this study as a means of evaluating resiliency of WDS.

GRA is done by assessing a system's inherent resilience using modeling of the basic failure modes with varying stress and estimating the corresponding strain (Diao et al. 2016). GRA in this model is conducted following the same approach. An existing calibrated WaterCAD-based model for the WDS is needed to complete this task. Potential failures are identified as applicable throughout the life cycle of the WDS. Stress condition is simulated by varying levels of pipe failure, pump failure, excess water demand, and substance intrusion. Pump is a critical component of the WDS, as it is one of the common reasons of water system failure. The WaterCAD model can provide potential failures throughout the network. The corresponding number of failure scenario (number of incidences of system-wide failure) is documented as the strain. This study plans to develop a resiliency index based on a number of criteria critical for evaluation of resiliency of WDS.

Similar to sustainability analysis, different scenarios of resource allocation for improving resiliency index for different decision alternatives are considered. The model will generate resiliency index (Z_2) to be computed using a multi-criteria additive model, shown in Eq. 15.2. Similar to sustainability index, advanced soft computing techniques can also be used:

$$Z_2 = \beta_1 Y_1 + \beta_2 Y_2 + \beta_3 Y_3 + \beta_4 Y_4 + \beta_5 Y_5 \quad (15.2)$$

where:

Y_1 = Pipe failure
Y_2 = Excess water demand
Y_3 = Water contamination
Y_4 = Duration of failure
Y_5 = Time of recovery

β_1, β_2, β_3, β_4, and β_5 are the coefficients representing individual weights similar to the weights in Eq. 15.1 but, for different metrics, representing measures of resiliency as opposed to sustainability. Also, all five metrics or Ys in Eq. 15.2 are subjective scores, assigned by the decision-making authority for each decision alternative.

Similar to sustainability, the relative importance, expressed in terms of weights (β), of different parameters (Y)), toward achieving resiliency is often rarely agreed. However, it can be estimated through a survey-based study relying on expert and professional opinion. Again, similar to the previous equation, the weights are percentages expressed in a scale from 0 to 1.

3 Hypothetical Example

An analysis for different decision alternatives or scenarios is provided to illustrate the proposed decision model. The model is developed based on a combination of impacts on sustainability and resilience during these scenarios. Since this model combines considerations of both sustainability and resilience, the term unified model is being used. The model itself is built with enough information of any WDS; hence, the application can be limited with insufficient data.

The model is illustrated hypothetically (using fictitious numbers) on a typical WDS, for example, the City of Sharjah. In Sharjah, desalinated water is supplied mostly through more than 3000 km of pipe network buried throughout the city (Fig. 15.5). There are not many overhead storage tanks. The water pressure in the household level is mostly maintained through a network of pumps. Majority (more than 80%) of the pipes are made of asbestos cement. However, newer installations are made of high-density polyethylene (HDPE), polyvinyl chloride (PVC), glass reinforced epoxy (GRE), and glass reinforced polymer (GRP) pipes. Seven different water treatment plants supply water throughout the city. However, desalination plant located at Layyah provides more than 60% of the water. The water from different desalination plants is distributed through seven different injection points throughout the WDS. The network covers most part of the City of Sharjah. There have been concerns of water quality failure in the distribution network (Mortula et al. 2019; Mortula et al. 2016). Other notable failures in water supply were observed in recent times. For this reason, evaluation of resilience is important for the WDS. The city grew remarkably over the past several decades. However, the

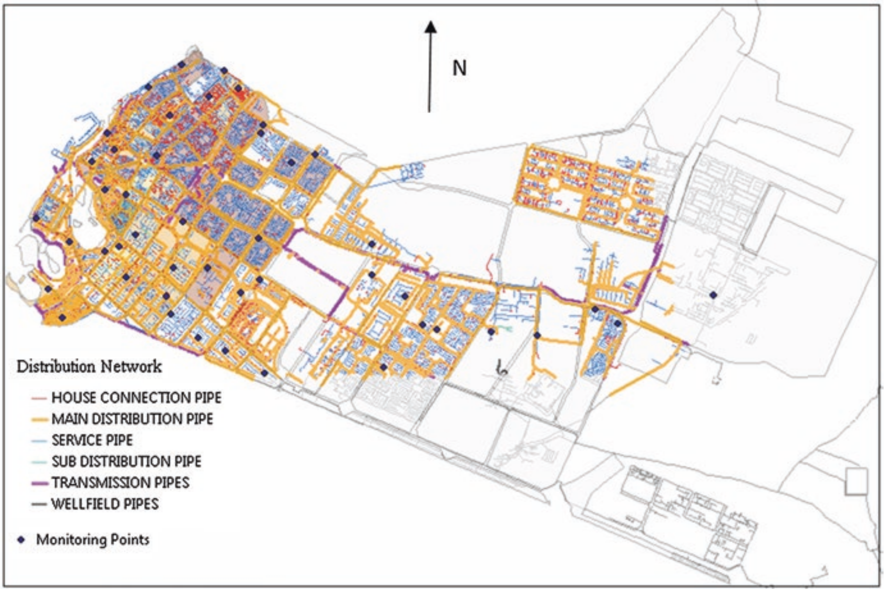


Fig. 15.5 Water distribution network of SEWA (drawn not to scale). Note: The position of the circle represents the sustainability-resilience index. Scenario numbers are shown in circle. (Adapted from Mortula et al. (2019))

increase of population strained the already limited resources. For this reason, improving the sustainability has been a challenge for the city. Similar cities around the world would be expected to face similar challenges.

In order to examine the relative impacts of improving both sustainability and resilience during decision-making, five hypothetical scenarios (decision alternative) are considered. One of the scenarios is based on the existing conditions. Two scenarios are based on improvement of sustainability, and the other two are based on enhancement of resiliency.

The scenarios are selected to illustrate the opposing or contradictory effects of sustainability and resilience improvement measures. As pointed out earlier, in most cases, improvements in sustainability are complemented by improvements in resilience and vice versa. The emphasis of this book chapter, however, is on the contradictory nature of sustainability and resilience. The model presented in this book chapter outlines a conceptual procedure that can be used as a decision support system with a consideration of trade-offs between the two.

The scenarios are listed below:

- Scenario 1: Existing condition
- Scenario 2: Cut direct services to distant communities (improving sustainability).
- Scenario 3: Save resources from operation and maintenance (improving sustainability)

- Scenario 4: Add a significant number of overhead storage tanks (improving resiliency)
- Scenario 5: Replace all pipes installed prior to 30 years (improving resiliency)

Scenario 1 represents the existing condition of the distribution system. It includes examination of the current set of pipes, pumps, storage tanks, and all other components of water distribution system. Scenarios 2 and 3 represent efforts on improving sustainability, and scenarios 4 and 5 represent efforts on improving resiliency.

Scenario 2 reduces water services to distant communities. In turn, those communities are to receive water through tankers. It is going to reduce the resource consumption through saving finances on construction, operation, and maintenance for the WDS. It improves the sustainability through reduced resource consumption. However, during the event of disaster, water supplies for those communities are going to be difficult. For this reason, quality of service is going to drop.

Scenario 3 cuts access to resources for operation and maintenance. It saves money for future generations and improves sustainability. However, fewer operation and maintenance reduces the reliability of pipes, pumps, and other critical infrastructure and increases the probability of water supply failure. Also, during the time of disaster, it increases the time required for recovery.

Scenario 4 identifies adding appropriate overhead storage tanks as a means of improving resiliency. It reduces the reliance on direct services and provides enough water during the times of emergency. However, it requires extra resources for construction, operation, and maintenance. For this reason, it increases the environmental impacts leading to reduced sustainability. Scenario 5 identifies all the pipes older than 30 years being vulnerable. These pipes being replaced reduces the likelihood of pipe failure and improved the resiliency of the WDS. However, replacing older pipes requires significantly high amount of resources, leading reduced sustainability.

3.1 Assessment of Impacts on Sustainability

The WDS is investigated for sustainability based on all five scenarios described in the previous section. Relative sustainability score (X) of these scenarios can be estimated based on LCA. The different impacts are assessed based on the life cycle of the WDS. For example, material consumption is expected to be among the highest for scenarios 4 and 5. Similarly, energy consumption is high for scenario 5. Other criteria as described in Sect. 2.1 are estimated. As an example, 3000 Kg of CO_2 as global warming potential (X_5) is equivalent to the environmental impact originated from the existing WDS, and a score value of 10 as the sustainability score is assigned to X5 for the existing WDS scenario. The values used in this study are hypothetical and assumed in consideration from study conducted by Ginley and Cahen (2012).

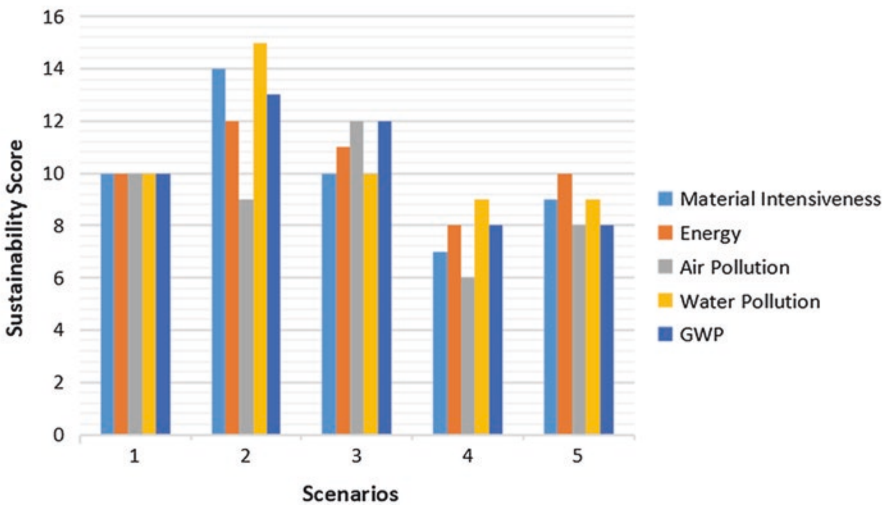


Fig. 15.6 Environmental sustainability of different hypothetical scenarios

Let us assume that a hypothetical improvement of the existing WDS, based on sustainability, would lead to a global warming potential of 2500 Kg of CO_2. For this alternative (scenario 5), the score assigned is 12. Figure 15.6 shows the relative environmental sustainability caused by different measures of sustainability.

Thus, in this example, the existing scenario (scenario 1), as shown in Fig. 15.6, gets a score of 10 for all five metrics. Other scores are subjectively assigned based on the decision-making authorities' assessment of impacts on sustainability of the decision alternatives considered (scenarios 2 through 5). Scores that are greater than 10 indicate improvement, whereas the ones that are lower than 10 indicate adverse impacts.

In this example, scenarios 2 and 3 are supposed to favor sustainability; thus, their impacts show improvements (values higher than 10 across all five metrics). Scenarios 4 and 5 show the reverse (scores are less than 10, as sustainability is not improved under these alternatives or scenarios).

Figure 15.7 shows the total sustainability index (aggregate score) Z_1 for all five scenarios according to Eq. 15.1. For the sake of simplicity, equal weights (0.2 or 20%) were assigned for all sustainability indices.

3.2 Assessment of Impacts on Resiliency

The evaluation of resiliency of WDS is also studied for all five scenarios as described in the previous section. Relative resiliency score (Y) of these scenarios are estimated based on GRA. Different disaster scenarios (lack of water due to climate change, major pipe breakage due to earthquake) are examined hypothetically. The

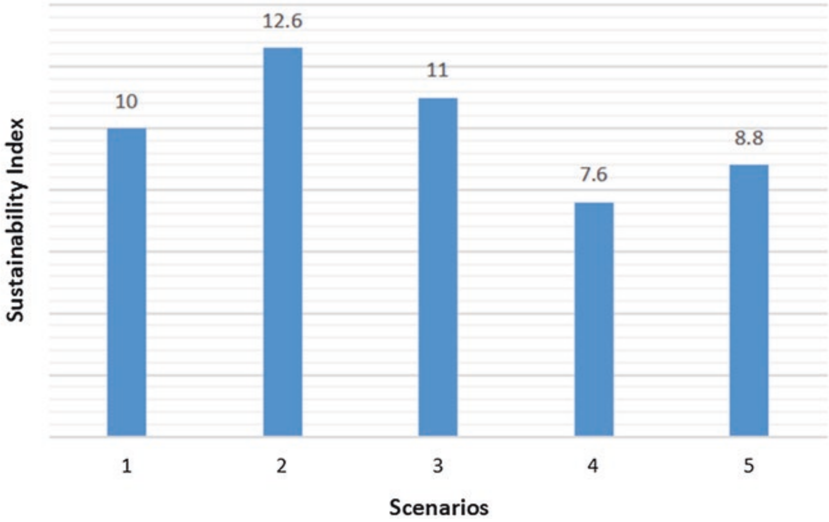


Fig. 15.7 Total sustainability index

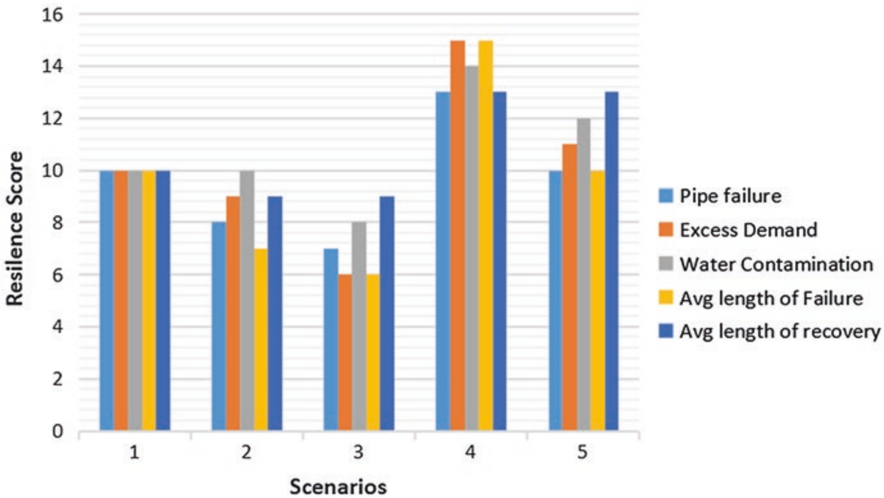


Fig. 15.8 Environmental sustainability of different hypothetical scenarios

stress on the WDS is identified based on five different metrics, already described in Sect. 2.2. The evaluation of resiliency for all the five scenarios is shown in Fig. 15.8, with scores higher than 10 indicative of improved resiliency.

As before, score of 10 on all five metrics indicates the existing scenario, lower than 10 indicates adverse impacts, and higher than 10 indicates improvement in resiliency. For instance, the impacts on all the criteria for scenarios 4 and 5 are higher than the existing system.

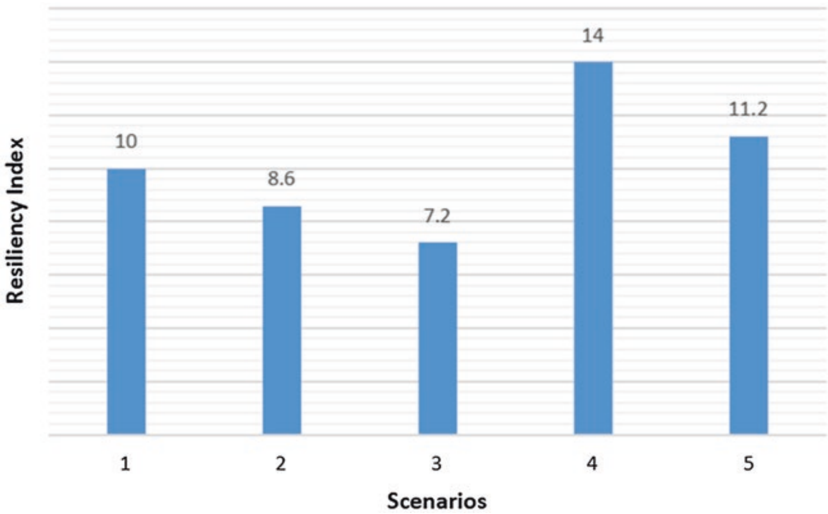


Fig. 15.9 Total resiliency index

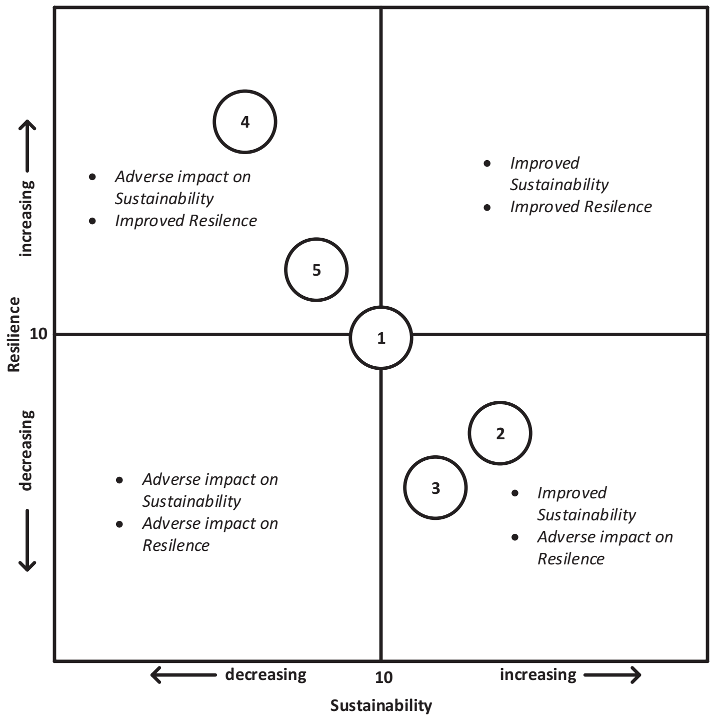
Figure 15.9 shows the total resiliency index (aggregate score) Z_2 for all five scenarios according to Eq. 15.2. Again, as before, equal weights (0.2 or 20%) for all metrics are assumed.

4 Discussion: Development of the Unified Model

Sustainability and resiliency indices are assessed using Eqs. 15.1 and 15.2. The final indices are shown in Figs. 15.7 and 15.8, respectively. It shows the relative significance reflected by indices of different scenarios or alternatives. In general, improvement of sustainability does not always correspond to the improvement of resiliency. Likewise, improvement in resiliency does not always correspond with improvement in sustainability. This model captures that reality and presents a structured approach to help decision-making when a number of alternatives or courses of actions are present. These alternatives are represented by scenarios in this model as illustrated.

Thus, the model can be used as a decision support tool for choosing among the alternatives such as the four different scenarios in the example and as illustrated in Fig. 15.10.

As shown, the top right region indices signify improvement (favorable impact) in both sustainability and resilience, and the bottom left region indices signify reduction (adverse impact) in both. The top left region values indicate improvement in resilience but reduction in sustainability indices. Values in the bottom right region show improvement in sustainability but adverse impacts on resilience. Since two scenarios (2 and 3) were chosen, they will improve sustainability but may have adverse impacts on resilience and the other two (4 and 5) to have the opposite



Note: The position of the circle represents the sustainability-resilience index. Scenario numbers are shown on the circle.

Fig. 15.10 Unified model – sustainability and resiliency indices

effects; all four scenarios fell in the top left and bottom right quadrants. It is possible that a certain scenario will have favorable impacts on both sustainability and resilience. In that case, the location of the scenario will be in the top right quadrant. Similarly, scenario with adverse impacts on both sustainability and resilience will be located in the bottom left quadrant. The unified model as depicted in Fig. 15.10 can be used to determine the appropriate alternative by trying different scenarios and assessing their corresponding sustainability-resilience indices for optimal decision-making.

5 Summary and Conclusions

Water distribution infrastructure is a resource-intensive infrastructure for supplying water to the municipalities. For this reason, ensuring sustainability is very critical. Similarly, it is one of the most critical infrastructures for any municipalities. Ensuring resiliency is also critical to consumers. However, the objectives, and as a result the consequences, of sustainability can at times be in conflict with resiliency.

For this reason, finding a balance between sustainability and resilience is necessary but can often prove to be challenging. In that context, a decision support model will be very useful for ensuring appropriate trade-off between the two. The conceptual model as developed and illustrated in this chapter has the potential to address the inherent challenges in meeting the objectives of a sustainable and resilient water infrastructure.

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Chapter 16
Hazard Evacuation Management and Resilience: Case Study Examples in the USA

Kyle Breen

Abstract Hazard evacuation management is a critical piece of the disaster management cycle of mitigation, preparedness, response, and recovery. Community resilience is another important aspect of hazard evacuation management. However, current hazards and disaster literature often focuses on warning and risk communication, evacuation intentions and behavior, evacuation predictions, and evacuation models rather than connecting community resilience and hazard evacuation management. This chapter firstly provides the current research on evacuation management to show the gap in research exploring the explicit connection between evacuation management and community resilience. Secondly, background on community resilience is provided to build the connection between evacuation management and community resilience. Finally, Two case studies are provided to show how hazard evacuation management – or a lack of evacuation management – and community resilience relate to one another.

Keywords Evacuation management · Disaster resilience · Community resilience · Hurricane Katrina · Hurricane Harvey

1 Introduction

The frequency of natural hazards that become disasters has been increasing over the past number of years (Froment and Below 2020; Guha-Sapir et al. 2017; Metaxa-Kakavouli et al. 2018; Yaghmaei 2019). The International Disaster Database recorded at least 396 natural disasters in 2019, which was over the average of the

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last 10 years (343 disasters on average) (Froment and Below 2020). Due to the increased frequency of natural hazards, there has also been increasing interest in disaster preparedness and resilience by disaster researchers and emergency management personnel.

In terms of disaster preparedness, hazard evacuation management is part of a "…planned and organized protective action…" that is implemented "in response to a recognized and/or anticipated threat" (Zhang et al. 2019, p. 525). Much evacuation management research has primarily focused on evacuation behavior (Huang et al. 2016; Karaye et al. 2019; Meyer et al. 2018), evacuation predictions and intentions (Lazo et al. 2015; Meyer et al. 2018), and evacuation modeling (Blanton et al. 2020; Choi and Chi 2019; Davidson et al. 2020). Meanwhile, there has been less attention given to connecting community resilience and evacuation management. Therefore, it is critical to examine hazard evacuation management as it relates to resilience and, specifically, community resilience.

Hazards and disaster researchers have primarily focused on determining how to define resilience holistically while also investigating connections between the built, social, and natural world and the ability of these worlds to withstand and recover from hazards (Kendra et al. 2018). Meanwhile, emergency management personnel have placed their efforts into putting systems in place that best allows for communities to be resilient based upon the latest research, information, and technology.

In hazards and disaster research, there are often multiple definitions for resilience (Kendra et al. 2018). Additionally, hazards and disaster scholars often debate the scales (such as individual vs. community) and systems (such as built infrastructure vs. social) with regard to conceptualizing resilience (Kendra et al. 2018). For the sake of clarity, in this chapter, I will use the definition of resilience put forth by Cutter et al. (2008). They defined resilience as "…the ability to survive and cope with a disaster with minimum impact and damage" and "incorporates the capacity to reduce or avoid losses, contain the effects of disasters, and recover with minimal social disruptions" (p. 600). Further, with regard to scale, I will be focusing specifically on community resilience in this chapter. Thus, I define community resilience as the capabilities of communities to withstand disaster while supporting effective responses to disaster (National Academies of Sciences, Engineering and Medicine 2019; Patel et al. 2017; Wells et al. 2013).

In this chapter, I examine hazard evacuation management and the connection to community resilience. First, I will examine the current research on evacuation management. This will provide an understanding of one aspect of disaster preparedness – a significant area in the field – while also revealing the existing gap in the research between evacuation management and community resilience. Next, I will discuss community resilience within a process-oriented framework in order to build connections between evacuation management and community resilience. Finally, I will examine two case studies to illustrate the relationship between hazard evacuation management and community resilience. The case studies include examples of a range of evacuation management practices including a lack of evacuation management in Hurricane Harvey and poor evacuation management in Hurricane Katrina. Using these two case studies *does* bring unique limitations. For example, these case studies only explore hurricane evacuation management. As it will be discussed later, evacuations can occur for multiple events and at a range of scales. Also, evacuation management possesses far more nuance than can be understood in just two cases. These cases provide examples of hazard evacuation management but are by no means representative due to the vast differences in variables and outcomes in each evacuation decision. While there are notable limitations, by utilizing examples of the evacuation management shown in these case studies in the USA, we can begin to further understand the relationship between hazard evacuation management and community resilience.

2 Hazard Evacuation

2.1 Defining Hazard Evacuation Management

Evacuation management is commonly accepted as a necessary action to properly prepare for disaster, to enhance response operations, and to reduce risk (Rivera 2020). Quarantelli (1980; p. 10) has described evacuation as "the mass physical movement of people, of a temporary nature, that collectively emerges in coping with community threats, damages or disruptions." The primary goal of evacuation management is to move evacuees outside of the threatened area quickly and safely as to reduce and/or avoid chances of harm or death (Rivera 2020; Zhang et al. 2019). The mass physical movement of people described by Quarantelli (1980) can occur on multiple scales ranging from small areas like rooms or buildings (Guan and Wang 2019; Yang et al. 2020; Zheng et al. 2017) to larger areas such as cities or entire regions (Feng and Lin 2019; Martín et al. 2020; Meyer et al. 2018; Zhang et al. 2015). Additionally, evacuation can occur for multiple events including natural hazards such as hurricanes and floods (Karaye et al. 2019; Wallace et al. 2014), wildfires (Asfaw et al. 2019; Christianson et al. 2019; Toledo et al. 2018; Walpole et al. 2020), or volcanic eruptions (Kuri et al. 2017; Lechner and Rouleau 2019); technological hazards such as explosions or chemical accidents (Gai et al. 2018; Hou et al. 2020); and terrorist attacks (Averill et al. 2012; Kendra and Wachtendorf 2016). However, for the purpose of this chapter, I will discuss evacuation management in relation to natural hazard events.

2.2 Research on Hazard Evacuation Management

Hazard evacuation management is a detailed process and has been studied extensively (Siebeneck et al. 2020). Evacuation management is often characterized by three phases, which include the warning phase, confirmation, and the actual evacuation from the threatened area (Drabek 1969 as cited in Siebeneck et al. 2020,

p. 196). Of the three phases, the warning phase and the evacuation process – including intentions, behavior, and modeling – have accounted for much of the current research on evacuation management (see Thompson et al. 2017 for a review).

2.3 Evacuation Modeling

There has been considerable research in the hazards and disaster literature completed on evacuation modeling. Specific modeling types are beyond the scope of this chapter. Rather, I aim to provide some research that shows how evacuation modeling is one of many aspects of evacuation management and an important step in supporting evacuation decision-making processes (see, e.g., Yang et al. 2019). The purpose behind simulating or modeling evacuation is for researchers and officials to better understand behaviors of social systems under conditions such as a disaster (Haghpanah et al. 2018). In disaster research, evacuation modeling and simulations are an essential step in the process of ensuring public safety (Haghpanah et al. 2018). Therefore, from an emergency management perspective, planning is required to examine the necessary logistics for evacuation (Bian et al. 2019). These logistics include, but are not limited to, departure time (Dow and Cutter 2002); evacuation destinations and distances – including return delays (Dash and Morrow 2001; Dow and Cutter 2002; Lindell et al. 2011; Siebeneck and Cova 2008; Wu et al. 2012); shelter accommodations (Lindell et al. 2011; Mileti et al. 1992; Wu et al. 2012); and evacuation costs (Lindell et al. 2011; Whitehead 2003; Wu et al. 2012). Due to the number of logistics involved in evacuation, emergency management personnel must plan accordingly to determine proper evacuation preparations (Bian et al. 2019). Therefore, many evacuation models (note: this list is non-exhaustive by any means) include aspects of transportation, travel, and traffic (Gehlot et al. 2018; Na and Banerjee 2019; Sadri et al. 2013; Sadri et al. 2014) and social networks (Sadri et al. 2017; Widener et al. 2012). Finally, recent research by Davidson et al. (2020) and Blanton et al. (2020) examined new "integrated scenario-based" evacuation modeling to further understand uncertainties and human-natural interactions to support decision-making processes that are critical to evacuation management.

2.4 Warning and Risk Communication in Evacuation Management

Warning systems and risk communication play an integral role in evacuation management (Dash and Gladwin 2007). As such, hazards and disaster research has placed an emphasis on gaining a comprehensive understanding of warning systems and processes (Dash and Gladwin 2007; Lindell 2018). Lindell (2018) also noted that research findings can be categorized by using the Protective Action Decision Model (PADM) (Lindell 2018, p. 452; Lindell and Perry 2012). The PADM includes prominent warning research areas such as information sources (where the information is coming from) and warning messages (the transmission of that information from the source) (Lindell 2018, p. 452; Lindell and Perry 2012). The PADM also includes the behavioral response aspect, which will be discussed in the following section.

One of the important parts of warning systems and risk communication is the source of information used to distribute the warning (Dalezios et al. 2017). Warning information sources may have profound effects on evacuation depending on source trustworthiness and potential demographic factors (Thompson et al. 2017). For example, warning information received from community officials and emergency management (Burnside 2006; Fischer et al. 1995; Gray-Graves et al. 2011; Howard et al. 2017; Lamb et al. 2013; Meyer et al. 2018; Morss et al. 2016; Sun et al. 2017), peers, friends and family (Adeola 2008; Hasan et al. 2011), and media – including social media (Branicki and Agyei 2014; Haataja et al. 2016; Roy et al. 2020; Sadri et al. 2017) – have been identified as warning information sources that have potential to impact evacuation behavior.

Another important aspect of warning systems and risk communication is the actual warning message. According to Lindell (2018, p. 457), warning messages "should describe the threat, affected (and safe) areas, protective action recommendations, message source, implementation deadline, and sources to contact for additional information and additional assistance." Recent research has examined warning messages (Wood et al. 2018) and the extent of the inclusion of the elements of effective warning messaging (Lindell et al. 2015; Lindell et al. 2017; Wang et al. 2020). However, there is more research needed on warning messaging and its effectiveness because there is limited research on the subject (Lindell 2018). There *has* been considerable research on warning messages such as evacuation communications, orders, and recommendations[1] from officials. Prior research has found that evacuation communication that mandate individuals leave a particular area has been effective for evacuation decision-making and intentions in hurricanes (DeYoung et al. 2016; Goodie et al. 2019 Meyer et al. 2018; Mitchell et al. 2017; Pham et al. 2020). There have also been similar results found regarding official warnings for wildfires (McCaffrey et al. 2018; Paveglio et al. 2014).

[1] Mandatory evacuation orders require everyone to evacuate from the area. Voluntary evacuation orders (or evacuation recommendations) suggest that individuals evacuate, but it is not mandated by emergency management personnel (Meyer et al. 2018).

2.5 Intentions, Behavior, and Decision-Making in Evacuation

A large amount of current research on evacuation focuses on evacuation intentions, evacuation behavior, and evacuation decision-making (see Hasan et al. 2011; McCaffrey et al. 2018; McLennan et al. 2019 for a review of research; Meyer et al. 2018; Nguyen et al. 2018; Toledo et al. 2018). Research has shown that multiple factors play a role in evacuation intentions, behavior, and decision-making including hazard proximity and strength, risk perceptions and prior evacuation experience, and demographics (Goodie et al. 2019; Meyer et al. 2018). I will discuss each of these aspects in the following sections.

2.5.1 Hazard Proximity and Strength

Hazard proximity and strength (when applicable) are important to understanding evacuation behavior and intentions. Huang et al. (2016) conducted a meta-analysis of hurricane research. In their analysis, they found that in over 80% of the studies they reviewed, there were positive correlations between the risk area of the hazard and evacuation (Huang et al. 2016). There have also been additional studies on hurricanes and flooding with regard to evacuation and proximity. Results have been similar, indicating greater likelihood of evacuation for those living near the coast (Huang et al. 2012), those who are in proximity to areas likely to experience flooding such as 100-year or 500-year flood plains (Wallace et al. 2014), and those who perceive greater flood risk (Whitehead et al. 2001). Toledo et al. (2018) found similar results in their study on wildfire evacuation in Haifa. They found that when individuals perceived their home to be at a high risk, they were more likely to evacuate (Toledo et al. 2018). However, it should be of note that there has been little research conducted in the area of wildfire proximity and evacuation decision-making (Edgeley and Paveglio 2019). Finally, in research on hurricanes and evacuation behavior, decisions to evacuate often depend on storm strength among other storm characteristics (Meyer et al. 2018). Research shows that individuals are more likely to evacuate from stronger storms – measuring as category 3 or higher on the Saffir-Simpson Scale – as opposed to weaker storms, measuring as category 1 or 2 (Huang et al. 2016; Meyer et al. 2018; Mitchell et al. 2017; Whitehead et al. 2001).

2.5.2 Risk Perception and Prior Experience

Risk perception and prior evacuation experience also influence evacuation behavior and intentions. For risk perception, I am adopting the definition as put forth by Lindell and Perry (2004). They define risk perception as it relates to the "…certainty, severity, and immediacy of disaster impacts to the individual, such as death, property destruction and disruption of work and normal routines…" (Lindell and Perry 2004, p. 127). Heightened risk perception can play a significant role in the adoption of greater protective behaviors including evacuation (Meyer et al. 2018). Trumbo et al. (2016) also found that higher risk perception increases the intention to evacuate. In terms of prior evacuation behavior, there have been mixed results in the research literature. For example, some research has shown positive (Sharma and Patt 2011; Solis et al. 2010), negative (Hasan et al. 2011; Hasan et al. 2012), and no relationship (Lazo et al. 2010; Lindell et al. 2005) between prior disaster experience and evacuation behavior and intentions. Interestingly, Goldberg et al. (2020) noted these mixed results and used a meta-cognitive approach to propose that evacuation intention may go beyond previous experience. Their findings suggest that individual confidence in that prior decision to evacuate or not substantially increases the likelihood of the person making the same decision in the future (Goldberg et al. 2020).

2.5.3 Demographics and Evacuation

Prior research on evacuation has provided insight into relationships between demographic characteristics and evacuation behavior and intentions. According to Meyer et al. (2018), "…social stratification along the lines of race, class, and gender, among others, affects individuals' disaster experiences throughout the disaster lifecycle…" and "…vulnerable populations are more likely to experience greater risk and slower recoveries…" (p. 1232). Evacuation research on gender shows that those identifying as women or female are consistently more likely to exhibit evacuation behavior and intentions (Cahyanto and Pennington-Gray 2015; Meyer et al. 2018, Morss et al. 2016; Mozumder et al. 2008; Reininger et al. 2013; Smith and McCarty 2009). Racial differences have also been at the forefront of research on demographics and evacuation behavior and intentions, but results have been mixed (Elliott and Pais 2006; Petrolia and Bhattacharjee 2010; Reininger et al. 2013; Rivera 2020; Thiede and Brown 2013). Two recent studies exemplify these mixed results. Meyer et al. (2018) found in their study of previous evacuation behavior and future intentions that race was correlated with all intentions and prior evacuation behavior. They also found that race was statistically significant with regard to future evacuation intentions for all storm strengths and under no evacuation order, recommended evacuation, and mandatory orders (Meyer et al. 2018). On the other hand, Karaye et al. (2019) found that race was not significant in their multivariable logistic regression model on predictors of hurricane evacuation. However, their bivariate analysis shows that evacuees were more likely to be racial and ethnic minorities, thus showing the complexities to the nature of racial demographics and evacuation behavior and intentions (Karaye et al. 2019).

Indicators of socioeconomic status such as income (Elliott and Pais 2006; Hasan et al. 2011) and education (Goodie et al. 2019; Huang et al. 2016; Meyer et al. 2018; Reininger et al. 2013; Thiede and Brown 2013; Toledo et al. 2018) have also been inconsistent in the evacuation literature. Meyer et al. (2018) found that education and income were significant in Hurricane Katrina evacuation behavior, but were not significant for Hurricane Gustav and Isaac evacuation behavior. They also found that when predicting evacuation intentions, income was only significant for those making less than $25,000 and receiving no evacuation instructions for a category 1–2 hurricane (Meyer et al. 2018). Educational predictors on intentions to evacuate were also only significant for those with a high school degree or less who receive no instructions for a category 1–2 hurricane or recommended or mandatory orders for a category 3+ hurricane (Meyer et al. 2018). It should also be of note that gender, race, and socioeconomic indicators have not been the only demographic indicators researched (see, e.g. Thompson et al. 2017, p. 824 for a review of demographic studies).

2.6 Evacuation Management to Enhance Resilience

The definitions and prior research on hazard evacuation management have shown that the primary goal of evacuation is to protect the lives of those in the community at risk or those in the community affected by disaster. This ideology behind hazard evacuation management directly relates to the concept of community resilience because resilient communities "…will suffer fewer losses and will recover more quickly when faced with a hazardous event" (Scherzer et al. 2019, p. 1). For example, in a study on climate disaster resilience in urban cities in coastal Asia, Razafindrabe et al. (2009) found that in certain cities, poor evacuation and early-warning plans impacted resilience negatively in their resilience measurement aggregate. Further, much of the policy recommendations carried out by the researchers discussed the need for improved evacuation planning and early-warning systems for the cities that were analyzed (Razafindrabe et al. 2009). Although Razafindrabe et al. (2009) analyzed a component of evacuation planning with resilience, most current evacuation research has primarily focused on evacuation behavior and intentions as opposed to the relationship to the resilience of individuals and communities. To date, there is still a gap in the research with regard to how evacuation management connects to community resilience and the overall importance of that connection. The next section will provide information on community resilience in order to build connections between hazard evacuation management and community resilience.

3 Community Resilience

3.1 Conceptual Understandings of Resilience

The term resilience has become convoluted due to multiple and differing definitions of the term spread across various disciplines over the last half-century. The case is no different within the context of disaster and hazards research among the social sciences as there is not a widely accepted definition (Adger 2000; Cutter et al. 2008;

Klein et al. 2003; Manyena 2006). In this section, I define resilience using a hazards research approach. In hazards research, according to Kendra et al. (2018), "…resilience is primarily focused at the community level" (p. 91). Therefore, in this section, I will be directing my attention to community resilience as it relates to hazard evacuation management. There are also two schools of thought as it relates to resilience. Resilience has often been broadly viewed as outcome-oriented or process-oriented (Kaplan 1999 as cited in Manyena 2006). A process-oriented approach for this section will be used because the process-oriented approach places an emphasis upon the holistic course of action by which resilience occurs, which includes evacuation management.

3.2 Community Resilience Defined

Similarly to "resilience," the term community resilience often has mixed definitions with no clear consensus about how to define it (Patel et al. 2017). Therefore, for clarity I have defined community resilience as the capabilities of communities to withstand disaster while supporting effective responses to disaster (National Academies of Sciences, Engineering and Medicine 2019; Patel et al. 2017; Wells et al. 2013). This definition combines aspects of a few definitions provided in the research literature. Additionally, because this definition includes the phrase "supporting effective responses to disaster," the connection to evacuation management becomes clearer. As the literature in the previous section has shown, effective evacuation management can result in the protection of lives and reduction of risk (Rivera 2020; Zhang et al. 2019). Also, "[t]he concept of 'community resilience' is almost invariably viewed as positive, being associated with increasing local capacity, social support and resources, and decreasing risks, miscommunication and trauma" (Patel et al. 2017, p. 2). Therefore, effective evacuation management relates to and supports community resilience by definition.

3.3 Dimensions of Community Resilience

Community resilience can examine multiple scales – from looking at larger spatial areas such as counties and towns (Cutter et al. 2014; Cohen et al. 2017) to smaller spatial areas such as individual neighborhoods or wards (Aldrich 2012) – as well as multiple dimensions (National Academies of Sciences, Engineering, and Medicine 2019) and multiple elements (Patel et al. 2017, pp. 7–10). This multidimensionality is a key characteristic of community resilience (Beccari 2016; Cutter 2016; NRC 2012 all as cited in National Academies of Sciences, Engineering, and Medicine 2019). Thus, the multidimensionality of community resilience is all-encompassing in terms of the resources that are available to the community. According to the National Academies of Sciences, Engineering, and Medicine (2019), the dimensions can also be referred to as “capitals” (p. 15). Conceptually, community capitals “…are grounded in community development and disaster research…” (National Academies of Sciences, Engineering, and Medicine 2019, p. 15) and include six types of capital including natural or environmental, built or infrastructure, human and cultural, financial or economic, social, and political or institutional. While each form of capital plays a pivotal role in community resilience, I am focusing attention on two specific forms of capital: social capital and institutional capital. I am focusing on those forms of capital because they best exhibit the connections between hazard evacuation management and community resilience. The next section discusses each of the two forms of community capital in further detail and provides connections to hazard evacuation management within the context of community resilience.

3.4 Community Capitals

3.4.1 Social Capital

The first type of community capital I am discussing in relation to community resilience and hazard evacuation management is social capital. Social capital has been explored and defined among multiple contexts (see Kadushin 2004; Lin 2001; Sherrieb et al. 2010; Woolcock and Narayan 2000) and has also seen a dramatic increase in importance to disaster research (Aldrich and Meyer 2015; NIST 2016; Ritchie and Gill 2007). For the purpose of this section, social capital will refer to “the social networks and connectivity among groups and individuals within a community” (National Academies of Sciences, Engineering, and Medicine 2019, p. 15). For the purposes of community resilience, the primary focus will be on the elements Norris et al. (2008) and Patel et al. (2017) provide, which include social support, participation, and community bonds as well as community communication.

Social support is formed by the intimate bonds created through informal networks with friends and family members (Sherrieb et al. 2010). Building upon the informal networks of social support, social participation refers to the structured and formal relationships individuals have with groups and organizations, which contain professional, economic, health-related, and social participation (Sherrieb et al. 2010). Finally, the establishment of community bonds through an individual’s participation in community activities. These aspects of social capital are critical for building community resilience. As communities begin to form stronger networks and are better connected, there can be positive effects when facing a crisis (Patel et al. 2017). In addition, strong community bonds and community engagement are critical to the social capital of a community (NIST 2016). Strong community bonds and engagement will allow communities to have “…a collective belief in the potential threat from hazard(s) and the value of investing in resilience” (NIST 2016, p. 11). Therefore, communities that exhibit these connections will have a better understanding of how to effectively respond to risks (NIST 2016). In terms of evacuation management, as the social capital of communities increases as evidenced by NIST (2016) and Collins et al. (2018), the ability to plan and prepare for hazard events can also increase. For example, Collins et al. (2018) found that "the density and diversity dimensions of social connections have a significant effect on the decision to evacuate…" (p. 467). Finally, NIST (2016) explains that Cedar Rapids, Iowa, prepared plans and executed evacuations during flooding in 2008 and there was no loss of life (NIST 2016). Strong social ties within the community following the flooding prompted community engagement processes that developed further resilience planning within the city (NIST 2016).

In addition to strong community ties, community communication networks are a critical aspect of social capital in a community. Strong communication networks and risk communication strategies are essential for community resilience (Cartier and Taylor 2020; Chandra et al. 2013; Patel et al. 2017; Spialek and Houston 2018). In terms of hazard evacuation management, prior research has shown that having strong social networks will increase the likelihood that individuals will respond to warnings (AEP 2017) and thus evacuate (Sadri et al. 2017). In their research, Sadri et al. (2017) found that social network sizes of three or more have a positive effect on evacuation decision-making. They go on to note that this positive effect "…suggests the significant effect of social capital in the form of social ties in reinforcing the making of good resilience-related decisions" (Sadri et al. 2017, p. 10). Finally, social network research has increased its focus on social media because usage of social media has grown exponentially over the past two decades (Knoke and Yang 2020). This growth in use has prompted greater research on social media use in disaster (Lovari and Bowen 2019; Martín et al. 2020; Palen and Hughes 2018; Roy et al. 2020; Yan and Pedraza-Martinez 2019). Research on social media use in disaster has grown because of the implications it can have for emergency management (Palen and Hughes 2018; Silver 2019). Social media use by emergency management personnel allows for two-way communication with the general public (Palen and Hughes 2018). For evacuation management specifically, these communication channels can allow for emergency management personnel to distribute information such as warning messages and risk communications to assist in evacuation (Lovari and Bowen 2019; Yan and Pedraza-Martinez 2019).

3.4.2 Institutional Capital

The second type of community capital I am discussing in relation to community resilience and hazard evacuation management is institutional capital. Some of the major components to institutional capital in relation to hazards and disaster research are governance and leadership, experience in disaster response and recovery, and the capacities of emergency management (National Academies of Sciences, Engineering, and Medicine 2019). These components also reflect critical aspects of community resilience. Patel et al. (2017) discussed both governance and leadership and preparedness – in terms of experience and emergency management capacity – as key elements of community resilience.

Governance and leadership are crucial to the handling of disaster by communities. Patel et al. (2017) provided a review of governance and leadership with respect to community resilience and note in the research reviewed that community services being effective, efficient, and capable were important to community resilience. Effective, efficient, and capable community services as part of community resilience have direct relationships to hazard evacuation management. This is exemplified through the adaptation seen during the waterborne evacuation (see Kendra and Wachtendorf 2016) and rerouting of subway trains for evacuation (PWC 2013 as cited in NIST 2016) in the aftermath of September 11, 2001, in New York City.

Experience in disaster response and recovery and the capacities of emergency management are also elements of institutional capital. Both of these elements rely on proper preparedness as a piece of community resilience (Patel et al. 2017). Prior research has provided evidence of preparedness as a piece to community resilience as it relates, definitionally, to institutional capital. For example, research has discussed using past experiences in disaster to provide insight for future disaster preparedness (see Patel et al. 2017, Supplementary Material Table 2 for a full review). Proper preparedness can also include aspects within a community's emergency management system such as hazard mitigation plans, emergency services, emergency response plans, and hazard evacuation planning (Cutter et al. 2008). Indeed, Wu et al. (2019) noted that an evacuation plan is typically a significant part of the overall emergency planning of a community. Therefore, preparedness exhibited by emergency management within hazard evacuation management can support community resilience by reducing risk and reducing the probabilities that members of the community could face during a disaster.

4 Case Studies on Evacuation and Resilience

In the following section, two case studies are presented to illustrate the relationship between hazard evacuation management and community resilience. As stated prior, I chose these case studies in order to illustrate different evacuation management decisions and outcomes. Therefore, each case study will provide insight into how evacuation management decisions and community resilience relate to one another. The first case study focuses on the evacuation of New Orleans, Louisiana, and surrounding Gulf Coast areas before Hurricane Katrina in 2005. Secondly, I provide a case study on Hurricane Harvey to explore the relationship between evacuation management and community resilience during a storm where no evacuation orders are given.

4.1 Hurricane Katrina

On August 29, 2005, one of the largest disasters in the history of the USA took place along the Gulf Coast. Hurricane Katrina made landfall as a category 3 storm east of New Orleans just after 6:00 a.m. with winds upward of 150 miles per hour and a storm surge of 8–22 feet (Duram 2018; Huang et al. 2017). With a hazard of such magnitude, proper evacuation procedure and management is of the utmost importance. While some may argue that the evacuation of New Orleans, Louisiana, and surrounding areas in Louisiana and Mississippi was a success – despite media portrayal – due to the amount of people that were evacuated and the lower than expected deaths (see Haney et al. 2010; Schmidlin 2006), others note that there were systematic failures across the board during the evacuation process and overall emergency management (GPO 2006; Wolshon 2006). Due to such differing interpretations, the evacuation and emergency management processes cannot be deemed "positive" or "negative" in strict terms but should rather be looked at as simply problematic.

Three days prior to Hurricane Katrina making landfall, the Governor of Louisiana declared a state of emergency and sought help from FEMA. The Governor's state of emergency alongside predictions and warnings from meteorologists and the NWS allowed individuals and communities to begin evacuation from the potential impact zone. In New Orleans, however, the city's Mayor, Ray Nagin, did not announce a mandatory evacuation order until the day before the storm made landfall (Duram 2018). Although there were no mandatory evacuation orders for New Orleans until a day before the storm made landfall, state officials in Louisiana had evacuation plans[2] that had been previously tested for deficiencies by way of other storms that largely missed Louisiana and New Orleans, specifically (Wolshon 2006). These evacuation plans that had already been prepared allowed for government officials to plan accordingly for the amount of traffic that would be experienced going outbound from New Orleans. Following the emergency declaration from the Governor of Louisiana for Hurricane Katrina, these plans were put into action. Louisiana Department of Transportation data showed elevated volume of traffic leaving New Orleans westbound on I-10. In addition, the peak vehicle flow rate out of the city was 2500 vehicles per hour, hundreds more than the 3-week average prior to the evacuation (Wolshon 2006). The plans put into place led to the evacuation of approximately 80–90% of the population of New Orleans and surrounding impact areas. Further, more than a million total people were forced to leave both Louisiana and Mississippi (Duram 2018; Wolshon 2006). While it has been estimated that over one million people were able to evacuate New Orleans and surrounding areas of potential impact, an estimated 130,000 people were unable to evacuate the heavily impacted four-parish regions of New Orleans, and approximately 65,000 of those who did not evacuate were stranded in floodwater due to the storm surge breaching the levee system (Boyd et al. 2009). Many of these individuals were those who were

[2] Including plans regarding traffic coordination and contraflow (Wolshon 2006). See Wolshon and McArdle (2011) for further discussion on traffic impacts, reentry patterns, and evacuation routes.

unable to evacuate because of a lack of transportation or populations low in mobility such as the elderly or those who were hospitalized (Russell 2005 as cited in Wolshon 2006 p. 32–34; Wolshon 2006). In a congressional hearing about 6 months following Hurricane Katrina, Senator Joseph Lieberman from Connecticut pointed out the failures of the pre-storm evacuation that lead to a problematic post-storm evacuation of citizens that remained in New Orleans:

> No one acted to ensure that the pre-landfall evacuation of New Orleans would be aggressive, let alone complete. Not the city, whose citizens were at risk. Not the State, which was responsible under the plan for arranging transportation for evacuees. And not the Federal Government, which had the authority to assist in the event of a catastrophe but instead stood on the sidelines as the hurricane approached. (GPO 2006, p. 4)

These failures at all institutional levels created catastrophic consequences for the secondary evacuation as there was a lack of transportation because of flooding as a result of the levee failures, unpassable streets due to damage, and finally failures in public communication (Boyd et al. 2009).

Now that I have discussed the hazard evacuation management processes, I aim to make clear its relationship to community resilience. Overall, the evacuation management process saw partial successes and partial failures in regard to community resilience. Drawing from the prior research on community resilience and the "community capitals" (National Academies of Sciences, Engineering, and Medicine 2019), involved, institutional resilience was one of the partial successes. For Hurricane Katrina, there were systems in place such as evacuation plans that had been continuously edited as more information presented itself following practice runs during times when hurricanes were slated to hit the Louisiana coast, but ultimately missed. There were also vehicle rate increase plans put into place to streamline the evacuation process, making it easier for as many vehicles to leave the city as possible and as quickly as possible. As discussed in the previous sections, evacuation planning and emergency management experience are a key component to institutional capital and the building of community resilience (Cutter et al. 2008; National Academies of Sciences, Engineering, and Medicine 2019; Patel et al. 2017; Wu et al. 2019) However, with partial successes come partial failures. In terms of institutional capital (National Academies of Sciences, Engineering, and Medicine 2019), emergency management was also a partial failure in the sense of transportation failures noted, and that planning did not account for those populations that were most vulnerable – elderly and vulnerable health status – as there were many that remained in the city (Boyd et al. 2009).

As a part of social capital, communication networks and proper risk communication are critical for enhanced community resilience (Chandra et al. 2013; Patel et al. 2017; Spialek and Houston 2018). There was communication pre-storm to begin the evacuation process set forth by the Governor declaring a state of emergency 3 days prior to landfall, which can be determined a partial success. However, as discussed earlier, the Mayor of New Orleans did not issue a mandatory evacuation order until 1 day prior to landfall (Duram 2018). Previous research has shown that communication from officials has the potential to impact evacuation behavior (Burnside 2006;

Fischer et al. 1995; Gray-Graves et al. 2011; Howard et al. 2017; Lamb et al. 2013; Meyer et al. 2018; Sun et al. 2017). Therefore, there could have been potential to evacuate more people from the city of New Orleans had an evacuation order been given sooner.

4.2 Hurricane Harvey

Hurricane Katrina saw emergency management personnel put evacuation procedures into place. This was not the case for the city of Houston, Texas, during Hurricane Harvey. Hurricane Harvey made landfall near Rockport, Texas, on August 25, 2017. At the time the storm made landfall, it was categorized as a category 4 storm. In addition to the damage from the hurricane itself, rainfall over Texas during the course of the next week caused unprecedented flooding. According to FEMA (2017), more than 19 trillion gallons of rainfall fell over parts of Texas. Houston, Texas, was impacted greatly as each of the area's 22 watersheds experienced flooding because of the largest amount of rainwater accumulated due to one storm – nearly 52 inches (FEMA 2017; Sebastian et al. 2017).

Evacuation procedures for Hurricane Harvey and the subsequent flooding were notably different than for previous comparably sized storms. The fourth largest city in the USA, Houston, Texas, was not put under any – voluntary or mandatory – evacuation orders as Hurricane Harvey was threatening the Texas coast (Sebastian et al. 2017, p. 25, 62). Although Houston Mayor Sylvester Turner advised individuals and communities in Houston to stay in place, Texas Governor Greg Abbott stated the opposite, telling people in the Houston area to leave if they had the ability (Domonoske 2017; Sebastian et al. 2017). Other communities did have evacuation orders in place based upon differing factors such as geographic and local circumstances. Following the storm, multiple news outlets questioned why there was no evacuation for a storm that size and one that carried such a flood risk (Andone 2017; Domonoske 2017). The answer stems from prior evacuation experience following Hurricane Katrina in 2005, when Hurricane Rita threatened Houston. During Hurricane Rita, in attempts not to recreate the negative situations seen with the evacuations (or lack thereof) of Hurricane Katrina, an estimated 2.5 million people evacuated urban and suburban areas of southeastern Texas (Carpender et al. 2006). As all of the vehicles left Houston in the evacuation effort, there were many accidents in addition to people dying because of the indirect activities due to the evacuation process (Carpender et al. 2006). After the mass exodus from Houston, Hurricane Rita changed course and the effects were not as great on Houston as projected. In fact, the death toll from the evacuation was higher than the storm itself (Domonoske 2017). With this experience in mind, city officials in Houston made the decision not to evacuate the city, despite the Governor's concerns and warnings. Instead, Houston city officials decided to rely upon rescue efforts and citizen knowledge to evacuate without warning citing that individuals living within flood plains should not require warnings to evacuate when intense rainfall is forecasted (Andone 2017).

In the case of Hurricane Harvey, the connection between community resilience and evacuation management is intriguing because of the lack of evacuation orders from city officials in Houston. First, in terms of social capital, the social networks within the city could be considered a strength in relation to community resilience. Community members worked together to provide rescue operations for individuals whose homes had been flooded. In addition, community organizations and grassroots efforts were taking place with recovery efforts and also generated community initiatives to help with response operations. One such example was the use of the "walkie-talkie app" Zello, to coordinate rescues, recruit and train volunteers, and connect people with resources they needed (Sebastian et al. 2017). On the other hand, communication – in terms of building strong community resilience – was unclear due to the differing messages from the Governor and Mayor (Domonoske 2017; Sebastian et al. 2017). Finally, institutional capital could also be seen as negative with regard to evacuation management because an evacuation plan was not implemented – even with prior experience with Hurricane Rita and the ability to adjust plans a decade later. Also at the institutional level, there were criticisms of local officials being "underprepared" for the storm (BBC 2017).

Although Hurricane Harvey provided insight to the relationship between community resilience and hazard evacuation management, there are still further research needed on this relationship and large-scale storms with no evacuation orders in place.

5 Summary and Conclusions

As this chapter has presented, hazard evacuation management and community resilience are connected because of relationships between aspects of community capitals and how evacuation management is defined. Yet, much of the current research in the hazards and disaster literature focuses on the two as separate entities rather than as related. Therefore, background research on hazard evacuation management – a significant area within the field – has been provided. By doing so, the gap in the literature surrounding community resilience and evacuation management was identified. Due to this gap in the research, background on community resilience to build connections between the different dimensions or "capitals" of community resilience and hazard evacuation management was provided. Finally, two case studies were examined: Hurricane Katrina and Hurricane Harvey. These case studies were used to provide concrete, applied examples of evacuation management to illustrate how community resilience is related to evacuation and to give insight as to how differing evacuation management procedures relates to differences in community resilience.

As hazards continue to grow in number and intensity, hazard evacuation management and community resilience grow more importantly. The cases of Hurricane Katrina and Hurricane Harvey demonstrate the importance of this particular relationship and provide researchers and policy makers with background on how to manage evacuation effectively while also promoting community resilience. However, there should be further attention paid to hazard evacuation management and community resilience as a topic of research. This further research should aim to continue examining the relationship between hazard evacuation and community resilience.

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Chapter 17
Developing Factors for Socio-Ecohydrological Resilience

Lauren Victoria Jaramillo, Mark Charles Stone, and Melinda Harm Benson

Abstract All life relies on water. The abundance, scarcity, and capacity of hydrological systems impact resilience and vulnerability of social and ecological systems everywhere. Socio-ecohydrological systems encompass this convergence. Resilience theory provides a structured way of defining these systems, developing factors, and identifying points of strength and vulnerability. Defining these systems and the influential factors driving them is necessary in order to understand system behavioral response to stresses. This fundamental knowledge of a system can then be used to inform any potential disaster risk reduction. Comprehensive methods of evaluating resilience help support decision-making and water resources management. Two approaches are presented. One approach presented is an internal assessment in which the system is defined using a *resilience lens*, and another is an external assessment in which the resilience of the system is evaluated after the system framework has been developed. These contrasting approaches to ecohydrological resilience are then implemented in two case studies, Nepal and New Mexico, USA, where diverse conditions exemplify the use of these methods for a range of system conditions and stresses.

Keywords Vulnerability · Adaptive capacity · Framework · Transformation · Ecohydrological · Resilience · Decision-making

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1 Introduction

Ecohydrological systems are complex and dynamic, with influences from physical to biological, cultural to economic. Efforts to understand the vulnerability of riverine landscapes demonstrate the need for interdisciplinary work addressing hydrology and ecology with a focus on resistance, resilience, and buffering capacity (Janauer 2000; Zalewski et al. 2016). These systems have dramatic impacts on human safety, environmental safety, and natural resources. Resilient systems are able to tolerate the stresses of development, disasters, and the changes in between. Resilience theory provides a structured way of defining a system and identifying points of strength and vulnerability (Hosseini et al. 2016). Defining the system and influential factors is necessary to understand system behavioral response to stresses. This fundamental knowledge of a system is necessary for disaster risk reduction (Chang and Shinozuka 2004). Comprehensive methods of evaluating resilience help support decision-making and water resources management.

This chapter discusses frameworks for developing various factors, their influences, and constraints necessary to assess socio-ecohydrological system resilience. Two case studies are presented to illustrate these frameworks.

2 Definitions and Theory

Resilience has been defined and largely accepted as the ability of a system to cope with external stresses and disturbances from social, political, and environmental change (Folke and Berkes 2000). Vulnerability can be defined as the exposure to those same stresses and disturbances (Chambers 1989; Adger 2006). Resilience and vulnerability provide different perspectives and ways of illuminating strengths and weaknesses of a system. This is because resilience, vulnerability, and adaptive capacity are each facets of the same system response to external forces and drivers (Gallopín 2006). These relationships are important to environmental systems because there is a need to understand system responses to disturbances, which can be described by these relationships.

Environmental systems can be classified in many ways depending on the specific nature of the system and purpose of the work. Some system classifications include ecological, hydrological, socio-ecological, socio-hydrological, and ecohydrological, but all are recognized as complex adaptive systems. The purpose of this chapter is to address ecohydrological systems and the purpose of this handbook is to *build* resilience. For this chapter, *building* resilience is achieved by increasing adaptive capacity of the system and/or by reducing the exposure to system stresses. It is necessary to consider the human component to *build* resilience of *impacted* or *impaired* systems, and therefore this chapter will address *socio*-ecohydrological systems.

Socio-ecohydrological systems are inherently unique. Their many differences include ecology, climate, geography, and culture, all of which require consideration when evaluating their resilience. These differences reflect in variable behaviors, responses, and vulnerabilities and therefore the resilience of the system. These differences prompt a need for a detailed understanding and individualized assessment of each system. However, many systems share an increasing vulnerability to modern growth and globalization (Walker and Salt 2012). This commonality demonstrates a need for an organized approach that can be applied to these distinct systems. This chapter works to serve as a guide to address this need.

Information about these individual system classifications (i.e., ecological, hydrological, socio-ecological, socio-hydrological, ecohydrological, etc.) are relevant and can provide clarity to the dynamic and complex nature of socio-ecohydrological systems. Functionality and organization of these systems evolve through the growth (r), conservation (k), collapse (Ω), and reorganization (α) phases of the adaptive cycle shown in Fig. 17.1a. The adaptive cycle models the system regime because it goes through phases and still retains its identity. System behaviors such as strength of internal connections, flexibility, and resilience are different from one phase to another (Walker and Salt 2012). Panarchy, the framework of natural rules connecting hierarchical adaptive cycles, also applies and establishes connections and relationships between systems at different scales and is shown in Fig. 17.1b (Gunderson and Holling 2002). An example of a set of scales in a socio-ecohydrological system would be a watershed, tributary, and lake. Investigating resilience at various scales reveals behaviors and triggers specific to that scale as well as feedbacks between scales (Allen et al. 2014). Cross-scale interactions are critical, as resilience of a system defined at one scale depends on influences from scales above and below (Woods and Branlat 2006).

To develop an understanding of the system behavior and response, it is necessary to develop an understanding of the system disturbances which manifest as shocks or stresses. Shocks for socio-ecohydrological systems include events such as wildfire, landslides, hurricanes, earthquakes, and oil spills. Often these events lead to sustained stress such as poor water quality conditions for a prolonged period of time (Benson and Craig 2017).

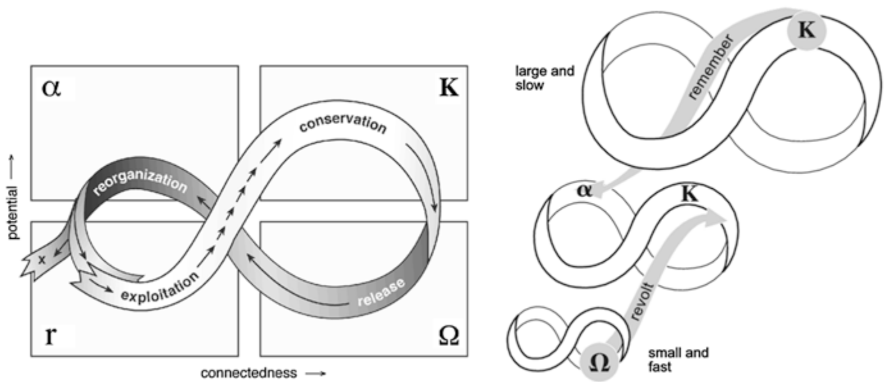

Fig. 17.1 (**a**) Adaptive cycle and (**b**) panarchal perspective. (Gunderson and Holling 2002)

An example of an event leading to sustained stress for a socio-ecohydrological system is wildfire which alters the landscape leaving a hydrophobic ash layer causing debris flows and impacting ecosystems and drinking water supplies (Certini 2005). When these system disturbances occur, the system is forced into one of the following threshold responses:

1. *No threshold response* – Most system variables observe this linear response with no dramatic change in behavior (e.g., diverting water from reservoir storage).
2. *Step change* – This response occurs when a small change in a controlling variable leads to a large change in the system once a threshold has been reached. It has a reversible response crossing back (e.g., heat release from water changing to ice and then heat absorption back to water; a brief large reduction in river flow leading to loss of aquatic ecosystem, which reestablishes with return of flow).
3. *Altered stable state* – This response is a shift to a different regime (e.g., algal blooms and fish kills with the introduction of phosphorus in a lake system).
4. *Irreversible change* – This response is caused when a threshold is crossed, and the system is shifted into a different regime permanently (e.g., species extinction).

Understanding system-specific thresholds is crucial to the state of the system as they characterize the *safe operating space* or limits of the system or regime (Walker and Salt 2012). Efforts to reduce the risk of crossing a threshold are addressed by *building* resilience. These thresholds can also shift because of other changes in the system making it even more challenging to characterize them. If these critical thresholds are crossed, the system will no longer function in the same capacity.

Although identifying thresholds can prove difficult, triggers can be used to identify the approaching or crossing of a threshold. Trigger indicators are monitored to recognize when a variable or system is approaching a threshold (Gunderson et al. 2010). Triggers signify changes to regimes, such as a shift in annual streamflow patterns, as well as shifts in phases of the adaptive cycle, such as changing from winter to spring (Walker and Salt 2012).

Crossing thresholds can be avoided, or systems can be engineered to cross back into a desired regime by utilizing their adaptive capacity (Walker and Salt 2012). Coping ranges or adaptive capacities that absorb shocks and stresses caused by disturbances are flexible and change like the dynamic systems they are a part of (Smit and Wandel 2006).

Socio-ecohydrological systems' adaptive capacity can manifest in several ways including physical capacity, natural capacity, human resource capacity, and economic capacity. The Nature Conservancy Rio Grande Water Fund, a collaborative charter which focuses on multi-entity efforts to mitigate wildfire risk on forested uplands and river restoration in New Mexico, is a contributor to both human resource capacity and economic capacity (Benson and Craig 2017). The collaborative includes public and private partners that cross social, managerial, and governing boundaries providing an opportunity for businesses, organizations, and agencies to work together. Funding for this project is secured from both public and private investors, and its nature allows for projects to take place on public and private land, which is often a major limitation with large watershed-scale initiatives. Other examples of these capacities are reservoir storage as physical capacity, mountain snowpack as natural capacity, sense of community as human resource capacity, and flood emergency funding as economic capacity.

The next section presents some of the common issues and challenges associated with socio-ecohydrological systems.

3 Socio-Ecohydrological Resilience Issues, Challenges, and Considerations

There are many challenges unique to each socio-ecohydrological system; however one very common shared issue is the *silo issue*. Every system has stakeholders with a breadth of knowledge from governing regulations to scientific and financial resources and to traditional ecological knowledge. Often, a platform for the easy sharing of information does not exist. For example, an entity may have traditional ecological knowledge passed down for generations but does not share this knowledge and therefore is not included in the decision-making. Lack of communication and collaboration among stakeholders regarding financial and other information resources can result in redundant and inefficient efforts. There may be ongoing land restoration work that is successfully reducing the risk of severe wildfires, but the responsible parties may be unaware of available funding to continue the program. Though there is funding available, the lack of knowledge by management may put the program in jeopardy. A mechanism to cross domains is needed to avoid this situation. It is critical to look at resilience of all domains, social, ecological, and hydrological, coherently when considering socio-ecological resilience.

Disturbance is part of systems and system development. Preservation and prevention efforts can potentially cause larger disturbances. A prime example can be seen in the fire-suppression management practices enacted in the USA in the twentieth century, which have evolved the forests into dense and water-stressed areas at high risk of fire. These practices wrongly assumed natural resource managers have serviceable knowledge of ecological systems and can predict impacts of a proposed action (Benson and Garmestani 2011). Strategies such as *pathology of natural resource management* (Holling and Meffe 1996), which focus on preservation at all cost, may cause accumulation of disturbances that hit socio-ecohydrological systems at larger scales (Berkes et al. 1998).

Once the resilience of a socio-ecohydrological system has been evaluated, management of the system should include monitoring resilience. Consideration for monitoring, adjustment, and engagement for long-term planning is needed since resilience enhancement is the primary objective for developing factors and performing these assessments (Wang and Blackmore 2009). While there are many different ecosystem services, all are closely linked to one another by water. The system can be addressed as a whole, focusing on ecological health/ecosystem health. Managing and regulating limitations and abilities must be taken into consideration, as they may conflict with aspects of resilience practices (Gunderson and Light 2006). While most institutions focus on monitoring obvious indicators, few have the flexibility to direct resources to monitor emerging properties efficiently and cost-effectively (Benson and Garmestani 2011).

It is important to recognize domain value in order to secure the capacity to sustain life. Establishing the human benefit demonstrates the interconnectivity and is one clear motive to assess and maintain socio-ecohydrological resilience. The goods produced by terrestrial and aquatic ecosystems such as crops (agroecosystems), timber (forest ecosystems), and grazing (grassland ecosystems) should be acknowledged. The ecosystem services, such as creating buffer zones from natural hazards and disturbances, regulating carbon dioxide through photosynthesis and respiration, and improving water quality through denitrification, also add value. These systems have hydrologic value as they provide hydrologic services (Brauman et al. 2007), contributing to the amount and location of water availability with processes such as groundwater infiltration and retention of surface water runoff.

Unique solutions have cascading effects on the socio-ecohydrological system. The Nature Conservancy Rio Grande Water Fund is a project that exemplifies that effect on mitigating wildfire risk in the semiarid landscape. The initiative launched in 2014. By 2018 the Rio Grande Water Fund treated 108,000 acres with thinning, controlled burns, and managed natural fires (The Nature Conservancy of NM 2018). This collaborative charter was fostered by the Nature Conservancy of New Mexico, a nonprofit organization, to focus multi-entity efforts on forested uplands and river restoration. The project allows any entity to join as a collaborator and has grown a large network and even become a model to be adopted by other socio-ecohydrological systems including California, Colorado, Idaho, Montana, Nevada, and Cape Town, South Africa (The Nature Conservancy of NM 2018).

The next section utilizes this information to present a method for developing factors for assessing and building ecohydrological resilience.

4 Methodology

Investigating ecohydrological resilience of a system requires a detailed understanding of the system which can be described by a framework. Fundamental aspects and how they connect to the rest of the system can be presented in a framework which can be a resilience theory-based framework or a system process-based framework. The framework identifies key variables of the system and describes how the variables are related to other components of the system. Developing these variables and describing their system functionality in a framework is necessary to understand system behavioral response(s) to stresses, including disasters. This fundamental system knowledge is necessary for any potential disaster risk reduction.

The framework is constructed after aspects, components, and variables of the system have been identified and characterized. Identification and characterization is accomplished through the following procedural steps that have been adapted from previous work including Allen et al. (2014), Cosens and Gunderson (2018), Gunderson et al. (2010), and Walker and Salt (2012):

1. *Define the system* – In order to define the system, the scope of the assessment must be well established. What is the primary issue of concern for the socio-ecohydrological system? Based on the primary issue, what is the goal? Establishing a clear goal or desired outcome is achieved by targeting either general resilience or specified resilience (Walker and Salt 2012). General resilience is the ability of the entire system to absorb all kinds of disturbances. An example of specified resilience is the survivability of cottonwoods from a reduction in peak flow releases from an upstream reservoir.

   Establishing boundaries is another requirement of defining the system. The boundary types include:

   a. Physical boundaries (e.g., watersheds, etc.)
   b. Temporal boundaries (e.g., 5-year, 10-year, 25-year periods)
   c. Governing/managerial boundaries (e.g., water utility authorities, tribal, federal, state, city, county, state, national, districts, provinces)
   d. Social boundaries (e.g., urban, rural, suburban, cultural, religious)

      Investigating these boundaries will help identify larger- and smaller-scale systems and their cross-scale interactions
2. *Define the stress(es)* – Setting the target of either general or specified resilience provides the opportunity to define stress(es) of the system. With general resilience, there are many stresses the system will experience, while specified resilience will prompt only a couple of stresses. How often does the disturbance occur and is the frequency changing? What component of the system is most effected and what is the severity? Are there anticipated future disturbances? Answering these questions can help characterize the identified stress(es) of the system.
3. *Determine thresholds, triggers, and capacities* – All three domains (social, ecological, and hydrological) should be considered when listing potential thresholds of concern. The degree of certainty for the threshold should also be noted. Typically, many variables are influenced by a disturbance; a trigger indicator or threshold-associated slow-changing variable may help manageably track the system status (Gunderson et al. 2010). What are the components that contribute to the adaptive capacity? What contributes to physical, natural, human resource, and economic capacity? Listing the contributors to adaptive capacity helps identify the ability and flexibility of the system.
4. *Assess vulnerability, resilience, and adaptive capacity* – The information developed over the previous steps is used to concisely assess the system's resilience. With these assessments the resilience can be periodically monitored to maintain an understanding of the system status. This step is used to address the following questions: How vulnerable is the system? Based on the adaptive capacity of the system, how resilient is the system to the defined stress(es)? What adaptive capacities could be addressed to *build* the resilience of the system?

These procedural steps have been applied qualitatively to quantitatively in many ways (Hosseini et al. 2016) and generally follow one of two approaches presented in this chapter. One approach presented is an internal assessment in which the system is defined using a *resilience lens* and is discussed in Sect. 4.1. Another approach presented is an external assessment in which the resilience of the system is evaluated after the system framework has been developed and is discussed in Sect. 4.2. These different approaches demonstrate the flexible application of frameworks based on specific situations including system scale, geographical location, and knowledge about the system. Vulnerability assessment frameworks are more readily applied to built environments, while system frameworks are well aligned with system processes understood by the interconnectivity of socio-ecological systems.

4.1 Vulnerability Assessment Framework

Vulnerability assessment frameworks (VAFs) are needed because otherwise vulnerabilities of a socio-ecohydrological system might not be discovered until there is a shock to the system. In the case of India's driest regions, Ladakh shown in Fig. 17.2, a large spike in water demand brought on by domestic tourism has magnified the water stress. The unprecedented domestic tourism was brought on by the popularization of Lake Pangong in a Bollywood film, inadvertently linking pop culture to water exploitation and scarcity. The vulnerabilities that are now very visible are

Fig. 17.2 Map of Ladakh, India. (Spindle 2019)

domestic tourism population growth, mismanaged water resources, and increased drought conditions brought on by climate variations (Spindle 2019). The system is now in a reactionary high-risk state instead of a proactive state with time to explore solutions that would be revealed with the use of a VAF. Surges in high water-use visitors caused hotels to drill deeper wells, depleting the aquifer, impacting agriculture, and causing interstate legal battles over control of surface water from rivers (Spindle 2019). Surface water availability directly impacts aquatic, riparian, and terrestrial ecosystems. Increased water stress in India has revealed the socio-ecohydrological interconnectivity. This example of a cascading system response demonstrates the dimensional interconnectivity that is characterized in VAFs.

VAFs model the resilience of the system, framing the system in terms of stresses and capacities. The framework is developed during the procedural steps discussed in Sect. 4. The stresses and capacities of the system are represented as nodes in the framework. How those nodes relate to the vulnerability and resilience of the system depends on the adopted theoretical relationship. For example, resilience can be expressed as a relative complement of vulnerability, and it is dependent on adaptive capacity (Smit and Wandel 2006). Most often, socio-ecohydrological systems are evaluated in terms of water stress. There are many approaches to defining the relationship between water stress and adaptive capacity as they relate to vulnerability including a deductive method (Liu et al. 2013), averaging method (Alessa et al. 2008), simple quotient method (Fontaine and Steinemann 2009; Babel et al. 2011), as well as others. These methods create sub-parameters that characterize the contribution to overall water stress and adaptive capacity. The model outcome is the resilience of the system and can be either qualitative or quantitative. Discussion-based vulnerability assessment frameworks are the most commonly used to evaluate socio-ecohydrological systems. They allow for the easy collaboration of various stakeholders. Multiple parameters can be compared and assessed at once using thresholds in an index-based approach. VAFs provide a foundation that can be easily assessed and interpreted. However, VAFs have difficulty with linkages between benefits and negative impacts of a specific component because they are defined as contributing to either a stress or capacity.

An implementation of a VAF is presented in Sect. 5.1.

4.2 System Framework

Management and planning can mitigate system vulnerability by *building* resilience. As an example, co-restorative management practices are being used on the Four Daughters Ranch in Valencia County, New Mexico, USA. This ranch is a microcosm of the larger socio-ecohydrological system. The proactive soil health management practices being implemented demonstrate an understanding of a system framework as it pertains to ranching in New Mexico. These practices are targeted at preventing overgrazing of cattle pastures and causing a decline in soil health, which would push this system state across an irreversible change threshold by causing desertification, erosion, or the spread of invasive species or non-native plants. The Four Daughters Ranch management works closely with the New Mexico State University Agricultural College and US Department of Agriculture's Natural Resource Conservation Service to study soil, vegetation, and wildlife conditions (Davis 2019). Combining rural and urban conservation practices between these stakeholders is an example of knowledge sharing that can be represented as a well-functioning link between social and physical boundaries in a system framework (SF). The ranch prevents overgrazing of pastures by moving cattle using supplemental feed and solar-powered groundwater pumping to irrigate pasturelands.

Another example of a system approach to mitigating vulnerability and increasing system resilience can be seen in the water resources strategies employed in Albuquerque, New Mexico, USA. When Albuquerque discovered rapid declines in regional groundwater levels in the 1990s, its water utility authority realized that its primary source of drinking water was significantly smaller than had been previously assumed. The Water Utility Authority adapted which resulted in an aquifer rebound. Understanding SF linkages between aquifer drawdown and water usage moved the water utility authority to implement water conservation programs and develop additional surface water sources. Groundwater levels have risen 9 m (30 ft) to 12 m (40 ft) from 2008 to 2016 in the Middle Rio Grande River Basin, located in New Mexico. New Mexico is the most water-stressed state in the USA according to the World Resource Institute which was determined using a water stress framework (Hofste et al. 2019). Despite the fact that it is a water-stressed system, the system-level connectivity allowed the Water Utility Authority to build resilience through increasing adaptive capacity. Adaptive capacity was increased through municipal water-reduction programs and a water infrastructure project. The San Juan Chama River project has helped the city of Albuquerque reduce their groundwater withdrawals by 67% from 2008 to 2016 by diverting water from one basin to another as part of a diversion of water allocated to New Mexico under the Colorado Interstate Water Compact (Theresa 2019). SFs help build adaptive capacity of socio-ecohydrological systems by providing decision-makers with transparency of the system's interconnectivity. This increased understanding has led to complementary projects, policies, and initiatives that support system resilience.

Utilizing a SF approach, the system is defined by its drivers/components, and the resilience of the system is externally assessed after the system framework has been developed. A SF is flexible because it builds off existing models, networks, and/or frameworks. They can be adapted from conceptual or physical models that can be comprised of social, hydrological, and/or ecological components. They incorporate specified expert knowledge of the system such as a food web, water balance, or a physical process model. Once the system framework has been developed, it is assessed using the procedural steps discussed in Sect. 2.4. The procedural steps are enacted analytically in either a qualitative or quantitative manner by denoting which SF aspects (e.g., a node, a link, a scale) represent a resilience feature (e.g., stress, capacity, threshold). Quantitative approaches range widely and include general measures, probabilistic approaches, deterministic approaches, structural-based models, optimization models, simulation models, and fuzzy logic models (Hosseini et al. 2016). The ability to construct a framework based on existing process-based frameworks of models is a strong advantage of SFs. It is often difficult to anticipate, model, and describe the stress imposed on socio-ecohydrological system using a SF approach. Despite the limitations, these frameworks help identify areas for building adaptive capacity or reducing exposure to stresses or in other terms *building* resilience.

An implementation of a SF is presented in Sect. 5.2, a quantitative example which addresses the procedural steps through a sensitivity analysis (entropy analysis) of a network structure framework.

5 Case Studies

Two case studies are presented below to demonstrate the two approaches described in this chapter for developing factors for ecohydrological resilience. The vulnerability assessment framework method case study is based in Nepal, and the system framework method case study is based in the Gila River Basin, New Mexico, USA.

5.1 Indicator-Based Approach in Nepal: Vulnerability Assessment Framework

As previously mentioned, vulnerability assessment frameworks are constructed in many ways depending on the available information and primary objective. Indicator-based frameworks are one approach which have been used for vulnerability assessments on various spatial and temporal scales. They provide an immediate and clear understanding of the strengths and weaknesses of the system, allowing for potential discussions of interventions or even transformations. Indicators specified in the method should characterize the specific factors of interest. Huang and Cai (2009) developed a guideline for assessing freshwater resource vulnerability using indicators that reflect resources stress, population-based development pressures, ecological insecurity, and management challenges.

5.1.1 Study Area

This type of framework is particularly valuable in developing countries such as Nepal, where water resource development is rapidly increasing and driving changes in historical socio-hydrological systems. Socio-ecohydrological vulnerability in Nepal has been linked to poor management capacity as well as scarcity and exploitation of resources (Pandey et al. 2010; Babel et al. 2011). The impact of climate variations and increased glacial melt, geohazards such as the 7.8 magnitude Gorkha earthquake in 2015, and developmental pressures such as riverbed gravel and sand mining have drastically altered this large socio-ecohydrological system.

Historically, the summer monsoon which brings humid air and torrential rainfall is extremely important to economic prosperity in Nepal through the country's agricultural sector. The winter season is the driest season in Nepal, characterized by clear skies and cold temperatures from October to February (Shrestha 2000). This climate regime combines with Himalayan snow and glacial melt to establish the regions hydrologic regime for its five major river basins: the Sapta Koshi, Sapta Gandaki, Karnali, Mahakali, and the Southern Rivers. These basins make up a total of 147,181 square kilometers (Sharma and Awal 2013). As with many developing countries, data scarcity makes quantitatively describing the country's hydrology challenging, with many systems monitored inconsistently or not at all and lack of publicly available data.

Nepal is comprised of 75 districts, 14 administrative zones, and 5 development regions. In 2015, with the adoption of the constitution, Nepal has restructured into seven provinces. For the purposes of this study and the period of interest, Nepal's five development regions are evaluated: Eastern, Central, Western, Mid-Western, and Far Western (Fig. 17.3 and Table 17.1).

Fig. 17.3 Nepal's development regions

Table 17.1 Development region (Nepal and United Nations Development Programme, Nepal 2014)

No.	English name	Zones	Number of districts	Headquarters	Population	Area (km^2)
1	Eastern Development Region	Mechi, Koshi, Sagarmatha	16	Dhankuta	5,811,555	28,456
2	Central Development Region	Janakpur, Bagmati, Narayani	19	Kathmandu	9,656,985	27,410
3	Western Development Region	Gandaki, Lumbini, Dhawalagiri	16	Pokhara	4,926,765	29,398
4	Mid-Western Development Region	Rapti, Bheri, Karnali	15	Birendranagar	3,546,682	42,378
5	Far-Western Development Region	Seti, Mahakali	9	Dipayal	2,552,517	19,539

5.1.2 Method

The vulnerability assessment framework adopted for this study presents water resource-related disturbances as a function of water stress and adaptive capacity as shown in Fig. 17.4. The one primary stress of concern for this study is hydropower development, and therefore hydropower is built into the framework. The objective is to develop an indicator-based approach to assess socio-hydrological systems and apply the approach to evaluate the influence of hydropower development and other water influences in Nepal. Based on limitations in hydrologic data, the study adopts an effective and simplistic metric that has been applied in global and large-scale studies (Nilsson 2005; Anderson et al. 2008; Vörösmarty et al. 2010). The results are assessed with an emphasis on identifying specific areas in need of improvement and potential solutions.

Descriptions of the vulnerability index (VI), water stress index (WSI), adaptive capacity index (ACI), and their contributing parameters are presented below in Table 17.3 along with how each parameter value was calculated. Once all the parameter values are calculated, they are combined into two subindices and evaluated to determine the VI for each development region. The VI is compared to a range determining the level of vulnerability and is presented in Table 17.2.

5.1.3 Case Study Results

The resulting vulnerability assessment for all five Nepal development regions for 2011 is shown in Table 17.4. The parameters, subindices, and indices are calculated using the methods described in Table 17.3.

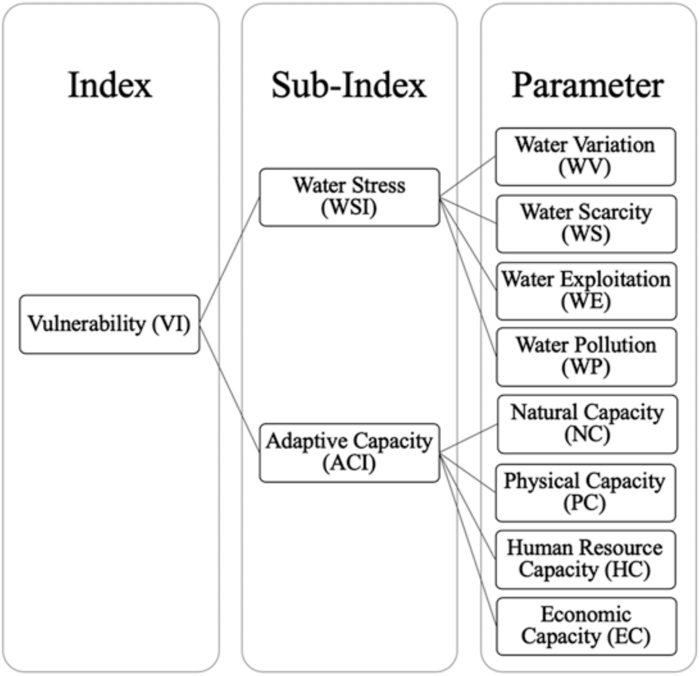

Fig. 17.4 Vulnerability assessment framework. (Adapted from Babel et al. (2011))

Table 17.2 Vulnerability index range

Vulnerability index range	Description
1 or less	Little to no vulnerability
1–2	Moderate vulnerability
2–3	Significant vulnerability
3 or greater	Extreme vulnerability

The radar plots shown in Figs. 17.5 and 17.6 are a graphical representation of the WSI parameters and ACI parameters for Nepal's development regions. Each parameter is represented on the axes, all of which originate at the center of the graph.

5.1.4 Discussion

Overall Nepal experiences moderate water stress as all development region WSIs ranged from 0.46 to 0.62. Nepal's Western and Central Development Regions experience the highest water stress of all five regions. Two major contributors are population density and hydropower development, as both regions have a large population and the majority of dams, as shown in Fig. 17.7. The population density causes an increasing demand on existing water and wastewater infrastructure due to rapid

Table 17.3 Vulnerability assessment parameters

Parameter	Equation	Description
Vulnerability index (VI)	$VI = \frac{\text{WSI}}{\text{ACI}}$	Vulnerability is defined as the relative complement of resilience. The vulnerability index (VI) is the quotient between the water stress index (WSI) and the adaptive capacity (AC)
Water stress index (WSI)	$\text{WSI} = \sum_{i=1}^{n=4} w_i WP_i$ where WP_i represents a water resource parameter and w_i is its associated weight	Water stress is represented by a normalized composite index or water stress index (WSI), which is composed of four weighted parameters: water variation (WV), water scarcity (WS), water resource exploitation (WE), and water pollution (WP)
Water resource variation (WV)	$WV = \frac{c_v}{0.4} \quad \forall c_v < 0.4$ $WV = \frac{c_v}{0.4} = 1 \quad \forall c_v \geq 0.4$	The water resource variation parameter (WV) accounts for potential temporal water shortages due to resource variability. WV is determined by evaluating the relative standard deviation or coefficient of variation (c_v) of annual precipitation data for a 10-year period and establishing a critical variance threshold
Water scarcity (WS)	$WS = \frac{\sqrt{p^2 + a^2 + f^2}}{\sqrt{3}}$ $f = \begin{cases} \frac{1700}{\text{WR per capita}}; \\ \forall \text{WR per capita} > 1700\text{m}^3/\text{year} \\ 1; \\ \forall \text{WR per capita} \leq 1700\text{m}^3/\text{year} \end{cases}$	Water scarcity (WS) is estimated using (p) percentage of the population with poor access to water, (a) adequacy of public drinking water facilities, and (f) water availability using the Falkenmark indicator method. Poor access, for this study, is defined as water sources other than piped or household connections (i.e., hand pumped, covered well, uncovered well, spout, stream/river, and others). The widely known Falkenmark indicator method (Falkenmark and Widstrand 1992) compares water availability to a minimum threshold of 1700 m^3/capita/year. The three indicators were aggregated using the standard error method

(continued)

Table 17.3 (continued)

Parameter	Equation	Description
Water resource exploitation (WE)	$WE = \frac{\sqrt{\rho_d^{\ 2} + \overline{D_r}^{\ 2} + L^2}}{\sqrt{3}}$ $\rho_d = \frac{\text{No.of dams}}{\text{Total area}\left(1000\text{km}^2\right)}$ $D_r = \frac{\text{Total freshwater Withdrawal}}{\text{Total freshwater available}}$ $\overline{D_r} = \begin{cases} \frac{D_r}{0.4}; \forall D_r < 0.4 \\ 1 \quad ; \forall D_r \geq 0.4 \end{cases}$ $L = \frac{\text{Area affected by soil degrade}}{\text{Total area}}$	Water resource exploitation (WE) is the beneficial use of water resources and its impact on sustainability. Beneficial use is characterized by energy harvesting, agricultural and industrial use, and potable consumption. WE is calculated using the standard error method. The indicators are dam density (ρ_d), normalized water resource development rate ($\overline{D_r}$), and land degradation due to erosion, chemical deterioration, and physical deterioration (L). The water resource development rate (D_r) is the ratio of total water use to water available. D_r is normalized by a critical threshold of 0.4 established by the UN Commission on Sustainable Development (Kjellen and McGranahan 1997)
Water pollution (WP)	$WP = \frac{\text{NPS pollution} + \left(100 - \text{WQI}\right)}{2}$ $\text{WQI} = 1 - \frac{\sqrt{F_1^2 + F_2^2}}{\sqrt{2} \times 100}$ $F_1 = \frac{\text{No. offailed Measures}}{\text{Total No. of Measures}}$ $\text{excursion} = \left(\frac{\text{failed test value}}{\text{guideline value}}\right) - 1$ $\text{nse} = \frac{\sum \text{excursion}}{\text{total no. of test}}$ $F_2 = \frac{\text{nse}}{0.01\text{nse} + 0.01}$	Water pollution (WP) is calculated using major river water quality data and domestic nonpoint sources (NPS) of pollution. Water pollution is calculated as the average of NPS pollution and water quality. For water quality, a modified water quality index (WQI), based on Global Water Quality Index Report (2007), is implemented in order to represent all available water quality measures, both physical and chemical (pH, TDS, DO, and BOD). Additionally, WQI has flexibility in terms of modification based on available data. The WQI compares the observed measures to the World Health Organization (2017) guideline targets with F_1, the excursion, the normalized sum of excursions (nse), and extent of failure of the excursion. The NPS pollution is calculated as the percentage of households that do not contain sanitation facilities (i.e., households without toilets)

Parameter	Equation	Description
Adaptive capacity index (ACI)	$\text{ACI} = \sum_{i=1}^{n=4} w_i CP_i$ where CP_i represents a capacity parameter and w_i is its associated weight	Adaptive capacity, like water stress, is represented by a normalized composite index or adaptive capacity index (ACI) composed of four parameters: natural capacity (NC), physical capacity (PC), human resource capacity (HRC), and economic capacity (EC)
Natural capacity (NC)	Natural capacity is the environment's ability to cope with water stresses. Major contributors to the capacity are glacier area, snowpack, waterbodies, and vegetated area, because of its ability to attenuate flows and runoff and provide hydrologic services contributing to the amount and location of water in a watershed (Brauman et al. 2007). Glaciers, snowpack, and waterbodies serve as a natural buffer and are an indicator of natural capacity. Vegetation cover is representative of forest area and wetlands and therefore an indicator of natural capacity (Babel et al. 2011). NC was estimated by calculating the percentage of hydro-available area (i.e., forest, shrub, water, and snow) using land use data	
Physical capacity (PC)	$PC = (w_I I + w_{DW} DW) + S$	The integrated capacity of farmers, local community members, and government entities to divert water to meet water demand is defined as physical capacity (PC). Physical infrastructure such as stream diversions, reservoirs, private and communal water distribution systems, and pumping contribute to the adaptive capacity of the socio-hydrologic systems. PC is estimated using irrigation coverage, drinking water coverage, and reservoir storage capacity. Reservoir storage capacity was calculated as the ratio between estimated hydropower dam storage and estimated total water use
Human resource capacity (HRC)	Human resource capacity is the sociological ability of a system that can help manage or adapt to water stresses or disturbances. This parameter is also an indicator of individual's ability to adapt to new conditions brought on by water stress. HRC is estimated as the average of literacy rate and economically active population (Babel et al. 2011; Pandey et al. 2011). The calculation of this parameter is limited in scope due to data scarcity but is a viable indicator of education. Education is an important contribution to human resource capacity which could be further characterized by indicators for communication, coordination, and planning for local communities and their government structures	
Economic capacity (EC)	$\text{GDPI} = \dfrac{\log\begin{pmatrix}\text{per}\\ \text{cap.}\\ \text{income}\end{pmatrix} - \log\begin{pmatrix}\text{min.}\\ \text{ann.}\\ \text{income}\end{pmatrix}}{\log\begin{pmatrix}\text{max.}\\ \text{ann.i}\\ \text{ncome}\end{pmatrix} - \log\begin{pmatrix}\text{min.}\\ \text{ann.}\\ \text{income}\end{pmatrix}}$	Economic capacity is the financial resource status of a socio-hydrological systems that can help adjust or adapt to water stresses or disturbances. One readily used indicator of financial status is the gross domestic product (GDP) index (Nepal and United Nations Development Programme (Nepal) 2014). In order to account for cost of living and inflation rates, GDP per capita at purchasing power parity (PPP) is used in the calculation of the GDP index

Table 17.4 Vulnerability assessment results

		Development region				
Parameter	AHP Weight	Far Western	Mid-Western	Western	Central	Eastern
Water stress parameter						
WR variation (WV)	0.11	0.56	1.00	1.00	0.77	0.51
WR scarcity (WS)	0.33	0.61	0.54	0.48	0.53	0.62
WR exploitation (WE)	0.36	0.08	0.07	0.55	0.66	0.29
Water pollution (WP)	0.2	0.62	0.63	0.52	0.54	0.53
Water stress index (WSI)	–	0.42	0.44	0.57	0.60	0.47
Adaptive capacity parameter						
Natural capacity (NC)	0.25	0.70	0.62	0.68	0.54	0.49
Physical capacity (PC)	0.23	0.66	0.53	0.75	0.73	0.63
Human resource capacity (HRC)	0.38	0.59	0.60	0.62	0.55	0.60
Economic capacity (EC)	0.14	0.34	0.37	0.40	0.44	0.40
Adaptive capacity index (ACI)	–	0.60	0.56	0.63	0.57	0.55
Vulnerability index (VI)	–	**0.70**	**0.80**	**0.90**	**1.05**	**0.86**

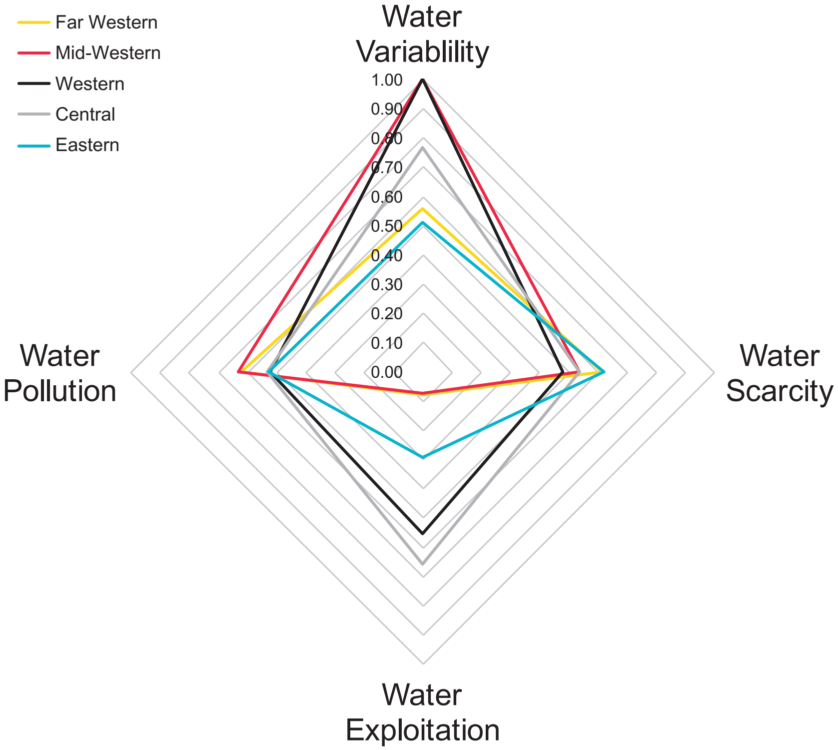

Fig. 17.5 Development region water stress radar plot

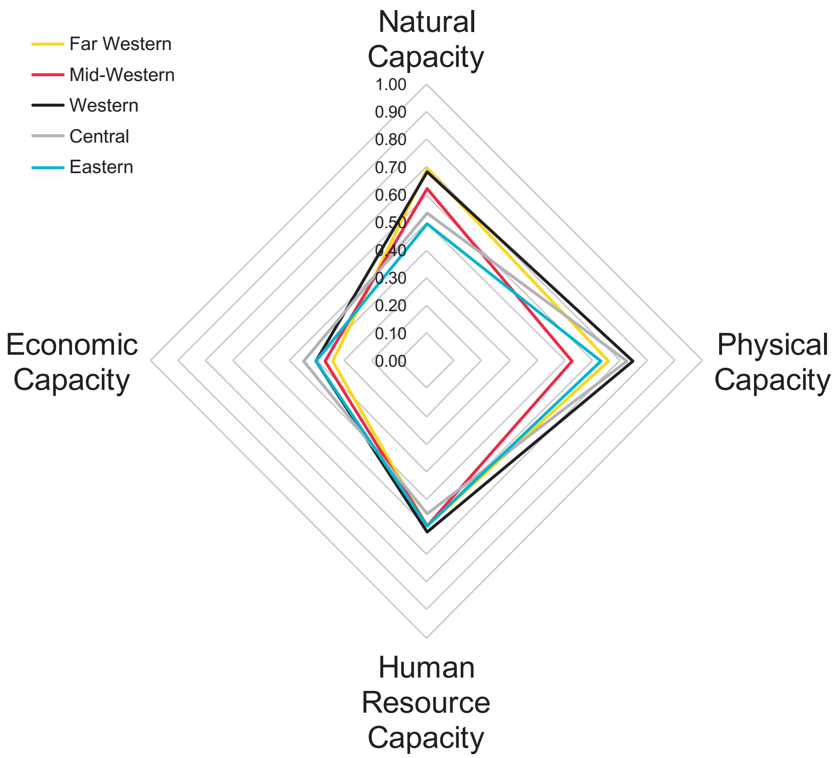

Fig. 17.6 Development region adaptive capacity radar plot

development. The large hydropower development in these regions obligate resource and hydrologically segregate the region, which is reflected in the water exploitation parameter (WE). The Far-Western, Mid-Western, and Eastern Development Regions show a much smaller impact from hydropower development as there are fewer dams in these regions.

Nepal's Western Development Region has the highest adaptive capacity, although all five regions had similar adaptive capacity with ACI ranges from 0.54 to 0.63. A major system limitation demonstrated in this study as well as others is the weak economic capacity (EC) in Nepal. The inability to invest in permanent and robust water infrastructure leads to cheap temporary solutions such as unimproved sanitation or no installation of household toilets, as reflected in the water pollution parameter (WP).

Despite increased hydropower development and financial and social resource limitations, only Nepal's Central Development Region is categorized as moderately vulnerable based on the assessment and the vulnerability index classifications presented in Table 17.2. This finding reveals that the systems have the ability to adapt and cope with various disturbances related to water stress.

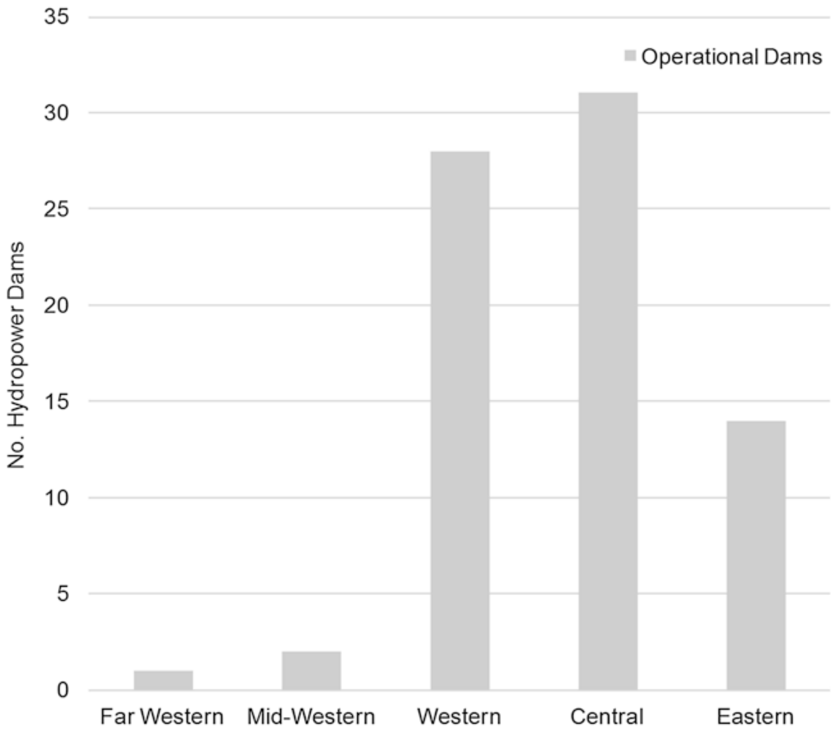

Fig. 17.7 Region hydropower dam density

Hydropower development was incorporated into both the water stress index (WSI) and the adaptive capacity index (ACI) to reflect the impact and benefit. Although the impact of hydropower is significant, the benefit is not. The benefit of the hydropower development is reservoir storage capacity, which dampens the effects of water resource variations and shortages. Nepal only experiences a marginal benefit to ACI because stored water is not a primary source. Figure 17.8 compares regional water use to dam storage and reveals the minimal contribution of reservoir storage to demand. However, as hydropower development increases, storage capacity also increases, creating more adaptive capacity.

The major findings reveal (1) that hydropower development, defined as the primary stressor to be addressed in this study, can also increase the adaptive capacity of the socio-ecohydrological system and (2) Nepal's Western and Central Development Regions, both with high population densities and hydropower development, are the most water stressed and also have the highest adaptive capacities.

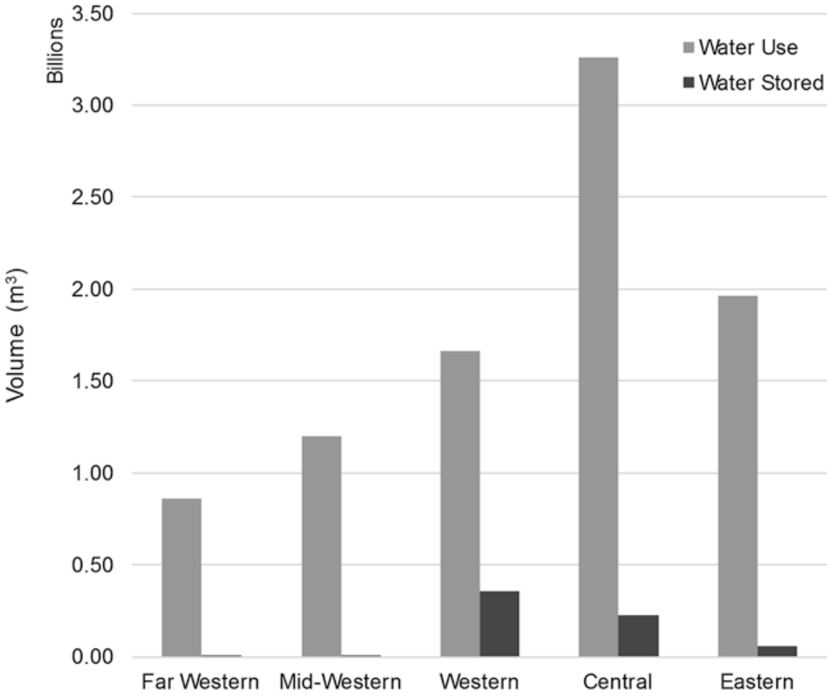

Fig. 17.8 Reservoir storage capacity indicators

5.2 Bayesian Network for the Gila River, NM: System Framework

System frameworks are developed based on an understanding of how the socio-ecohydrological system functions. The system-specific functions include abiotic, biotic, and social processes. The body of knowledge of specific systems expands when disturbances occur. The Gila River in the Southwestern USA has undergone many disturbances in the form of water policy and appropriation.

These social stresses have been amplified by drought conditions and efforts to develop an infrastructure project under the terms described by the Consumptive Use and Forbearance Agreement (CUFA) which entitled New Mexico to develop and use water as part of the 2004 Arizona Water Settlement Act. The development project has resulted in several potential streamflow diversion scenarios that would store water for New Mexico use.

A Bayesian network (BN) approach is used to understand the impact of these scenarios on floodplain vegetation potential for the Upper Gila Basin, New Mexico, USA, shown in Fig. 17.9. A coupled 2-D hydrodynamic and BN model is used to determine the likelihood of floodplain vegetation recruitment for native riparian species, willow/cottonwood (*Chilopsis/Populus wislizeni*), given three diversion

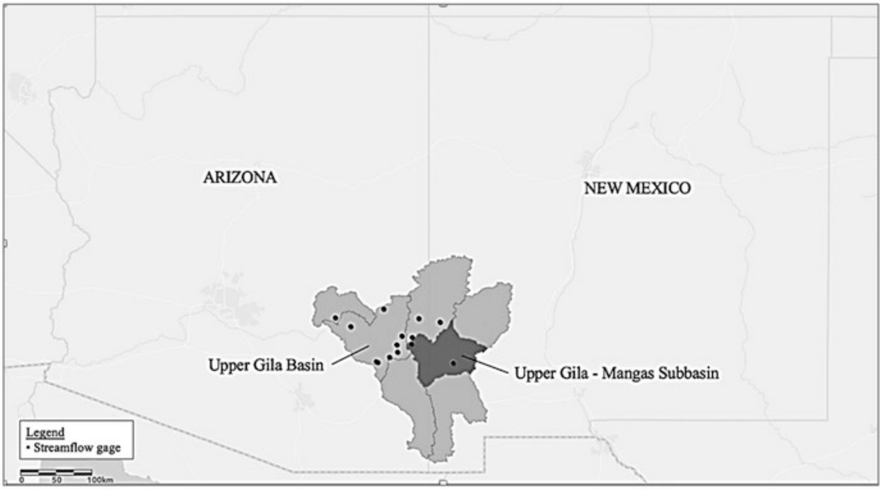

Fig. 17.9 Upper Gila Basin

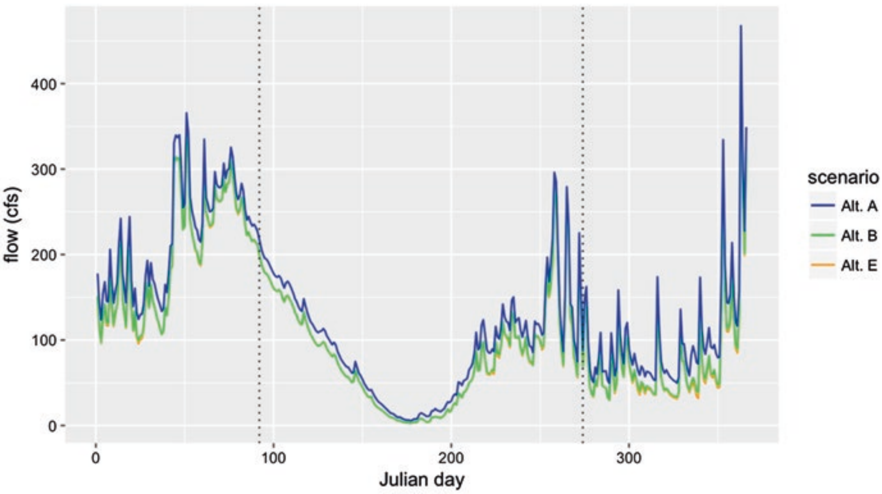

Fig. 17.10 Upper Gila-Mangas Subbasin mean daily flow from 1936 to 2017 (dotted line denotes vegetation recruitment period April to September)

scenarios: alternative E, concrete dam diversion structure; alternative B, concrete dam diversion structure; and alternative A, no action/existing conditions. These alternative diversion scenarios are presented in Figs. 17.10 and 17.11.

A total of 15 different flows are modeled for steady-state conditions including 200 cfs (5.7 m^3/s) as the lowest flow and 4000 cfs (113.3 m^3/s) as the highest flow. The constant hydraulic roughness values (Manning's roughness) 0.035 and 0.05 are

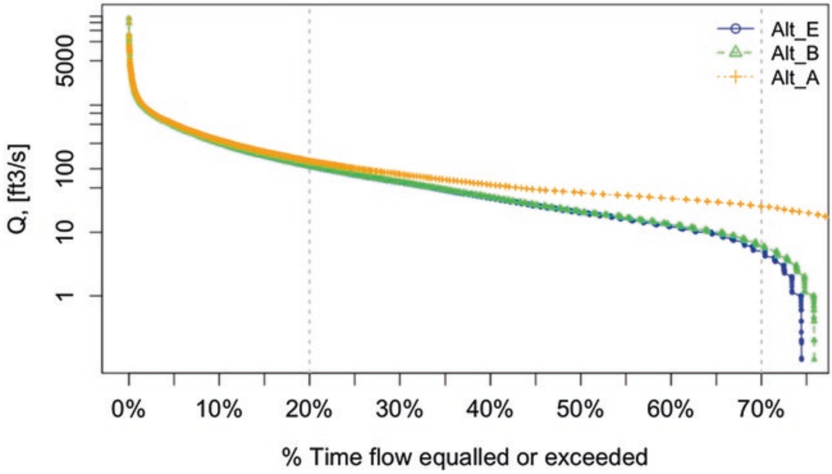

Fig. 17.11 Flow duration curves for alternative flow scenarios

assigned for mainstream and floodplain, respectively, which were determined by evaluating empirical methods using grain size.

5.2.1 Case Study Results

The results from this study reveal limited impact of proposed diversions on current riparian cottonwood and willow recruitment. Based on the modeling assumptions and methods adopted in this study, there are not significant differences in impact to recruitment for the scenarios evaluated which can be explained by the impact of the proposed diversions on the hydrograph as shown in Fig. 17.12. The flow duration curve shown in Fig. 17.13 shows that the variation between scenarios impacts flows less than 200 cfs, which are not the high-magnitude events needed to inundate the floodplain for riparian vegetation recruitment.

Figures 17.12 and 17.13 illustrate the flow frequency and diversion frequency in cubic feet per second (cfs) for each scenario, where the frequency plots are considered by number of standard deviations in each row and scenario by column. The BN model reinforces what the flow data parameters indicate statistically, that the difference between likely flows as compared to diversion scenarios will not produce a significant effect in riparian recruitment. This is because when a flood event occurs which is large enough to overrun the stream channel banks and inundate potential recruitment areas, the magnitude of the difference in flows between the scenarios is not large enough to produce a measurement of those times when one scenario sees the banks overrun and another does not.

Using a similar approach to one developed by Morrison and Stone (2014), Bayesian network (BN) models were developed for the three study reaches. The modeling framework is based on the box-recruitment conceptual model, first

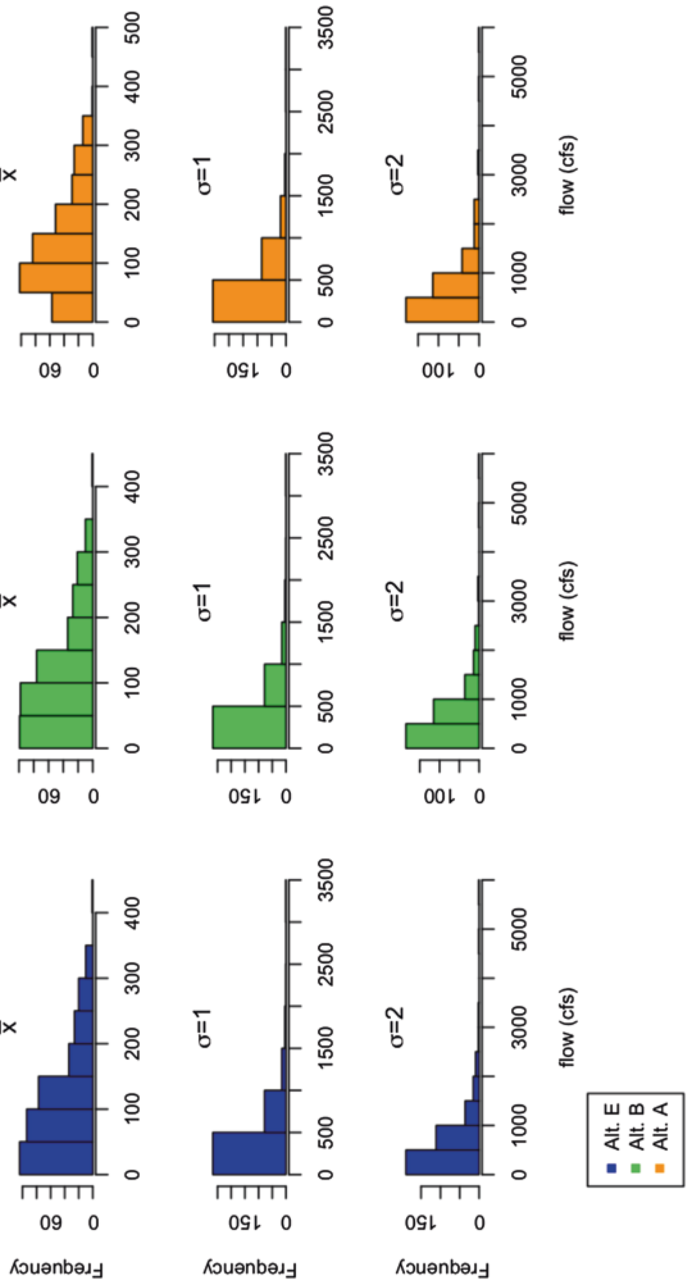

Fig. 17.12 Flow frequency plots in cfs by number of standard deviations and scenario

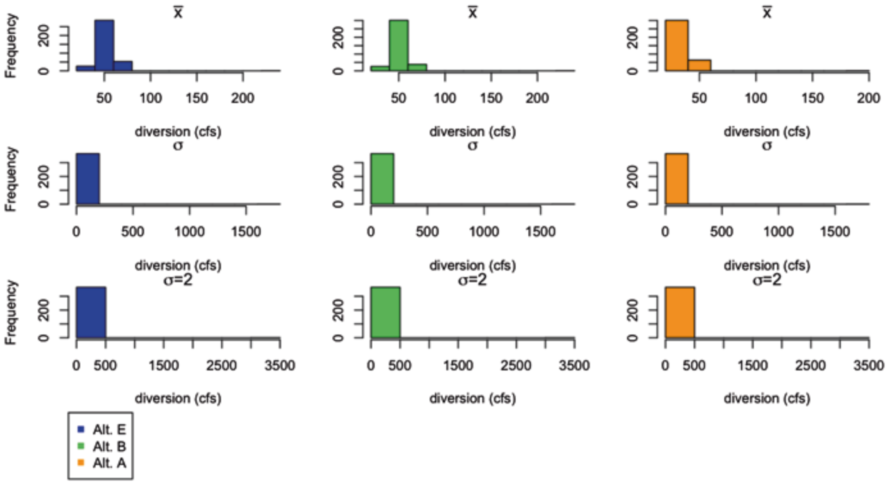

Fig. 17.13 Flow diversion frequency plots in cfs by number of standard deviations and scenario

proposed by Mahoney and Rood (1998). The BN model uses conditional probability tables (CPTs), *structure learning*, *inference*, and the bnlearn package for R, a software environment for statistical computing and graphics. bnlearn is used to execute a cpquery function, which estimates the conditional probability of an event given evidence, following a likelihood weighting inference algorithm where historical evidence is used to weight the random sampling as described in Korb and Nicholson (2004). The BN model uses variables that address timing, hydrologic conditions, groundwater conditions, and recruitment constraints for the plant types based on expert knowledge, literature, and previous work.

System frameworks represent an understanding of how the system functions. The SF for this case study is the Bayesian network structure developed from expert knowledge and literature. Specific influences of riparian vegetation recruitment used are streamflow, timing, groundwater conditions, and surface water recession rate. Characterization of node comes from permutations of historical data to represent scenarios. The BN network structure created in R is presented in Fig. 17.14 and shows the node relationships (e.g., parents, children, neighbors). Each node represents a distinct influence on vegetation recruitment. Discrete states and node parameters were established based on literature, expert knowledge, and analysis of field data. Each node probability is binomial.

This SF shows the influences of recruitment and how they are related based on the specific knowledge of this system. A sensitivity analysis of these linkages would determine the strength of these relationships and the impact each node or parameter had on the recruitment outcome. In this SF, the stress imposed on the system is represented by the diversion scenarios.

This case study presented a BN structure as a system framework to represent the socio-ecohydrological system of the Upper Gila Watershed. This case study demonstrated how system frameworks are informative tools that represent an

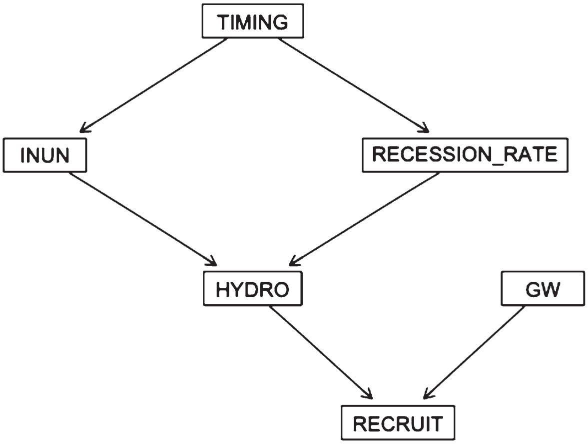

Fig. 17.14 Network structure developed with bnlearn in R

understanding of holistic system processes and behaviors. Advanced modeling techniques such as BNs are needed to synthesize information from the many dimensions of these complex adaptive systems. BNs allow model developers to assign relationships and thresholds based on expert and site-specific knowledge. Other advantages of BNs include the ability to utilize small and incomplete datasets and explicitly account for uncertainty in the system (Uusitalo 2007). Information from socio-ecohydrological models translate a wide range of expert knowledge, local knowledge, and data into a form that can help decision-makers make well-founded interventions.

6 Summary and Conclusions

There is inherent value in creating a framework to develop factors for socio-ecohydrological resilience. The two framework approaches, vulnerability assessment framework and system framework, provide a clear guide which can be replicated for any socio-ecohydrological system. They can be applied to systems regardless of their data diversity or limitation. The modularity/flexibility of the approaches in this chapter allow for the implementation across different system scales and geographical location. These framework approaches can be repeated for adjacent systems and be used for continued monitoring over time. With the attempts of interventions to *build* resilience, assessments of the framework can clearly monitor for improvement of the system. Understanding the system's specific capacities provides knowledge of available resources to address impacts of stresses that are the biggest contributors to the system vulnerability. The two approaches possess these values but have different advantages and limitations that address a wide range of understanding of specific socio-ecological systems. The advantages and disadvantages of VAFs and SFs should be considered when deciding on which of the two framework approaches to apply to a specific system.

Building resilience of socio-ecohydrological systems comes at a cost. Managing the system resilience requires periodic evaluation of system resilience and regular monitoring of trigger indicators. These complex adaptive systems are in a constant state of change. The frameworks described in this section serve as a tool that should be continually referred to for a qualitative or quantitative reassessment. Incorporating resilience into the management of a socio-ecohydrological system means embracing losses in efficiencies. Water conveyance in streams is a great example; there losses to evapotranspiration and groundwater serve a vital role for the aquatic life and riparian vegetation.

The cost to implement interventions may be great, but the cost of not doing it may be greater. The Los Angeles Water and Power Department moved forward with a unique solution for one of their drinking water reservoirs. They used shade balls to stop the formation of bromate, a reaction byproduct from chlorine, bromide, and UV radiation. The high-density polyethylene (HDPE) balls were a less expensive alternative to others including tarping the reservoir and building an enclosed storage tank. Reduced evaporation losses and cooled water temperatures added value beyond solving the water quality issue. It has received criticism for being water-expensive including the water used to produce the balls (Grennel 2018), but no action would have resulted in the continued exposure of city residents to bromate.

Transformation of the system may become the goal of an impaired socio-ecohydrological system. In this situation, resilience management will reduce the resilience of the existing regime and enhance the resilience of a desirable regime/state (Walker et al. 2002). Discussions of intentional transformation are held once all interventions aimed at improving socio-ecohydrological resilience have been considered. Interventions include (1) financial, (2) management, (3) educational, and (4) political and institutional (Gunderson et al. 2010). The knowledge gained from using a framework to monitor to ecohydrological system resilience can inform interventions and whether system transformation is eminent or should be planned.

The transdisciplinary nature of resilience theory and socio-ecohydrological systems require the convergence of separate field-specific bodies of knowledge that have developed over decades. This merging of knowledge has been ongoing, and this chapter serves as a contribution. This convergence strengthens the body of knowledge to reference for future work and field advancements. This convergence also provides a common language to speak to one another.

Ultimately, the intent of this chapter is to support well-founded interventions which result in building adaptive capacity and reducing system vulnerability. Well-founded interventions can be developed by initial reflecting on the foundational questions, *Resilience of what? To what?* discussed by Gunderson et al. (2010) and formalized in this chapter.

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Chapter 18
Disaster Risk Reduction by Urban Resilience for Architectural Heritage

Qazi Azizul Mowla

Abstract With the massive rate of unplanned urbanization and the inherent risks or vulnerability that are faced by dense urban areas, there is a need for an alternative approach for risk reduction or management of heritage by structural resilience measures. Since people, properties, infrastructure and capital stock are mostly concentrated in urban areas, there is always a competition between immediate economic priorities, where heritage sites seldom receive any attention. Man-made and natural heritage sites are both considered vital for the identity of a city and for its passing on to the coming generations. These sites in urban areas are often susceptible to the impact of all types of hazards due to the neglect. Heritage sites are generally associated with some open spaces around, providing a tool for disaster risk reduction (DRR) opportunity. Traditional green-blue-grey (GBG) networking of open spaces provided appropriate urban resilience to reduce vulnerability and disaster risk. This study attempts to integrate these two concepts by identifying the vulnerabilities in an urban area and assessing possible response to contain them in a systematic manner by institutionalizing local resilience approaches through the heritage site integration within the urban planning/design framework. The study also attempts to identify the types of vulnerabilities to urban architectural heritage sites and proposes to reduce their risk from disasters by integrating them with local traditional resilience practices. Study process is based on a logical argumentation of some case scenario analysis with available data mostly from secondary sources. The data analysis is coupled with their historic interpretation and authors' own experience in the field of urban design and heritage conservation. Certain application of traditional GBG resilience concept of the DRR for architectural heritage conservation proves to be effective. As the preventive DRR measures by improving resilience are found more appropriate for the conservation of heritage artefacts, it needs to be applied at planning stage. In a nutshell, the study advocates for an action plan for DRR on

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architectural heritage sites in the urban areas right from the awareness campaign to the urban planning and design stages for urban sustainability.

Keywords Disaster · Risk reduction · Resilience · Architectural heritage · Green-blue-grey network · Urban design and planning · Sustainability

1 Introduction

Since people, properties, infrastructure and capital stock are concentrated in urban areas, there is always a competition between immediate economic priorities, where heritage sites seldom receive any attention, and the impact of hazards/disaster in urban areas can be catastrophic. The socio-economic cost of their recovery from the loss of identity and the context, let alone the environmental cost, may run into billions of dollars. Traditionally, a balance is drawn between these competing priorities by developing a mixed-use network of green, blue and grey (GBG) open spaces. Sendai Framework for Disaster Risk Reduction (SFDRR) (SFDRR 2015) and United Nations Development Program – UNDP's sustainable cities and communities' guidelines of Sustainable Development Goals-SDG-2030 (UNDP 2020) – also call for addressing disaster risk and resilience by understanding the context (Fig. 18.1). A question naturally arises regarding determining the priorities in the urban risk reduction strategies.

Architectural heritage is exposed to the impact of natural and man-made hazards, and it is more evident in the context of urban areas. Heritage, in both its tangible and intangible manifestations, is essential for a city's spatial-cultural identity and continuity. Open spaces are crucial to both. Heritage may be tangible comprising of

Fig. 18.1 Approach based on SFDRR-2030 and SDG-2030 disaster risk reduction strategy for urban heritage. Source: SFDRR (2015) and UNDP (2020)

historic precincts of cities or culturally significant buildings and towns/areas besides intangible issues like extant culture of traditional buildings, skills and knowledge, also rites, rituals, social life and lifestyle of the inhabitants that are manifested directly or indirectly to give a particular identity or ambiance to an urban area; open space is an integral part of heritage for their functional optimization. Architectural heritage is also adversely affected by insensitive urban planning and design, which in turn results in cultural discontinuity and identity crisis. Loss of identity, urban blight, hazards, pollution, traffic and water congestions, etc. are the symptoms of the problem associated with heritage destruction (Fig. 18.5). This may be attributed to lack of awareness regarding the contribution of natural and man-made heritage of a place by the people engaged in the development and planning process and environmental sustainability at large.

1.1 Brief Background of the Problem

Heritage sites and structures include all the historic areas, buildings, monuments or other artefacts/features of recognized architectural or historic importance with their spatial context which contribute to the cultural, social, economic, political, artistic or architectural significance to a place. Recognizing their uniqueness of character and value, these are needed to be conserved and preserved in order to retain area's historic resources and pass them on to the posterity. The disaster for heritage artefacts is a serious disruption of the functioning and maintaining of heritage sites by a community or a society involving widespread human, material, social, cultural, economic or environmental losses and impacts, exceeding the inbuilt resilience capacity of the community to cope using their own resources. With careful planning this disaster can be checked or reduced. This gives rise to the concept of disaster risk reduction (DRR) in the heritage management. Detail area plan (DAP 2010) in Dhaka has identified preservation overlay sites in Dhaka urban area and recommended them to be conserved ensuring the buildings or signs to be erected, reconstructed so as to be architecturally compatible with the historic building within the stipulated zone (250 m from the edge of the artefact to be conserved) in the urban area. The DAP has identified the need for heritage conservation, but unfortunately it does not call for integrating heritage sites in the planning framework. The disaster risk to these heritage artefacts in the urban areas due to the unplanned urbanization without due consideration to the ecosystem services gives rise to long-term vulnerabilities, beyond the control of the community or urban governments (Fig. 18.2).

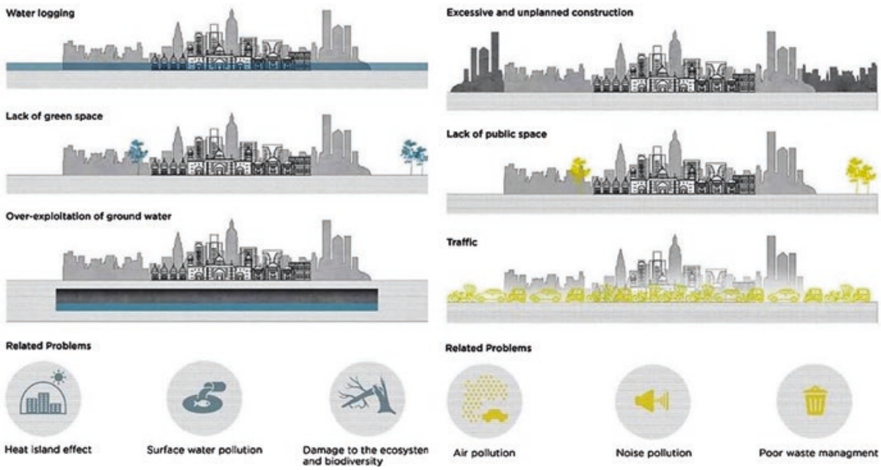

Fig. 18.2 Unplanned urbanization causes loss of open spaces, thereby reducing the resilience capability of the community. Source: Mei and Rahman (2019)

1.2 Vulnerabilities

The type of risk, to natural and man-made heritage, that needs to be mitigated is basically natural hazards leading to disaster like devouring of flourishing settlements by the meandering rivers or ravage of nature (cyclone, floods, earthquake, tsunami, etc.). Man-made hazards are the extreme pressure on land due to overpopulation and rapid (unplanned) urbanization, encroachments (of natural and man-made heritage sites), pollution and waterlogging (Fig. 18.5). Lack of awareness regarding the importance of architectural heritage conservation within the framework of urban design and planning, besides lack of skill for architectural conservation, put them in risk. Political ravage or indifference on heritage artefacts also cannot be overruled (Babri Mosque, India; Buddha of Bamyan, Afghanistan; etc. are the examples). Insensitive contemporary development and technology may also lead to a risky/vulnerable situation (e.g. development of polluting industry near heritage sites). Disaster risk is not only from a measure of external, potential threats but also due to the inherent vulnerabilities existing at any given site. Heritage sites are generally associated with open spaces which play a crucial role in fostering resilience by reducing vulnerabilities, and also by providing priceless assets for the sustainable sociocultural and economic development of an affected region during its recovery phase, by attracting investment, creating employment or providing renewable natural resources. This is why the protection of heritage sites in the event of disaster is of paramount importance (refer to Table 18.1 for brief history of natural disasters in Bangladesh).

Table 18.1 History of major natural disasters in Bangladesh

Major natural disasters in Bangladesh are due to the occurrences of flood, cyclone and cyclonic surge, earthquake, drought, tornado, riverbank erosion, landslide, etc. excepting droughts, all other above phenomena are direct threat to the heritage artefacts. The droughts cause poverty which indirectly effects the existence of heritage property
Bangladesh has experienced 44 floods in the last 65 years since 1954, 16 of which were large floods, and the total monetary value of the damage and losses is more than Tk. 700,000 million. Bangladesh has faced 48 major cyclones since 1584 of which 22 occurred after the independence of the country in 1971. Among these, the cyclones of 1971, 1991, 1997, 2007 (Cyclone Sidr), 2009 (Cyclone Aila) and 2020 (Cyclone Amphan) are major ones. Drought has become a recurrent natural phenomenon of the north-western Bangladesh (i.e. Barind Tract) in the recent decades. It hampers crop production and at the same time creates unemployment problems in that region. The historical seismic data of Bangladesh and adjoining areas indicate that Bangladesh is vulnerable to earthquake hazard. The record of approximately 150 years shows that Bangladesh and the surrounding region experienced seven major earthquakes (with ≥7). In the recent past, a number of tremors of moderate to severe intensity had already taken place in and around Bangladesh, e.g. the Chittagong earthquake of 21 November 1997 (magnitude = 6.1), the Bhuj earthquake of 26 January 2001 (magnitude = 7.9) and the Chittagong-Rangamati earthquakes of 27 July 2003 (magnitude = 5.9, magnitude = 3.69 and magnitude = 4.79) may be cited. In all such cases, availability of nearby open spaces provides the initial protection and relief, giving a boost to community resilience

1.3 Objectives of This Study

The objective of this book chapter is to integrate disaster risk management (DRM) into overall urban planning, design and management framework with heritage sites on board (Fig. 18.3).

Traditionally, people are resilient towards commonly occurring phenomenon. With the increase of the frequency and intensity of natural disasters in the recent past, there is a significant need of exploring the time-tested measures and improving them to fit in with the contemporary context, thereby making settlements resilient to disasters and contribute towards the sustainable urban development. Traditionally, green, blue and grey (GBG) open space network systems in the Bengal Delta provided necessary safety net and resilience to the community. In this paper, integrated network of various forms of open space is shown to provide opportunities for mitigation measure to adapt to geo-climate induced issues at different scale. GBG in combination with local context can provide some of the most effective and broadly beneficial solutions against cyclones, cyclonic surges, floods, landslide and earthquake hazards in the settlement areas of all levels and scales.

2 Methodology

The study highlights the impact of disaster on urban heritage sites. The book chapter attempts to identify the types of vulnerabilities to urban architectural heritage sites and proposes to reduce their risk from disasters by integrating them with the local

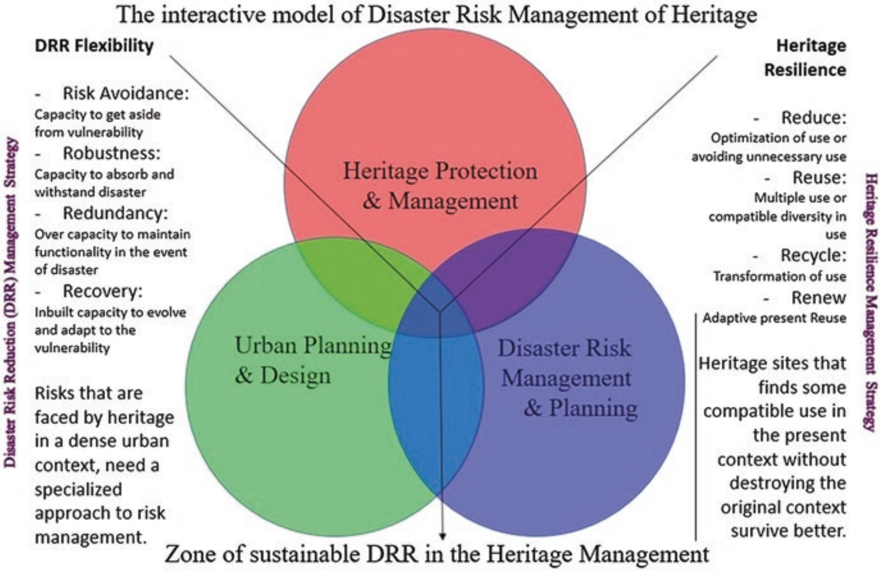

Fig. 18.3 Sustainable DRR model for architectural heritage in the urban areas (Mowla 2016a)

resilience practices. It also illustrates how urban heritage sites can contribute towards building resilience through traditional knowledge system accumulated over generations of human experience in dealing with hazard conditions. Various policies, strategies and planning measures necessary for mitigating and adapting to risk of hazards are discussed through examples along with transformative change needed for creating enabling conditions for implementation. Dhaka's planning documents did never take measures or did not evolve adequate tools within the spatial planning framework of Dhaka to safeguard its heritage sites, nor the disaster risk management (DRM) documents for Dhaka have any indication of considering heritage sites as an option (RajUK 2015). Given the massive rate of urbanization and the inherent risks or vulnerability that are faced by the heritage sites in dense urban areas, there is a need for an alternative approach to risk reduction or management of heritage sites. This study attempts to integrate DRR and traditional GBG concepts by identifying the vulnerabilities in an urban area and assessing possible response to contain them in a systematic manner by institutionalizing local resilience approaches through the heritage site integration within the urban planning/design framework (Fig. 18.3). It is therefore very important to invest in reducing disaster risks on heritage properties in order to mitigate the possible impact of hazards on these precious resources and for sustainable urban design and development.

Architectural heritage together with their site context contributes significantly to the vibrancy of urban planning and design. But it is seldom addressed in the planning process at any stage, and then it becomes too late to blend them harmoniously in the urban fabric, and the heritage gradually deteriorates, leading ultimately to their destruction. Destruction of heritage artefacts is a disaster to the urban image and social mindset. Besides unplanned urbanization and related issues, there are other contributing factors that increase vulnerability to architectural heritage sites. Study process is based on a logical argumentation of some case scenario analysis with available data mostly from secondary sources. The data analysis is coupled with their historic interpretation and authors' own experience in the field of urban design and heritage area conservation practice. Observation of existing mechanism of disaster risk reduction (DRR) on architectural heritage and lessons learned from the past disasters paves the foundation for this study.

3 Disaster Risk Response by Resilience for Architectural Heritage

Bangladesh is a densely populated country with rapidly urbanizing cities. Dhaka, the capital city, is over-urbanized without any holistic planning. The heritage sites, both natural and man-made, are the worst hit. Most recent detail area planning document (DAP 2010) and the regional development planning document, Dhaka Structure Plan, 2016–2035 (DSP 2015), do not have any guidelines of disaster risk management (DRM) as its integral part, and the conservation of urban heritage artefacts is not there in the agenda at all. Bangladesh cannot afford to ignore or further defer in completing the planned assessment of DRR and heritage for its designing and integration into the regional development plan. Many heritage natural features have already been destroyed and heritage buildings demolished. Bangladesh is at a point of no return, i.e. conservation delayed is conservation missed and disaster triggered. The ongoing strategic environmental assessment as requested by the UNESCO's World Heritage Committee (WHC) is, therefore, no longer important for Bangladesh simply because the UNESCO-WHC wants Bangladesh to do it. But, it is extremely crucial for the overall environmental sustainability of the disaster-vulnerable, history-/biodiversity-rich regions of the country (DS 2020). It is high time DRM includes heritage conservation as its integral part and embedded in the urban design and planning framework of urban areas, particularly of Dhaka.

A pilot survey on 50 heritage sites in Dhaka to assess the type of vulnerability they are facing shows 86% of them are victims of illegal encroachment and once they are out of sight, they are systematically eliminated. Visible locations survive better. Another major vulnerability is filling up of the natural drainage around heritage sites (64%) resulting in water clogging during heavy shower. Waterlogging and dampness weakens the structures accelerating natural deterioration (Mowla 2016b, 2019a). One thing is certain, that appropriate distribution of open spaces provides improved resilience towards disaster (Mowla 2019b). Following the Bengal Delta tradition, designing a network of open spaces has the potential to facilitate disaster resilience, urban resilience and sustainable cities. Studies show that the traditional concept of open space networking and buildings constructed with traditional techniques and materials when well-maintained were more resilient to local natural hazards (Mowla 2015). An appropriate use of land, water bodies and local vegetation (GBG network) including the conservation of natural areas (wetland, forests, etc.) have been identified as major contributors in preventing/reducing casualties due to cyclone, cyclonic surge, earthquake, landslides and floods, that is, indigenous knowledge/wisdom and resilience (Fig. 18.6), if improved upon, can play a vital role in the DRR or DRM (Mowla 2000). UNESCO (2007) report shows that traditional knowledge ensures fire protection at the World Heritage Site of the Kiyomizudera Temple of Kyoto, in Japan. During Urir Char cyclone (Bangladesh) in 1985, the surviving structures were observed to be well built on protected and maintained traditional homesteads and vegetated open spaces around; on the other hand, most casualties were from non-engineered, uncontrolled mix of contemporary techniques, materials and lack of sheltered space (Mowla 2000, 2015). Traditional materials, techniques and space utilization may therefore be improved upon in the present context to make them more effective. Resilience of indigenous house types in Bangladesh against local geo-climate or Japanese timber architecture against earthquake are well documented as local structural resilience (see Table 18.2 for DRM approach).

It is an irony that in the urban planning and design and also in the local disaster and preparedness response mechanism, experts on urban design (let alone heritage focused) are not included and traditional wisdom is ignored. As a result, most sites are critically exposed to potential hazards, while communities are not harnessing the full potential of their heritage sites for reducing disaster risk. To address to this gap, the UNESCO's (2007) World Heritage Committee (WHC) took an initiative to integrate heritage in DRR policies and programmes and to strengthen preparedness for disaster risks at heritage sites.[1] DRR for heritage sites is recognized formally as early as in 1994 (UN 1994). Since then, a meet in January 2005 adopted the "Hyogo Framework for Action 2005–2015", in Kobe, Japan, and another meet in Sendai, Japan (March 2015), adopted the "Sendai Framework for Action 2015–2030

[1] The following decisions adopted by the World Heritage Committee (WHC) are relevant to risks and disasters:

- *38 COM 7*, "State of conservation of World Heritage properties" (Doha, 2014)
- *36 COM 7C*, "Reflection on the Trends of the State of Conservation" (Saint-Petersburg, 2012)
- *35 COM 12E*, "Global state of conservation challenges of World Heritage properties" (UNESCO, 2011)
- *34 COM 7C*, "Reflection on the trends of the state of conservation" (Brasilia, 2010)
- *34 COM 7.3*, "Progress report on the implementation of the Strategy for Disaster Risk Reduction at World Heritage properties" (Brasilia, 2010)
- *33 COM 7C*, "General Decision on the State of Conservation of World Heritage properties" (Seville, 2009)
- *31 COM 7.1*, "Issues relative to the state of conservation of world heritage properties: the impacts of climate change on world heritage properties" (Christchurch, 2007)
- *31 COM 7.2*, "Issues relative to the state of conservation of world heritage properties: strategy for risk reduction at world heritage properties" (Christchurch, 2007)
- *30 COM 7.2*, "Issues Related to the State of Conservation of World Heritage Properties: Strategy for Reducing the Risks from Disasters at World Heritage Properties" (Vilnius, 2006).

Table 18.2 Framework of disaster risk reduction in heritage management

Analysis	*The analysis of disaster risk management for heritage needs to address the following:* 1. Conceptualizing the built environment as a socio-economic and environmental system 2. Systems thinking and the process of integrated planning and design 3. Collaborative modes of decision-making and policy formation
Management & policy	The significance of linking *disaster risk management* within *institutional frameworks* and policies for disaster risk management at the regional, city or local level is important, i.e.: Links between risk assessment and identification of heritage values with legal status of protection Links between mitigation, physical planning, conservation ethics and building byelaws Links between emergency preparedness and response procedures, site management systems and facilities planning Links between recovery plan of heritage property and inventories, documentation and preparation for their emergency use Links between public security and site management
Example	*E.g. Risk management in flood*: The institutional framework and various techniques to mitigate and prevent damage due to floods are: 1. rainfall runoff control; 2. flood control; 3. drainage system revival and development; 4. land use regulation; 5. traditional anti-flood buildings and houses; 6. hazard-maps and flood warning systems

Source: Mowla (2019a)

(SFDRR 2015)", of which the latter is particularly oriented towards disaster risk reduction (DRR) strategies and actions (Fig. 18.1). The Sendai Framework advocates for a culturally sensitive approach to DRR in general and calls for the protection of cultural heritage from disaster risks across its four priority areas of action (WBG-GFDRR 2017). The priorities are:

Priority 1: Understanding DRR: DRR strategy should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment.

Priority 2: Strengthening DRM to address DRR: Clear vision, understanding, plans, competence, guidance and coordination within and across sectors of risk governance, as well as participation of relevant stakeholders, are needed.

Priority 3: Investing in DRR for resilience: Public and private investment in DRR is a cost-effective mechanism to enhance the economic, social, health and cultural resilience of persons, communities, countries and their assets, as well as the environment.

Priority 4: Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction. Disaster response is also a unique opportunity to "Build Back Better", including through the integration of DRR into development measures.

4 Understanding the Context

Heritage cannot be thought in reductive terms, neither as isolated objects or images nor as a purely historic phenomenon. The decisions that are to be taken on disaster risk reduction (DRR) for “heritage” sites are not only based on the past, but they will also inform the future. Consequently, in redefining heritage as a historic, social, cultural, artistic, design, media, political and economic issue, it attempts to open up the concept to that of interdisciplinary studies. In questioning these relationships over time, it sought to understand the past in the light of the present and identify creative ways of operating in a globalized future (Cairns et al. 2018). Understanding the context is therefore of paramount importance.

Architectural heritage sites are exposed to the impacts of natural and man-triggered events, which often threaten their integrity and may compromise their value (Mowla 2016b). The loss or deterioration of these has severe negative impacts on local and national communities, both because of their cultural importance and because of their socio-economic values. The earthquake that occurred in Kathmandu (Nepal) in April 2015 and the fire (during renovation work) of Notre-Dame Cathedral in Paris (France) are examples of vulnerability of architectural/cultural heritage. The February 2019 Chawkbazar fire that claimed lot of lives is located near the Chawkbazar’s Shahi Mosque, while the June 2010 Nimtali tragedy that also claimed lives is located near Nimtali Newab Deuri and Hossaini Dalan, both in the historically and culturally significant old Dhaka (Bangladesh). Though chemical warehouses in the crammed neighbourhoods are attributed as the problem, in reality it was just a symptom of an unplanned urban growth (Figs. 18.4 and 18.5). Inherited open spaces around those heritage artefacts were illegally encroached upon, reducing the community resilience and increasing the disaster risk. However, in both the incidences, remaining open space around respective heritage sites reduced the disaster impact and helped the post-disaster management better. Intrusion of saline water in the historic Khalifatabad (Bagerhat, Bangladesh) results efflorescence in the heritage structures or have the damaging effect of air pollution on the historic building materials is both man-made and natural. For DRR in Khalifatabad, small dykes including site-sensitive landscape are proposed, and similarly Dhaka’s context can be seen in Fig. 18.4.

Above examples show that the disaster risk on architectural heritage sites is in part a function of their exposure to hazards that are ascertained by their natural and technological environment (e.g. earthquake- or flood-prone areas, industrialized zones, human activity, etc.).

If on the one hand hazards are harder to foresee or control, on the other hand, vulnerabilities can be more easily addressed in an effort for DRR at any given location; this is because vulnerability is related to a diminished capacity to anticipate, cope with and respond to the impact of a given hazard and is determined by factors that can be more easily influenced (e.g. risk awareness, existence of appropriate response capacities, employment of traditional tools, socio-economic factors, etc.)

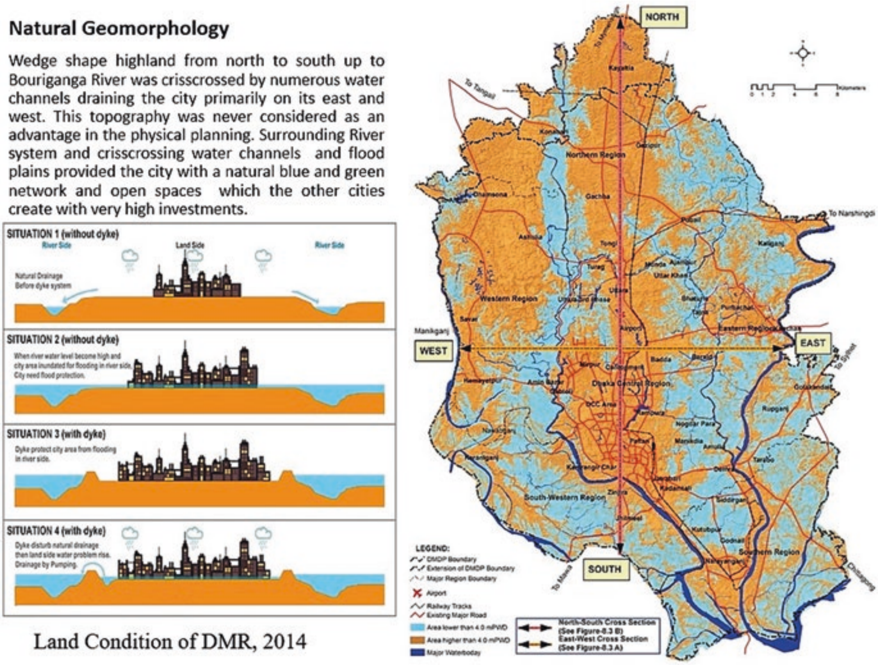

Fig. 18.4 Understanding the context and the response. (Source: DHUTS (2010) and DSP (2015))

Fig. 18.5 Unplanned urbanization triggers the risk of fire, air pollution, waterlogging, etc

(Fig. 18.5 and Tables 18.2, 18.3, and 18.4 for understanding and misunderstanding of disaster risk). The studies reveal that DRR strategies should be first focused on why and what DRR measures are needed in a particular context and determine what probable appropriate actions are needed to mitigate the problem. However, the DRR strategy for heritage should be in line with local regulations or international conventions (UNESCO 2007).

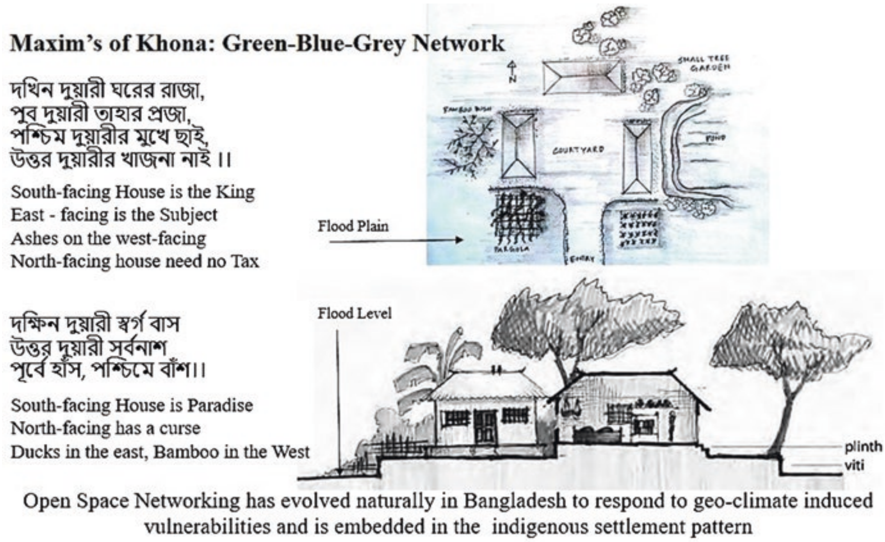

Fig. 18.6 Traditional approach of resilience in Bangladesh by integrated open space networking. (Source: Mowla 2019b)

Table 18.3 Understanding disaster risk reduction

Understanding disaster risk = hazard × exposure × vulnerability
Where vulnerability is the susceptibility and resilience of the community and environment to hazards. "Resilience" relates to "existing controls" and the capacity to reduce or sustain harm; "susceptibility" relates to "exposure"; hazard (natural or man-made) is any phenomenon, substance or situation, which has the potential to cause disruption or damage to infrastructure and services, people, their property and their environment (e.g. cyclone, unplanned urbanization, etc. have destructive potentiality but need not necessarily result in disaster). On the other hand, a disaster is a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, exceeding the ability of the community to cope using own resources (UNISDR 2019)

Source: UNISDR (2019)

5 Planning Risk Reduction for Heritage Artefacts: Integrated Response

5.1 Open Space Network for Disaster Risk Resilience

As mentioned before GBG network was central to traditional settlement layout in response to geo-climatic vulnerabilities. In the present context, planning and distribution of open spaces is an integral part of urban planning and design endeavours, but seldom are they considered in terms of disaster reduction or heritage conservation endeavours. Carmona (2010) stated that the external open spaces provide life breath to the cities by adding recreational opportunities, venues for special events,

Table 18.4 Misunderstanding disaster risk reduction

The government of Bangladesh has undertaken plans and programs for disaster reduction through disaster management. But still the country experiences huge losses every year due to natural disasters. The reasons being:
Disaster risk management (DRM) is not considered an integral part of national physical planning/development. Besides, conservation of heritage artefacts is never in the agenda.
Lack of public knowledge and awareness regarding the need of DRM and the value of heritage.
The structural measures so far undertaken at both national and local level to mitigate disaster have been inadequate and often inappropriate.
Some of the nonstructural measures like forecasting, warning, local action plans, etc. are taken in a short scale, as it is rather strongly believed that nonstructural mitigation measures need to be complemented by structural mitigation measures in order to reduce or prevent some disaster risk. Nonstructural measures without structural preparedness increase the vulnerability.
Most DRM measures are focused on post-disaster management, but for heritage artefacts, pre-disaster structural measures are more important or appropriate.
Poor linkage between DRM and heritage conservation approaches.
Weak institutional arrangement and management, political interventions, lack of awareness, irrational mitigation plan, lack of funding, poor monitoring, etc.

wildlife habitats and opportunities for the movement of the people and that is the general notion of planners. Open spaces available around heritage artefacts may be integrated with the system of urban spaces planned for the community use, as shown in the traditional approach of GBG networking applied in the contemporary urban context for disaster risk reduction and heritage conservation in Chittagong (Fig. 18.9). These preserved lands have potential to be used as public spaces and could be designed to make the use of hazard-prone areas safer for the community and wise use of the space aligned with everyday life of the cities (Jayakody et al. 2016), which in turn reduces their risk of being encroached upon and enables them to be conserved for the posterity.

5.2 Integration of Green-Blue-Grey Network for Disaster Risk Resilience

Three structural responses to DRR in the DRM were identified by Bijlsma et al. (1996), i.e. protection, accommodation and retreat, of which the first two strategies are found to be cost-effective for immoveable heritage artefacts. There are examples when the heritage artefacts are actually moved to another location, but that is the extreme situation and it tears apart the context in which the heritage is embedded. The *Strategy for Risk Reduction at World Heritage Properties* was presented and approved by the WHC at its 31st session in 2007, and the following is the Hyogo Framework for Action (UNESCO 2007):

1. Strengthen support within relevant global, regional, national and local institutions for reducing risks at World Heritage properties.
2. Use knowledge, innovation and education to build a culture of disaster prevention at World Heritage properties.
3. Identify, assess and monitor disaster risks at World Heritage properties.
4. Reduce underlying risk factors at World Heritage properties.
5. Strengthen DRM at World Heritage properties for effective response at all levels.

Small-scale protective measures like structural reinforcement/resistance, protection by dyke or vegetation belt, adaptive reuse, etc. have been observed to protect the sites. Adaptation at the micro (local) level often takes place spontaneously, which can be seen prominently in suburban areas in a piecemeal manner. People at micro level often adjust to a given situation on a short-term basis, and as such, adaptation often follows the cycle of act-learn-act as practiced in the traditional setting (Figures 18.6, 18.7, and 18.8). Figure 18.7 shows general practice of integrating heritage artefacts with the urban fabric. Some piecemeal efforts are also being taken within the urban areas to integrate heritage with the urban fabric by creating view corridors, creating setbacks or creating a focus (Fig. 18.8). Different studies suggest "hybrid" approach, which combines all green, blue and grey (GBG) network approaches, is an effective strategy for reducing risk to hazards in an urban context (Fig. 18.6). Apart from emergency management and recovery, the geo-climatic studies reveal the potentials of GBG network of open spaces to mitigate the related risks and vulnerabilities. Combining these three networks in a judicious manner will result in a safe and sustainable city (Mozumder et al. 2018). These indigenous resilience attempts need to be studied and adapted in the formal planning and design process (Mowla 2000, 2015).

Planning, designing and managing GBG open space network and DRR and resilience which is now being done in a piecemeal manner needs to be approached holistically. This can be applied in any scale and level. The GBG elements of the settlements exist naturally in all the settlements that are needed to be harnessed and brought into a formal planning/design framework. The indigenous adaptation and resilience measures are needed to be considered in different spatial scales and levels and improved upon to get the maximum benefit of the design approach taking into account diverse spatial-temporal dynamics including the interactions between

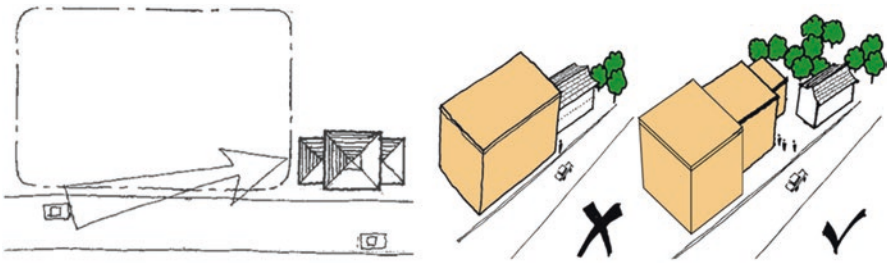

Fig. 18.7 Integration approaches of heritage artefacts into the city fabric

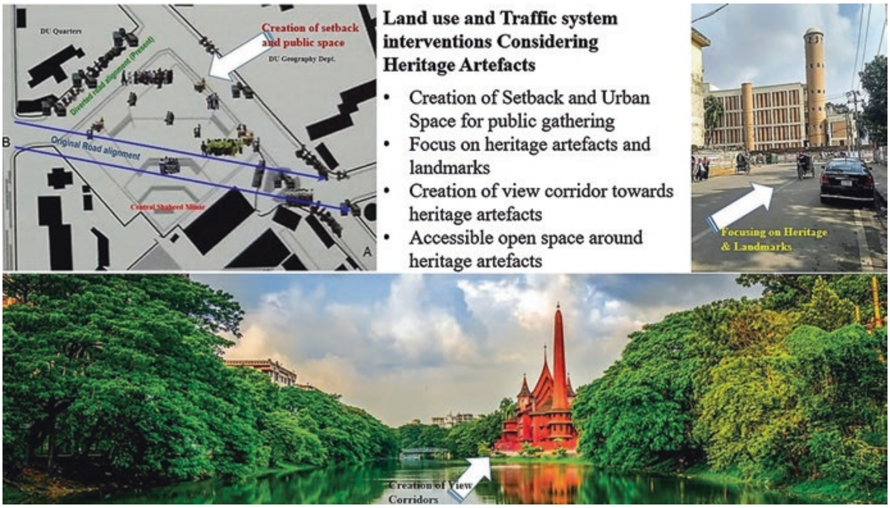

Fig. 18.8 Integrated planning interventions, considering DRR and heritage conservation

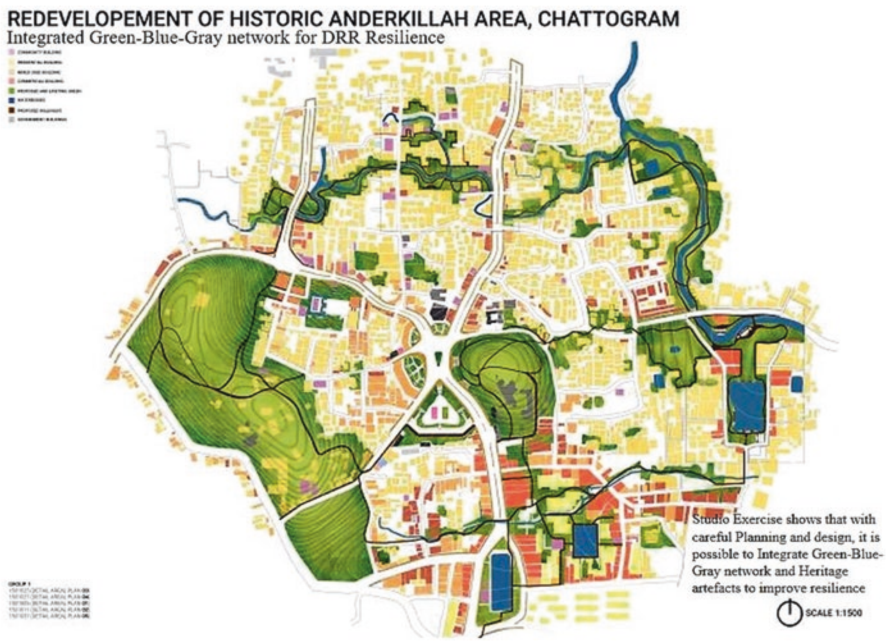

Fig. 18.9 Traditional approach of open apace networking applied in the contemporary urban context for disaster risk reduction and heritage conservation. (Source: 2019, 4/I B.Arch. Studio Exercise, BUET, Dhaka)

different functions of habitable area. Focusing on spatial scales can also help in linking activities and capacities of various local actors to support the holistic management of GBG infrastructure (Wyborn and Bixler 2013). Adaptation benefits may vary greatly by local conditions and related vulnerabilities (Heidrich et al. 2013), and the development areas need to adjust adaptation-oriented scalar frameworks for their specific local purposes. Academic exercise with integrated traditional approaches and universal urban design methods for heritage integration for DRR shows that it is possible to apply these in a congested urban context (Fig. 18.9) and can drastically improve the community resilience capability.

Integration of heritage conservation and risk reduction in the physical planning framework would be the response contributing to both for mutual benefit as explained in previous sections (Figs. 18.7, 18.8, and 18.9). New developments harmoniously blended with the setting, reflecting scale and proportion of the heritage besides minimizing the negative visual impacts enhances the integration of heritage site with the new development. It reduces the disaster risk to both old and new urban features. To minimize negative impact, massing of the new development should be compatible with heritage features. Terraced and landscaped podium could be adopted to integrate more coherently with scale and possibly the character of the nearby heritage feature. Scale, proportions, colour, materials or architectural design of the new development, especially in the lower floors, should be compatible with the heritage feature as far as possible. Suitable landscaping with tall trees, hanging plants, infill walls or panels (e.g. screens) may be introduced to minimize negative visual impact, if any, of the supporting structures.

Adequate setbacks and possibly adequate open space around heritage features added up to the green-blue network of the urban areas improve disaster resilience (Figs. 18.7 and 18.8). Basic approach should be:

(i) Suitable settings for heritage features be preserved or created. Individual or clusters of heritage features should be recognized as important contextual elements.
(ii) Wherever possible, views to the heritage features be preserved and opened up, which would improve the accessibility to heritage feature, thereby reducing the risk of disaster. Building heights of neighbouring new developments should generally respect and if necessary be lowered towards the heritage features. View obstruction towards heritage artefacts needs to be strictly removed for sustainability.
(iii) Create and maintain adequate space around heritage for DRR management. Best way to reduce the risk of flood is to get aside from flood flow zone (Dalezios and Eslamian 2016). Traditionally, settlements were following this principle while developing a settlement or heritage artefact. Dig-elevate-dwell was the common mantra for the safety of man-made artefacts. Illegal encroachments may be removed to revive the drainage and open spaces around heritage artefacts (Fig. 18.9). In extreme situation localized dykes around open space/heritage sites may be created.

6 Summary and Conclusions

DRR for heritage is realized formally as early as in 1994 by the UN, and subsequently UNESCO's WHC came up with addressing this gap. In the national level, most countries are yet to recognize the importance of DRR for architectural heritage. Once a heritage artefact is lost, people realize that a disaster in the sociocultural arena of the nation has happened, but then it is too late. Disaster prevention in the architectural heritage is therefore considered the best approach for DRM. The practice of reducing risks through systematic efforts to analyse and manage the causal factors of disasters to heritage, including through reduced exposure, lessened vulnerability and improved preparedness, is the main mantra for DRR in architectural heritage. The risk needs to be thoroughly understood, local strength (resilience) are to be harnessed and disaster risk management strategy should be determined. Traditional green-blue-grey (GBG) networking of open spaces is found to provide appropriate urban resilience to reduce vulnerability and disaster risk and therefore recommended within the holistic planning and design approach. Contemporary urban design and planning need to provide a network of open spaces may therefore be unified with the traditional GBG network practice.

Conservation delayed amounts to conservation denied and disaster invited. The study identifies the action areas for disaster risk reduction (DRR) and advocates for an action plan for DRR on architectural heritage in urban areas right from awareness campaign and urban planning to design stages, employing local resilience methods because preventive DRR measures are found more appropriate for the conservation of heritage artefacts, under the guidance of people who are sensitive and aware of the architectural heritage conservation issues and the context.

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Chapter 19
Insuring Natural Ecosystems as an Innovative Conservation Funding Mechanism: A Case Study on Coral Reefs

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Abstract Coral reefs are exceptional natural ecosystems. Not only do they provide direct and indirect employment for local communities, but they are key structures in local ecosystems, creating beaches and providing an important level of coastal protection against severe hurricanes and storms. The protection of reefs is of crucial importance for many coastal communities. In this article, the coral reef insurance mechanism that financially protects the coastal areas in the State of Quintana Roo, Mexico, is discussed. The authors explore why coral reefs are threatened and which ecosystem services they provide to humans, a crucial step in providing insurance coverage. Further, the authors show how technology has made insuring coral reefs a viable business proposition. Insurance can support conservation funding while it is a form of financial disaster risk management. Finally, the authors illuminate that the conditions bringing public and private sector actors together like in the case of Quintana Roo, Mexico, are not easily replicable; and more research and understanding will be needed to provide extensive coral reef coverage. Insurance manages residual disaster risk, but it is not a replacement for physical disaster risk management measures.

Keywords Nature-based solutions · Ecosystems · Natural assets · Disaster risk management · Financing resilience · Insurance of natural catastrophes · Conservation · Tourism

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1 Introduction

Coral reefs are the largest biological structures on earth. Several are large enough to be visible from space, including the New Caledonian barrier reef and reefs in the South Pacific. The impact of human activity is endangering several species of coral and degrading reef health (IPBES 2019).

Coral reefs have a significant protective value. With larger coastal development, the importance of coastal protection has become ever more important and valuable. Coral reefs reduce the impact of wind surges and waves on shorelines. They absorb the force of these elemental impacts before they hit the shore, thereby protecting coastal property and providing shelter for marine life (Beck et al. 2018; Zepeda-Centeno et al. 2018; Reguero et al. 2019).

Coral reefs foster biodiversity. Despite reefs constituting less than one per cent of the ocean floor, researchers estimate they house up to 25–30% of total marine life – or 5% of the described global biota (Reaka-Kudla 1997: 91; Morrison et al. 2019).[1]

The ecosystems housed by coral provide food and income for millions of people worldwide (Spalding et al. 2017). They account for a significant proportion of the tourism income that is generated from leisure activities such as snorkelling and scuba diving. Tourists love clear waters and white sand beaches, all of which are an integral part of coral reef ecosystems. Reefs provide a natural water filtration system, controlling the amount of carbon dioxide in the water and keeping water clear and safe. Other benefits of coral include its medical properties (Malve 2016).[2]

In monetary terms, coral reefs provide human beings with benefits that have an estimated value of USD 9.9 trillion. Currently the entire biosphere is valued at approximately USD 145 trillion (Costanza et al. 2014). Financial service providers cannot create insurance products without having a means of valuation. Valuing natural assets such as coral reefs constitutes one of the key challenges to developing insurance and financial products that can improve incentives to conserve natural assets. Both for the benefits they provide and from a sense of responsibility for the planet, humanity should protect coral reefs – before damage becomes irreparable. Finding ways to insure these structures is an important tool in the financial kit supporting conservation activities.

Improved technologies and innovative governance structures can positively impact new financial and insurance product development. In a division of roles between different actors, each actor has its limitations, especially when the aim is to drive wider productive social behaviour with respect to ex-ante and ex-post disaster

[1] For example, corals are home to over 4000 known species of fish, many of them the brightly coloured and patterned varieties that make this ecosystem so visually appealing (NOAA NOS 2020b).

[2] Researchers are using coral to study antimicrobial resistance. For example, ageliferin, a natural agent made by coral, can break down the biofilm coating bacteria, robbing them of their antibiotic resistance. Reef researchers are also developing medicine to aid the fight against cancer, viruses and Alzheimer's disease.

risk management. According to ECA (2009: 113), insurance-based risk transfer is efficient to provide financial coverage for the share of low-frequency high-impact 'risk which cannot be physically averted in a cost-efficient way'. ECA 2009 shows for Florida and Samoa (the Mexican region described is comparable to them to some degree) that already for today's climate, but also for future climate scenarios, half of the expected losses due to hurricanes (for Florida, ECA 2009: 105–109) or sea-level rise (for Samoa, ECA 2009: 110–114) can cost-effectively be averted through nature-based solutions (e.g. onshore vegetation management, beach nourishment, reef or mangrove restoration), mobile barriers and sandbagging, new home improvement (e.g. elevating and securing), building code establishment and enforcement, to ultimately relocation. Nevertheless, large residual, physical loss risk remains. Insurance as a tool for financial disaster risk management complements physical protection measures.

In this article, the authors analyse coral reefs through different lenses: (i) threats and benefits, (ii) insurability as demonstrated with a Mexico case study and (iii) transformative nature of coral reef insurance.

2 Coral Reefs Under Threat

Live coral cover on reefs has nearly halved in the past 150 years (IPBES 2019). Reef degradation has been accelerated by coastal development (Zepeda-Centeno et al. 2018)[3] or specific human activities like certain fishing methods (Munyi 2009).[4] Furthermore, climate change has developed into the most significant threat to coral reefs. Due to increased water temperature and ocean acidification, coral reef degradation has dramatically accelerated over recent decades (IPBES 2019). An estimated 94% of coral has experienced one or more episodes of bleaching since 1980 (Morrison et al. 2020). Coral can recover from bleaching over one or two decades (Morrison et al. 2019). But because consecutive bleaching occurs more

[3] Sewage, sediment and algae growth, all resulting from coastal building and investment, can coat and choke coral. Wear and Thurber (2015) state sewage from coastal settlement (Zepeda-Centeno et al. 2018) is underestimated as a threat to coral in the literature. Ali et al. (2020) found that the more a coastline is altered by human construction, the higher it is at risk. Even reefs not proximal to human settlement have suffered. In a study of the Samoan island Upolou, Ziegler et al. (2018) demonstrated substantial reef damage, with resulting impacts on fish populations and coastal storm damage. By way of balance, reefs located in marine protection areas around Samoa were in a much better state of health.

[4] Fishing methods, such as nets and traps, can be nonselective, particularly threatening juvenile stock. Satellite imagery has demonstrated how larvae in heavily fished seas are no longer swimming into the open ocean (Wolanski et al. 2020 and James Cook University 2020). Blast fishing, using explosives, is particularly devastating, causing substantial direct damage to the coral, killing fish indiscriminately and in a way in which many cannot be harvested.

Table 19.1 Threats to coral reefs

Threat	Definition
Overfishing, destructive fishing	Harvesting fish or invertebrates and damaging fishing practices such as the use of explosives or poisons
Coastal development	Coastal engineering, land-filling, runoff from coastal construction, sewage discharge and impacts from unsustainable tourism
Watershed-based pollution	Erosion and nutrient fertilizer runoff from agriculture delivered by rivers and coastal waters
Marine-based pollution and damage	Solid waste, nutrients and toxins from oil and gas installations and shipping and physical damage from anchors and ship groundings
Thermal stress	Warming sea temperatures, which can cause widespread or 'mass' coral bleaching and increase coral disease
Ocean acidification	Increased carbon dioxide concentrations. Acidification can reduce coral growth rates and make them more susceptible to breakage from storm impacts
Sea-level rise	Increase in global mean sea level because of an increase in the volume of water in the world's oceans from melting ice caps

Source: Burke et al. (2011)

often, recovery has become more difficult.[5] Many researchers predict that before the end of the century, ocean acidity will have reached such a dangerous level that coral will begin to dissolve (Eyre et al. 2018: IPBES 2019).[6]

The number of healthy coral reefs is in decline – from 43% to 22% in the Indo-Pacific (from the 1980s to 2003; Bruno and Selig 2007), 50% to 14.3% in the Caribbean (Jackson et al. 2014; Gardner et al. 2003; Williams et al. 2015) and 28% to 17% in Australia (from 1985 to 2012; De'ath et al. 2012, AIMS Long-Term Monitoring Program; all examples quoted from Zepeda-Centeno et al. 2018). While there are a few positive examples of initiatives to mitigate threats, much work remains to be done, as highlighted by the following condensed overview of threats to coral reefs (definitions are from the Reefs at Risk Revisited report by the World Resources Institute: Burke et al. 2011) (Table 19.1).

3 Coral Reef Benefits

In order to develop insurance for any kind of asset, an insurance company requires a robust objective estimate of 'value' or 'service' – here defined as nature's benefits contributed to humanity, in line with IPBES 2019 – together with a link to observable and measurable events that lower this value or service. Natural assets, such as

[5] In the 1980s the average of the gap between consecutive bleachings was 25 years; since 2010, it has been 6 years (Hughes et al. 2019, quote taken from Morrison et al. 2019).

[6] High levels of carbon dioxide in the water stop coral building skeletons. Even before reaching these widespread destructive levels, climate change is causing weaker and slower skeleton growth, leaving reefs more vulnerable to breakage.

coral reefs, have historically been difficult to financially insure given the lack of good models to estimate their services or their value. Further, linking observable and measurable events like hurricanes to reduction in natural assets' values or services can be even more difficult. In recent years, technology and data have created an environment in which a financial assessment of nature's contribution to people is beginning to become viable. Coral reefs are a good example of this trend.

This section focuses on coral reef benefits that can be valued in a quantitative framework. Note that the overarching goal is not to place an aggregate value on coral reefs, but rather to find valuable benefits in these ecosystems that fit into a disaster risk management as well as insurance modelling framework.[7]

As indicated in the introduction, coral reefs are valued at USD 9.9 trillion (Costanza et al. 2014). This estimate reflects two value streams: 'reef-adjacent value' and 'on-reef value' (Spalding et al. 2017). In the former, 'reef-adjacent value' reflects the valuation of indirect benefits from coral reefs particularly in the tourism sector. These are the services people enjoy that do not actually take place on the reef themselves, e.g. white sand beaches, small boat activities that require tranquil waters and healthy schools of fish, clear waters that accentuate sunsets that can be viewed from rooms and beaches and clean waves breaking on the beach to create the ambience tourists expect. 'On-reef value' refers to in-water activities such as diving and snorkelling. Approximately 30% of the world's reefs are of value in the tourism sector. Over 9% of all coastal tourism value in countries with coral reefs comes from 'on-reef value' services. They are estimated at nearly USD 36 billion, with Egypt and Indonesia showing the highest tourism-related values for corals, followed by Mexico, followed by Thailand and Australia (Spalding et al. 2017). In Mexico, for example, 27% of all tourism is coastal, with 9% being directly on-reef. Snorkelling and diving activities bring in almost as much revenue as the reef-adjacent tourism, starkly demonstrating the importance of on-reef tourism for Mexico.

Having previously listed the threats to the existence of coral reefs, now consider reversing these threat scenarios to assess coral benefits. Coral reefs near human populations will render more ecosystem services to humans than remote reefs, even if the latter are larger and more biodiverse. Accurately assessing the value of reefs can be challenging. Constanza et al. (2014) found that for benefits such as storm protection, people may undervalue the services provided to them or their

[7] Valuing ecosystem services is inherently complex. This body of work began in the last few decades, coming into prominence in the late 1990s. Proliferation of technology and available data eases estimations. Many disciplines have controversely discussed valuation (Costanza et al. 2014). The focus here is on nature's contribution to reduce expected losses, not on commodification. With growing societal ecological conscience, many think it is tawdry to value natural assets and the services they provide in monetary terms. An assigned monetary value to a species or an ecosystem service – and some might equal this value as a 'price' – could suggest tradability of (or the possibility to exchange) such a species against anything else with the same price, by taking the function of 'price' as a 'numeraire'. However, such a species could be unexchangeable, while manufactured goods are reproduceable. Nevertheless, monetary values can provide helpful insights for decision-making, depending on the context.

community. Globally there are 71,000 km of coastline protected by coral reefs against strong waves induced by storms. Coasts with plentiful, healthy coral usually suffer less storm damage than those areas without coral.

Millions of people rely on reef-dependent industries for their employment and their livelihoods. Many thousands are employed in tourism, boat crew or diving guides. In the United States, for example, approximately half of all federally managed fisheries, which feed and employ scores of people, depend on coral reefs and related habitats (NOAA NOS 2020a).

Despite other services, from biodiversity to medical research, tourism and the value of coastal real estate adjacent to reefs are the primary drivers of coral reef insurance against the impact of storms. Historically, the lack of readily comparable data to drive valuations has rendered insurance a nonstarter. It has been challenging for analysts and modellers to attribute a specific reef value change assessment in the wake of a storm or hurricane. However, technology advances, such as the use and availability of Global Positioning System (GPS) devices, and advanced weather observation capabilities (used to measure wind speed and intensity) facilitate the creation of insurance products.

4 Insurability of Coral Reefs with a Case Study from Mexico

Mexico suffers destructive storm surges on almost an annual basis. Since 1998, at least four major coastal floods have occurred in Mexico, resulting in the death of around 900 people and billions of dollars of economic damage. Thousands of people were relocated to emergency shelters, businesses were disrupted, and property damage due to landslides and burst riverbanks was extensive.

The perception of this vulnerability led to multiple actors coming together to create a reef-specific restoration funding mechanism and insurance policy. The financial coverage is based on a wind-speed trigger over a GPS-defined area of ocean. It provides payments to restore and protect the reef and shore habitats in the event wind speed exceeds specific thresholds. This is achieved by assessing coral reefs for insurability and applying these assessments to Quintana Roo, Mexico.

4.1 Assessing Coral Reefs for Insurability

Beck et al. (2018) and Reguero et al. (2019) partition coral reef risk assessment into distinct steps. First, height, energy and attenuation of offshore waves in combination with the local sea level are considered. In the second step, nearshore hydrodynamics and bathymetry are assessed to determine their modifying impact on wave energy. The third step estimates the reducing impact of coral on wave energy. The fourth step introduces the effects of a tropical cyclone or hurricane and builds different scenarios for flood heights which may hit the coast with or without the mitigating impact of coral reefs (along different storm categories and storm return periods). The socio-economic steps estimate the impact on land, people and

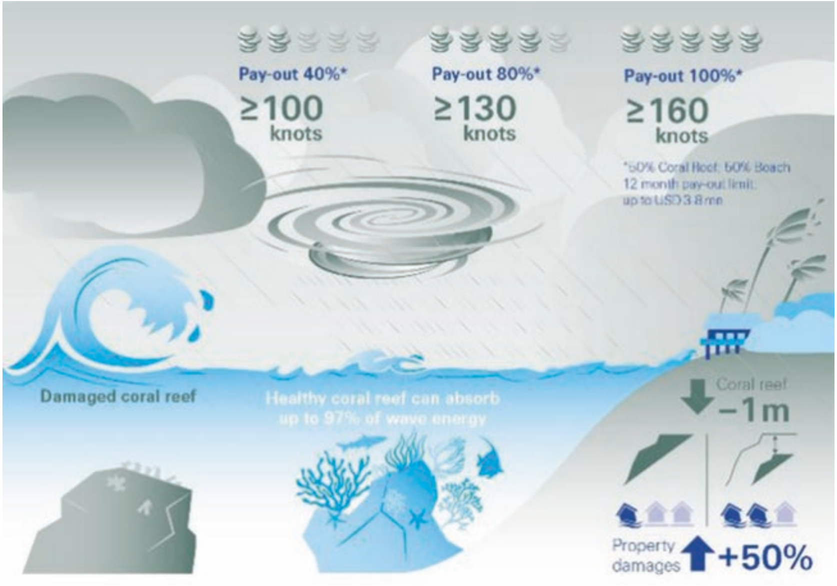

Fig. 19.1 Coral reef conservation funding and insurance mechanism. (Source: Swiss Re Media Production)

property along the coastline potentially damaged by flooding. Vulnerability asks for the impact of the storm on hotels and other buildings as well as on people, taking into consideration building codes and (modelled) historical damages. Furthermore, the results are compared for the situation with or without the natural ecosystem.[8]

By applying these steps, Beck et al. (2018) calculated the expected benefits of avoided flood damages for 25 countries in total built capital, relative to the size of the national economy and people protected (see Fig. 19.1 below). Table 19.2 demonstrates reefs are highly important, particularly in the first five countries, in protecting the national economy against storm surge.

Zepeda-Centeno et al. (2018) and Reguero et al. (2019) additionally focused on the positive contribution of coral reef ecosystem services to combat beach erosion. The authors state that coral reefs not only reduce the impact of a storm through wave attenuation but also support the production and retention of sand produced both by coral-dwelling fish and by physical forces (Bellwood 1995; Pascal et al. 2016; Ferrario et al. 2014; Elliff and Silva 2017). Consequently, Zepeda-Centeno et al. (2018) and Reguero et al. (2019) developed the understanding how to assess sand and beach protection services provided by reefs. This model was employed in making the Quintana Roo coral reef, and its outlying beaches, financially insurable against the impacts of a tropical cyclone. Table 19.3 provides key insights into this methodology.

[8] The steps follow the four classical natural hazard assessment modules, according to Zimmerli (2003): (1) hazard, where, how often and how severe; (2) vulnerability, damage at a given intensity, depending on, e.g. building codes, material and characteristics like height, roof, front and windows; (3) value distribution, location of assets, risks and their value; and (4) insurance conditions, what proportion of the loss is to be insured, insurance limits, deductible and exclusions.

Table 19.2 Averted storm damages

	Annual averted damages (USD mn)		Annual averted damages/GDP	
1	Indonesia	639	Cayman Islands	0.98
2	Philippines	590	Belize	0.37
3	Malaysia	452	Grenada	0.30
4	Mexico	452	Cuba	0.25
5	Cuba	401	Bahamas	0.16

Source: Beck et al. (2018)

Table 19.3 Assessing the natural ecosystem service of coral reefs in re to beach protection

Ecosystem services/drivers	Data needed for which purpose	How to obtain needed data/methods to be used
Wave energy dissipated	Large-scale bathymetric shape, considering horizontal variability of reef physiography	LIDAR (light detecting and ranging remote sensing);[a] if economically not feasible, multibeam echo-sounding, supervised classification of satellite images, single-beam echo-sounding
Coral cover (rugosity) for wave dissipation	Centimetre-scale resolution bathymetry	Spatial resolution methods; chain methods; video-transects of benthic cover
Beach sand volume	Topographical data to point to sand volume and elevation of dunes and buildings	Satellite imagery; numerical models to estimate beach erosion tendency, beach dynamics, erosion history
Urbanization, coastal development	Geolocation and type of coastal development, i.e. buildings categorized	Satellite imagery, addresses; to find out if buildings are too close to the sea
Wave propagation	Combing all influencing factors for wave transformation nearshore (shoaling, refraction, diffraction, reflection, breaking)	Numerical model set up with bathymetry, reef roughness, beach profile data, offshore wave regional climate, causes of erosion
Sediment transport and erosion	Combine wave dissipation information from the numerical model with sediment availability from the beach, generate beach tendency to erosion index	Analysis of wave-driven sediment transport volume compared with capacity of the existing to accommodate sediment transport

Source: Zepeda-Centeno et al. (2018)
[a]See source https://oceanservice.noaa.gov/facts/lidar.html

4.2 *Applying the Assessment to the Quintana Roo Reef to Develop an Insurance Product*

Quintana Roo is located on Mexico's Yucatan Peninsula. This peninsula is exposed to strong hurricanes from the east and southeast. The Mesoamerican Reef, which is offshore from the Yucatan Peninsula, is the largest coral reef in the Atlantic Ocean and one of the most biodiverse regions in the Caribbean. Reef-based tourism is very important for the local economy. Spalding et al. (2017), as quoted by Zepeda-Centeno et al. (2018), estimated income from reef-related tourism in the whole of Mexico at USD 3 billion annually. The whole Mesoamerican Reef ecosystem is a source for 'commercial and subsistence fishing, shoreline protection, reduction of coastal erosion, maintenance of habitats such as mangroves and seagrass beds, and climate regulation' (Zepeda-Centeno et al. 2018 referencing Moberg and Folke 1999). However, 'coral reefs in the Yucatan Peninsula have been damaged by increased coastal development and associated nutrient enrichment, sedimentation, overfishing of herbivore populations and increases in coral disease and bleaching' (ibid.).

The Yucatan Peninsula was struck by hurricanes Emily and Wilma in 2005 causing USD 8 billion damages, with USD 1.8 billion alone in Quintana Roo (Zepeda-Centeno et al. 2018).[9] Several hotels and beaches in Puerto Morelos suffered less damage than others in the state of Quintana Roo, likely resulting from an intact coral reef. Reefs sustain the tourism industry of Quintana Roo by providing coastal protection against storms, including reducing beach erosion.[10] The Nature Conservancy (TNC), different universities and local property owners, supported by governmental entities from different municipal levels, conducted research on the variable damage caused by 2005 hurricanes Emily and Wilma[11] and 2007 hurricane Dean in addition (Reguero et al. 2019). Employing the methodologies above, they discovered that the less-extensive damage was indeed due to specific natural characteristics (the reef itself, the reef's rugosity and nearshore bathymetry). In sum, Reguero et al. (2019) estimated that the whole Mesoamerican Reef services annually protect 4600 people from flooding and provide benefits of USD 42mn damage protection for buildings and USD 20.8mn for hotel infrastructure.

TNC estimates that between 20% and 60% of live coral cover would be lost after a category 4 to 5 hurricane, compared with an annual decrease of 2% to 6% in live coral due to other causes. However, 97% of the wave energy is estimated to be reduced by a healthy coral reef. Beck (2018) and TNC estimated that losing the top 1 metre of an existing coral reef doubles expected property damages from flooding.[12] Protection as a 'service' by a natural ecosystem (reef and associated beach) – also a key asset in deriving tourist income – has prompted the stakeholders to develop strategies to ensure the functioning of the reef and maintain the beaches. According to Reguero et al. (2020), the storm surge protection services of coral

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[9] Original source is CENAPRED (2006).

[10] The Nature Conservancy, 'Insuring nature to ensure a resilient future', global.nature.org, 2018.

[11] In detail, these institutions are The Nature Conservancy (TNC), the Center for Research and Advanced Studies (CINVESTAV) – Merida Unit, the Institute of Marine Sciences and Limnology (ICML) from the National Autonomous University of Mexico (UNAM) and the Engineering Institute (II) from UNAM. Mexico's National Commission of Natural Protected Areas (CONANP) supported the process, as well as the Marista University and the Reef Resilience Network, and Mesoamerican Reef Fund has given inputs.

[12] For a modelled tropical cyclone over a return period of 25 years, Beck et al. 2018 estimate: healthy coral reefs can reduce the flooded area by 8700 km^2, protect 1.7 million people living at the coast and avoid USD 36 billion damage to happen. Without reefs, the damage (on average) of tropical cyclones to coastal property would be 2× higher, flooded land would be +69% higher, and affected people would be +81% more (Beck et al. 2018).

reefs are a clear case to continuously invest into restoration (active planting, removal of disturbances and structural stabilization). Restoration reduces the expected damages of future hurricanes and may hence allow reduced insurance costs.

4.3 Structuring the Quintana Roo Coral Reef Conservation Funding and Insurance Mechanism

The Quintana Roo insurance is a parametric cover and hence different from a traditional insurance product. Payments from parametric insurance products are triggered by a specific variable, in this case maximum wind speed over a GPS-defined geometric area (with traditional insurance products, claims are made retroactively based on loss assessment). Parametric products are easily observable, allowing for swift payments following the trigger event. Table 19.4 shows the main differences between traditional and parametric insurance, here in the context of natural catastrophe disaster risk management.

Here, the insurance purchaser is the State Government of Quintana Roo. For June 2019 to June 2020, the insurance cover was up to USD 3.8 million to repair hurricane damage to the reef. The parametric product was provided by Mexico-based insurer Seguros Afirme SA de CV, with reinsurance provided by Swiss Re Corporate Solutions. The parametric cover's exact specification was as follows (TNC et al. 2019; also see Gonzalez 2019):

- If wind speeds are measured equal to be or above 100 knots within the covered area, there will be a pay-out (as listed in the schedule below) split as follows: 50% for reefs and 50% for beaches.
- Pay-out will increase up to the annual aggregate limit over the 12-month policy depending on the wind speed.
- 100 knots (hurricane category 3 on the Saffir-Simpson scale) or more will trigger a pay-out of 40% of the max limit.
- 130 knots (hurricane category 4 and 5 if above 137 knots) or more will trigger an 80% pay-out.
- 160 knots (hurricane category 5)[13] and above will trigger a full-limit pay-out.

The wind speed is measured as the highest wind speed sustained within the whole covered area (polygon). Depending on the wind-speed severity, the policy could pay out up to the full limit. If the limit is not exhausted on the first storm, a second storm would still be eligible for a pay-out up to the remaining limit. Figure 19.1 displays the structure visually.

Putting this insurance contract in place by itself does not necessarily resolve challenges related to the funding means or to govern potential insurance pay-outs. To address these challenges, TNC and several partners founded the Coastal Zone Management Trust Fund with the task of managing a portion of the collected

[13] Schott, T., Landsea C., Hafele G., Lorens J., Taylor A., Thurm H., Ward B., Willis M. and Zaleski W. 2019. The Saffir-Simpson Hurricane Wind Scale. National Hurricane Center and Central Pacific Hurricane Center. Online available at https://www.nhc.noaa.gov/pdf/sshws.pdf

Table 19.4 Comparing traditional and parametric insurance

	Traditional insurance	Parametric covers	Comments in re to finance disaster risk management
Insurance trigger	Loss or damage to physical asset	Event occurrence exceeding predefined threshold	Both protect against economic losses
Recovery	Reimbursement of actual loss sustained	Pre-agreed payment structure based on event parameter	
Basis risk[a]	Policy conditions, deductibles and exclusions	Correlation of chosen parameters and structure with actual exposure	
Loss assessment and payment	Months to several years – depending on complexity of loss	Very transparent and payment disbursement within 30 days; insurer saves claims assessment costs	Parametric pay-out mitigates short-term liquidity problems and helps to finance initial disaster response and maintain basic government functions after a disaster
Term	Usually annual, multiyear difficult	Single or multiyear (often up to 3 years)	Traditional needs to be renewed annually
Structure	Standard products and contract wordings	Customized product with high structuring flexibility (single trigger, multi-trigger)	Parametric can cover underinsured or traditionally uninsurable risks
Form	Insurance contract	Insurance contract	

Source: Diverse, and Swiss Re
[a]Risk that client's collected pay-out is not equal to the actual loss

tourism tax fee and the payment of the insurance premium. The partners included the State Government of Quintana Roo and its municipalities, the Cancún and Puerto Morelos Hotel Owners' Association, the National Commission of Natural Protected Areas (CONANP), some Mexican universities as well as Seguros Afirme and Swiss Re Public Sector Solutions.

The Coastal Zone Management Trust directs conservation investments for maintenance and repair of the reef and beaches. The trust aims to organize also the insurance premium payment and to manage the potential insurance pay-out in case of a triggering hurricane. Overall, the trust keeps the multiple stakeholders' incentives aligned to ensure that conservation goals are achieved.

5 Transformative Aspects of the Coral Reef Conservation Funding and Insurance Mechanism

The man-made pressures on coral reefs challenge policy-makers, economy and society. Threats will remain or even increase, which cannot all be mitigated by market or political interventions. Because of the complexity of the ecosystem, coral restoration can be expensive – Bayraktarov et al. (2019) calculate USD 6000/ha-1 for the coral gardening nursery phase up to USD 4mn/ha-1 for substrate addition to build an artificial reef, without further maintenance cost – or not applicable on a large scale (Morrison et al. 2019). The reported median survival of restored corals was 60.9% (Bayraktarov et al. 2019).

Any project should be assessed to consider its impact on local social and economic structures. Morrison et al. (2020) propose a new governance paradigm to cope with these challenges and tackle reducing greenhouse gas emissions, rebuilding fish stocks and improving water quality at the same time. Multiscale, multi-actor and interactive 'synergistic interventions' should encompass all spatial levels and 'require industry and government … to embrace a decarbonisation agenda that integrates investment into renewable energy with fossil fuel divestment, land-based aquaculture, and restoration of carbon sinks' (Morrison et al. 2020).

In the case of coral reefs, the different authors demonstrate that reef loss negatively influences well-being (Zepeda-Centeno et al. 2018, Morrison et al. 2020). Moreover, reef ecosystems are crucial for geographic identity and community building. Science and conservation organizations, working with 'keystone actors' (companies, financial institutions, nation states, academia, other NGOs and regional or local governments), can mitigate stress factors on coral reefs by creating insurance and financial products and well-governed management entities to keep incentives aligned. By bringing these actors together with a coral support and disaster relief programme, the insurance scheme described in this paper is transformative and synergistic, as outlined by Morrison et al. (2020: 71).

Following the definition of Seddon et al. (2020), the Quintana Roo funding scheme is a nature-based solution because it:

- Provides the means to reduce flood exposure of coastal buildings by investing in coral reef maintenance.
- Promotes greater community post-storm resilience by means of a trust fund which has been set up to manage insurance pay-outs to allow reef restoration and beach and house repairs.
- Facilitates local community management.
- Creates local adaptive capacity and empowerment defined by Seddon et al. (2020) as a key ingredient for a sustainable nature-based solution.

The specific Quintana Roo solution is not easily replicable. It depends on the regional situation – from the natural ecosystem and its importance for the local economy to the existence of the right mix of stakeholders. Moreover, insurance schemes can only be implemented when main insurability criteria are fulfilled (Heal and Kunreuther 2008; Brahin et al. 2015):

- **Randomness**: Storm events are random. It is impossible to forecast the exact time or place of a storm; the loss event is sudden; and it is accidental, independent of the will of the insured. The insurance mechanism described covers the residual risk for these kinds of natural catastrophe risks (hurricane risks). Major hurricanes and their storm surge can severely damage the coral reef and are therefore not a minor threat to the reef. The mechanism does not cover other risks like bleaching.

- **Quantification**: Storm events, although random, can be quantified. Insurers can calculate the probability of the frequency and severity of the loss event. This quantification increases transaction costs because of the research required to assess the role of the coral reef in reducing the power of storm-generated waves. New technology has made quantification easier.
- **Affordability**: The insurance premium must be affordable for the insured party and adequately cover the financial risk carried by the insurer. Quintana Roo has the benefit of an existing and dedicated tourism fee plus an engaged local insurer with backing of a reinsurer. In Mexico, reinsurance is used for all the natural catastrophe coverages. There are usually high financial costs for Mexican insurers to create the adequate capital reserves to retain the full risk. The design, pricing and implementation of this type of parametric solution is normally done by reinsurance companies.
- **Reciprocity/mutuality**: Insurers need reciprocity; portfolios must be diverse enough to avoid systemic risk. It should be possible to roll out a scheme such as Quintana Roo to neighbouring districts. At the Yucatan Peninsula, they would form a collective, providing financial coverage for hurricanes, which are not systemic. If all policy holders could be affected equally by the same (systemic) risk, for example, large-scale bleaching, insurance would be more difficult. Mutuality is between insurer and reinsurer and is given if they build a risk pool in which the risk is shared and diversified such that it is economically fair for both (Brahin et al. 2015).

In a division of roles between different actors, each actor has its limitations, especially when the aim is to drive wider productive social behaviour with respect to ex-ante and ex-post disaster risk management. According to ECA (2009: 113), insurance-based risk transfer is efficient to provide financial coverage for the share of low-frequency high-impact 'risk which cannot be physically averted in a cost-efficient way'. ECA 2009 shows for Florida and Samoa (the Mexican region described is comparable to them to some degree) that already for today's climate, but also for future climate scenarios, half of the expected losses due to hurricanes (for Florida, ECA 2009: 105–109) or sea-level rise (for Samoa, ECA 2009: 110–114) can cost-effectively be averted through nature-based solutions (e.g. onshore vegetation management, beach nourishment, reef or mangrove restoration), mobile barriers and sandbagging, new home improvement (e.g. elevating and securing), building code establishment and enforcement, to ultimately relocation. Nevertheless, large residual, physical loss risk remains.

Effective risk reduction and financing of natural catastrophe risk calls for a joint response from public and private sectors. While the public sector has the political and legal obligation to set the framework conditions, it often operates under financial constraints (Mitchell et al. 2008) as well as political considerations. The private sector has the financial resources but has also to operate within given regulatory requirements. Risk identification, risk assessment and pricing (suggesting the premium to the insured) generate information that allows a (re)insurer to signal incentives for behavioural change and recommendations for risk management. Table 19.5 shows a possible division of roles between the sectors in a disaster risk management environment, which would be applicable to transformative setups.

Table 19.5 Possible division of roles between the public and the private sector, science, nongovernmental organizations and local/regional citizens

Contributions	Public sector	Private industry incl. financial services	Science	NGOs	Local/ regional citizens
Risk awareness and risk identification For risks and solutions.	√	√	√	√	√
Risk assessment Knowledge about expected losses and event frequency.	√	√	√	√	√
Risk prevention Strengthen public resources, set regulatory framework for appropriate risk prevention measures and reduction of vulnerability (e.g. zoning, land use, building codes).	√		(√) support	(√) control	(√) engage
Risk mitigation (measure to reduce the physical damage), risk transfer (measures to limit financial impact) Build and improve the environment for risk transfer (e.g. regulatory and legal framework, data series).	√	(√)	(√) data		
Enable efficient access to markets and distribution.	√				
Plan and implement physical prevention measures.	√	√	√	(√) sound	√ engage, execute
Fund (and insure) physical prevention measures.	√	(√)			
Develop financial risk transfer products and structures that address the needs, especially for residual risks.		√	(√)		(√) demand
Manage, absorb risks, determine adequate premium.	(√)	√			
Financial support, particularly for startup and pilots.	√	(√)			
Transfer of 'best practices'.	√	√	√	√	√

Source: Swiss Re Institute, adapted from Mitchell et al. (2008)
√ = key role; (√) = limited role

6 Summary and Conclusions

Despite the continuing challenges associated with insuring natural ecosystems such as coral reefs, the increasing motivation of many companies, governments and individuals around the world to find more sustainable solutions for protecting natural ecosystems suggests optimism for seeing more insurance and financial innovation to align incentives in a way that makes us all better off. Technology plus innovation plus good governance structures can equal novel sustainable solutions to protect natural ecosystems. Through insurance, risks can be identified and assessed – and the premium as a price for a covered risk sets signals to markets, which over time can be a useful mechanism to align properly incentives across the different stakeholders who benefit from healthy coral reefs. Insurance as a tool for financial disaster risk management complements physical protection measures.

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Chapter 20
Spatiotemporal Distribution of Landslides in Nepal

Basanta Raj Adhikari and Bingwei Tian

Abstract The occurrence of landslides in the Nepal Himalaya is a common phenomenon due to active seismotectonics coupled with the strong monsoon, fragile landscape, and inadequate agricultural practices. This research has analyzed the trends of landslide events, total fatalities, and economic losses from 1971 to 2016 and discussed the landslide early warning system initiatives in Nepal. Spatiotemporal variation of landslide events shows an increasing trend with nonlinear relationships between events and deaths. The highest number of events and fatalities is concentrated in central Nepal due to population growth, rural-urban migration, and haphazard road construction. Moreover, the number of deaths and economic loss is higher in the hills compared to the mountain and Terai. Only few early warning system initiatives were applied either in project or community basis in Nepal. Most of those initiatives vanished after the project completion. Nepal government should start to build a nationwide dynamic landslide inventory database system connected with weather stations for the monitoring and forecasting of the landslide.

Keywords Landslide · Trend · Nepal · Monsoon · Road · Landslide early warning systems · Spatiotemporal variation

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1 Introduction

Landslide occurrence in the Himalaya is a natural process due to active seismotectonic activities, fragile landscape, and anthropogenic interventions. The continuous subduction of the Indian Plate beneath the Eurasian Plate creates earthquakes at different time scales and magnitude. Some large earthquakes that occurred in 1934, 1988, and 2015 had weakened the geology and created many coseismic landslides in the Nepal Himalaya. Moreover, strong Indian monsoon has been playing an important role for the generation of landslides and debris flow every year causing many deaths and loss of property. Some of the existing data estimated that the damage caused by landslide alone was more than one billion USD and 200 deaths every year. Moreover, 276 lives and 70 million USD economic losses occurred due to a landslide (MoHA 2017) in 2017.

Nepal Himalaya has experienced many large-scale landslides in different time that had changed the landscape completely (Table 20.1). Some large-scale landslides such as Darbang landslide and Jure landslide perished many lives and changed a spectrum of landslide research toward sustainable landslide risk reduction based on scientific research. Some previous researchers (Brunsden et al. 1975; Caine and Mool 1982; Dixit 1983; Fleming 1978; Kienholz et al. 1984; Laban 1979; Nepal 1992; Rimal and Tater 1968; Thouret 1981; Upreti and Dhital 1996; Wagner 1983; White et al. 1987) have presented a landslide mechanism using different models based on predisposing factors and geotechnical properties. These studies can be used for the spatiotemporal analysis to understand the trends of landslide and their impacts on the national economy (Adhikari and Adhikary 2019; Karmacharya 1989; Khanal 1991; Petley et al. 2007; Wagner et al. 1988). The losses of lives and properties are directly related to the anthropogenic activities, i.e., road construction and slope modification (Gerrard and Gardner 2000; McAdoo et al. 2018) in the mountains. These losses can be reduced with proper planning based on landslide susceptibility mapping because some studies (Acharya and Lee 2019; Devkota et al. 2013; Meena et al. 2019; Regmi et al. 2014) show that Nepal Himalaya has a high risk of landslides and debris flow hazard.

Landslide hazard mitigation is always a challenging task for developing countries due to the unavailability of sufficient resources and inaccessible geomorphological terrain. Different large- and small-scale interventions have already been applied for the slope protection; however, the country still lacks a holistic tool for landslide risk assessment, well-trained local professionals, comprehensive landslide databases, and sufficient programs to share good learning practices. Different approaches such as bioengineering, retaining walls and drainage management (Florineth et al. 2002; Howell 1999; Khanal and Watanabe 2005) with an awareness campaign, and enhancing preparedness and post-disaster management through early warning systems (Fathani et al. 2016; Michoud et al. 2013; Piciullo et al. 2018) have been applied in different parts of the country. Those engineering mitigation measures are sometimes not possible due to either inaccessibility or lack of sufficient resources. Therefore, landslide early warning systems (LEWSs) can be

Table 20.1 Large-scale landslides in modern history of Nepal

S.N.	Date	Name	Location	Description	Source
1	1934	Nepal	Nepal	1934 earthquakes have triggered many coseismic landslides	Auden (1935)
2	1962	Darbang	Myagdi	Buried the Darbang Bazzar and killed 500 people	YAGI et al. (1990)
3	1968	Lapu Besi	Gorkha	Blocked the Budhi Gandaki River and breaching of dam destroyed the settlement downstream	Sharma (1981)
4	1969	Bajhang	Bajhang	1969 earthquake triggered many landslides	Upreti and Dhital (1996)
5	1976	Jharlang	Dahding	Jharlang Village has shifted to another location	Yadav (1976)
6	1976	Bhagawati tar	Kaski	Landslide killed about 75 people	Upreti and Dhital (1996)
7	1978	Tinau	Palpa	Dry landslide destroyed a newly built bridge over the river at Butwal	Upreti and Dhital (1996)
8	1980	Bajhang	Bhajhang	Earthquake of 6.5 magnitude has triggered many landslides and 178 people died	Sharma (1981)
9	1988	Darbang	Myagdi	Killed 109 and dammed Myagdi Khola	Upreti and Dhital (1996)
10	1993	Phedi Gau	Makawanpur	Large-scale landslides and debris flow in Central Nepal and destroyed property. Phedigaon debris flow destroyed 52 houses and 52 deaths	Dhital et al. (1993)
11	1993	Jogimara	Dhading	The landslide blocked the Prithvi highway and carried two buses with passengers into the Trishuli River	Upreti and Dhital (1996)
12	2001	Krishna Bhir	Dhading	The debris and boulders blocked the Prithvi highway for 11 days	Maskey (1999)
13	2014	Jure landslide	Sindhupalchowk	Landslide has buried a village with 156 deaths and blocked the Sunkoshi River forming 55 m high dam	Van der Geest (2018)
14	2015	Central Nepal	Central Nepal	Gorkha earthquake 2015 has triggered more than 2000 landslides killing many people	Gnyawali and Adhikari (2017)

good option for continuous landslide monitoring to save lives. Different researchers applied LEWS in the past, but the history of LEWS is not so long in Nepal. Some regional LEWSs based on rainfall threshold (Dahal and Hasegawa 2008; Gabet et al. 2004; Kafle 2017; Malakar 2014; Phaiju et al. 2012) and local LEWS based on the displacement measurement of slope (MercyCorps 2014; Thapa and Adhikari 2019) were practiced. The establishment of LEWS is always a challenging task in difficult geomorphic terrain and diverse communities. In this context, this book chapter analyzes the trend of landslide distribution from 1971 to 2016 (Adhikari and Adhikary 2019; UNDRR 2019) and documents the previous LEWSs practiced in Nepal. This study only considered the data from 1971 to 2016 because the

Desinventar data set for Nepal has data till 2016. There are no segregated data that are collected from the published newspaper and has not exact spatial location with detailed description of types and dimensions of the landslides.

2 Material and Methods

The present study is a secondary data analysis of landslide events, deaths, and economic losses based on the data available from Desinventar (UNDRR 2019) and different published/unpublished papers/reports. Desinventar is a web-based platform managed by United Nations Disaster Risk Reduction (UNDRR) to store the data collected based on media reporting, i.e., daily national newspapers, periodicals, relevant reports, government records, journals, and researches in different countries. The data consists of deaths, affected population, and economic losses of all 75 districts of Nepal from 1971 to 2016. The downloaded data were analyzed using Statistical Package for Social Sciences (SPSS) and the ArcGIS platform. Similarly, information about LEWS was collected from published scientific research papers and unpublished reports.

3 Study Area

Nepal lies between China and India in South Asia and covers 147, 181km^2 surface area (Fig. 20.1). The altitude of Nepal ranges from 70 m (Terai) to the top of the world, Mount Everest (8848 m), within a north-south distance of 150 km. Nepal was divided of 75 districts and 5 developmental regions before 2015 where the distribution of population and economic activities differed significantly.

Nepal is divided into three ecological regions, namely, Terai, hills, and mountain which cover 15%, 68%, and 17% of the total area, respectively. These ecological divisions are based on altitude and climate. Terai lies in the southern part of Nepal that consists of Indo-Gangetic plain with a very gentle slope. The population density is very high (392) due to hill-Terai migration in different periods of time (CBS 2011). Terai districts consist of alluvial plain and the Siwaliks (Fig. 20.1).

Hill districts are distributed in the middle part of Nepal consisting of Chure and Mahabharat Lekh. This region has a steep slope, fragile geology, and deep river valleys. The population density is less than Terai, and most of the settlements are located either on old landslides or in midland valleys, i.e., Kathmandu, Pokhara, and Dang. This region has tropical to semi-temperate climate. Similarly, mountain region is located in the northern part of Nepal including Trans-Himalayan valleys, i.e., Mustang, Manang, and Dolpa. Settlements are very scattered with very low population density. The world's highest peaks such as Mt. Everest, Annapurna, Makalu, and Dhaulagiri lie in this region.

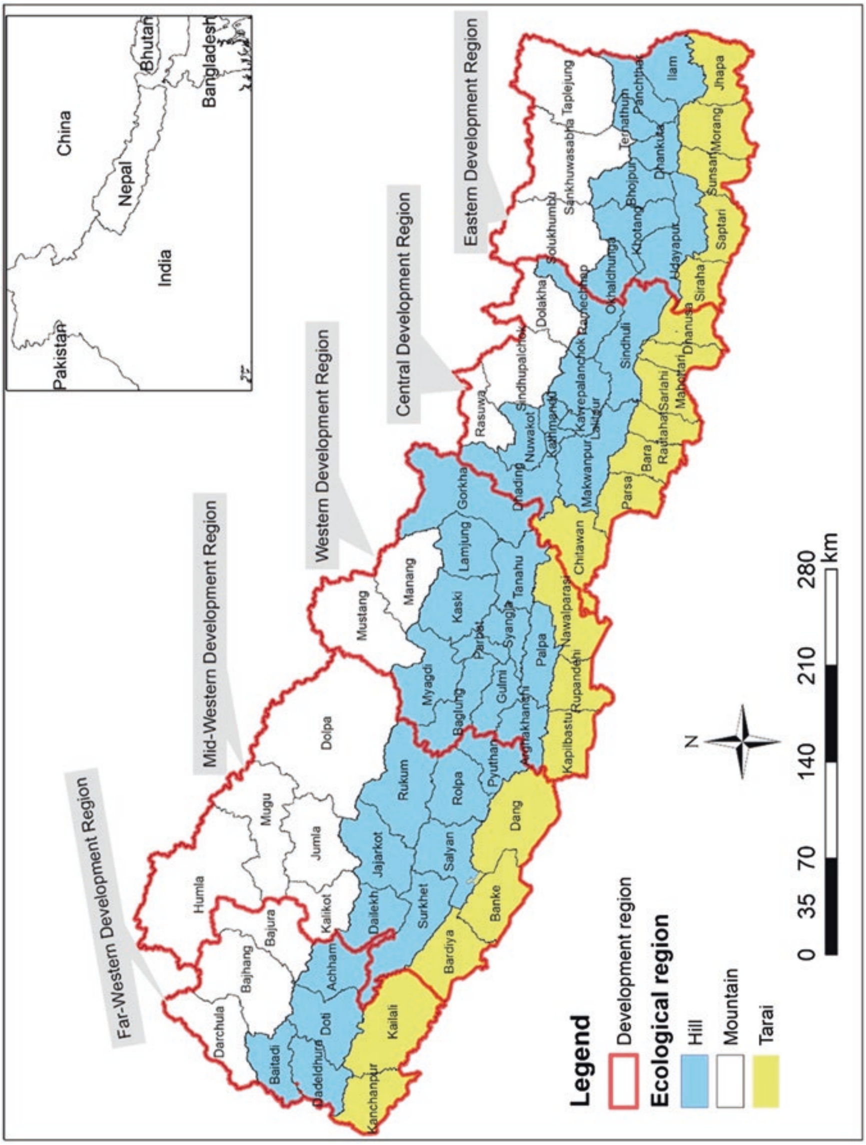

Fig. 20.1 Map of Nepal showing ecological boundaries. The inset shows the location of Nepal in South Asia

Nepal Himalaya lies in the central part of the Himalayan arc. Geologically, it is divided into five tectonic zones, namely, Indo-Gangetic Plain, Siwaliks, Lesser Himalaya, Higher Himalaya, and Tibetan-Tethys Himalaya. These zones are separated from each other by the principal Himalayan thrust/faults. Indo-Gangetic Plain lies in the foothills of the Himalaya and consists of sand, silt, and gravel (Mugnier et al. 1999). The Siwalik consists of sandstone, siltstone, and conglomerate (Dhital 1995; Dhital 2015; Nakayama and Ulak 1999). Low-grade metamorphic rocks, i.e., schists, gneiss, marble, and meta-sedimentary rocks like quartzite, limestone, and slate, are spread over the Lesser Himalaya (DeCelles et al. 2001; Frank and Fuchs 1970). Similarly, Higher Himalaya consists of leucogranites and high-grade crystalline rocks along the entire length of the Nepal Himalaya (Le Fort 1975; Upreti 1999). This region is overlaid by Tibetan-Tethys Zone that consists of sandstone, limestone, quartzite, and shale with a fossiliferous layer (Bordet 1971; Colchen 1999; Godin 2003). The nature and extent of the landslide in these zones are mostly controlled by geology and climate.

Nepal Himalaya has diverse climatic zones and receives a high amount of rainfall in the monsoon season due to the Asian monsoon originated from the Bay of Bengal. The maximum and minimum average annual rainfall are >2000 mm (Kaski) and < 100 mm (Mustang), respectively (DHM 2017). Districts of central and eastern development regions show a decreasing annual precipitation trend, whereas most of the districts of far-western and western development regions show an increasing trend from 1971 to 2014. Nepal Himalaya is drained by three river basins, namely, Koshi, Gandaki, and Karnali to the Ganga River. This region has about 6000 various types of rivers (including rivulets and tributaries) with drainage density of about 0.3 km/km^2, and the overall cumulative length of the rivers is about 45,000 km (WECS/DHMN 1996). Similarly, the temperature trend shows that the normal annual minimum temperature is low (<0^0 C) in the mountain districts (Humla, Mugu, Dolpa, Mustang, and Manang), while the districts of hills and Terai (Surkhet, Tanahun, Makwanpur, Sindhuli, and Udaypur) have a highest temperature (15^0 C–20^0 C) (DHM 2017).

4 Results

4.1 Landslide Trend

Spatiotemporal distribution of landslides in the Nepal Himalaya shows irregular trends. There were altogether 3419 events, which took 5190 lives, and 207,979 people were affected (Fig. 20.2). The distribution of landslide events and deaths differs in different years. The highest number (388) of landslides occurred in 2002 where 445 people lost their lives. The analysis shows that the relationship between events and deaths is not linear. The number of deaths not only depends on the number but also depends on size and extent of the landslides. The lowest number of landslide

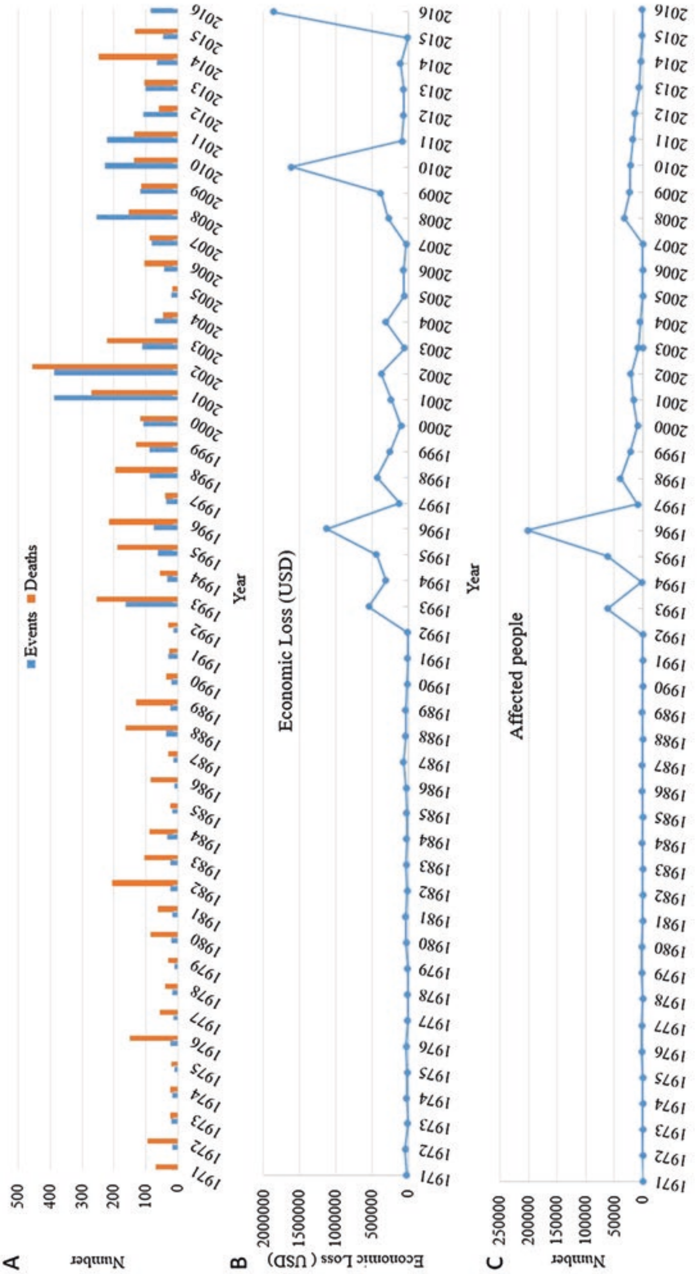

Fig. 20.2 Yearly record of landslide in Nepal from 1971 to 2016. **(a)** Number of landslide events vs. total deaths, **(b)** economic loss in USD, and **(c)** affected people

events (11) occurred in 1975, 1979, and 1986 in which 19, 29, and 86 people lost their lives, respectively (Fig. 20.2a). The number of landslide events was high (≥ 100 events) in 1993–1996, 2000–2003, and 2007–2013; however, the trend of the landslide was fluctuating over the period of time (Fig. 20.2a). There are no clear explanations for increased events; however, it might be a result of increased reporting or local governments started to construct village road during that time. Adhikari and Adhikary (2019) and Petley et al. (2007) reported a similar trend of landslide events and correlated with climatic factors. Similarly, the number of affected people was exceptionally high in 1996 due to heavy rainfall in the Nepal Himalaya (Fig. 20.2c). These landslides destroyed many properties, and country lost more than nine million USD during the analyzed period (Fig. 20.2b).

Geographically, almost all districts of Nepal have landslides (Fig. 20.3), but the density is mostly concentrated around the districts located in the Mahabharat Lekh, Chure range, and central Nepal (Dhading, Sindhupalchowk, and Syangja districts). The landslide distributions in the hills are mainly controlled by the fragile geology, rugged topography, and concentrated rainfall (Petley et al. 2007). There is a positive association between the number of landslides and fatalities; however, this is not true in all districts. For example, Makawanpur, Syangja, Kaski, Bhaktapur, Taplejung, and Doti districts have an inverse association between landslide and fatalities (Fig. 20.3a). The economic loss also shows irregular trends, i.e., Bajura, Kalikot, Gulmi, Taplejung, and Okhaldhunga districts have a high economic loss despite having a low number of landslide events (Fig. 20.3b).

The landslide fatalities were highest in the central development region (1762) followed by the western development region (1404) (Fig. 20.4). These fatalities are mostly related to the population density (CBS 2011) and scattered settlements on vulnerable mountain slopes.

The physiography and climate change significantly varies from Terai to Higher Himalaya due to the high elevation differences. Therefore, the distribution of landslides is also different in three different ecological regions. Hills and mountain regions consist of the highest number of the landslide events and deaths. The trend of landslide events was similar until 1992 in all ecological regions (Fig. 20.5); however, the trend increased after 1992 reaching highest in 2003 (Fig. 20.5a). A trend of deaths shows that the number of deaths is high in the hills followed by mountain and Terai regions (Fig. 20.5b).

4.2 Landslide Early Warning System

The history of LEWS is very short in the Nepal Himalaya. Based on the available literature, the Government of Nepal installed a landslide monitoring system in 1993 for the first time to monitor the Kathmandu-Trishuli road. Then, both government and development organizations started to install regional as well as local LEWSs in different places with different capacities. Regional LEWSs based on rainfall threshold are popular in Nepal because of the cost-effectiveness, easy applicability for

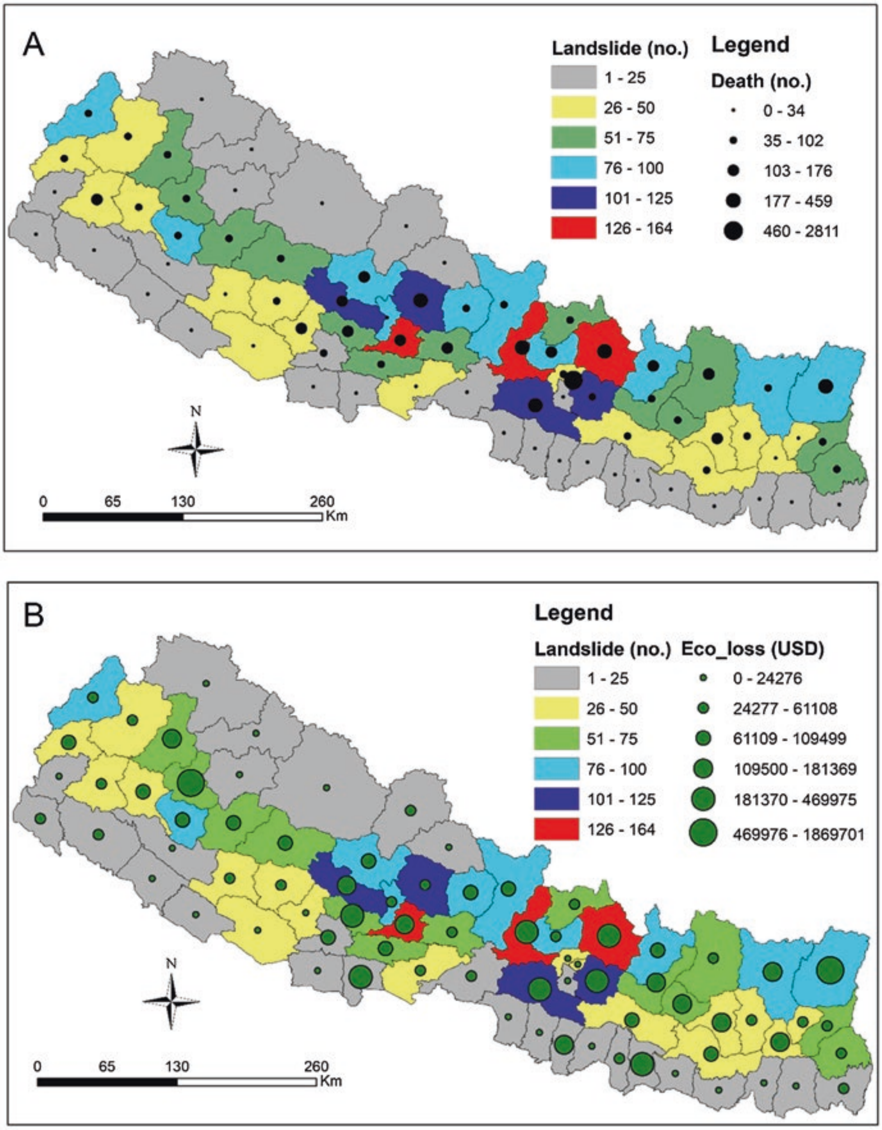

Fig. 20.3 Distribution of landslides from 1971 to 2016. (**a**) Number of landslides vs total death; (**b**) Number of landslides vs economic loss

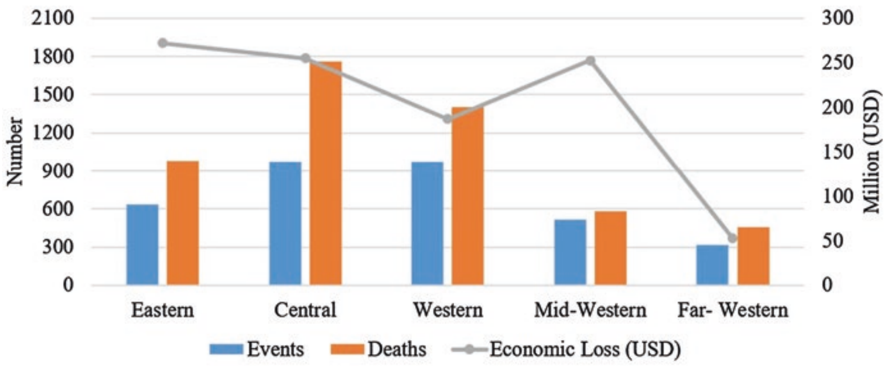

Fig. 20.4 Distribution of lightning events, death, and economic loss in different development regions

large and densely populated areas, and easy to upgrade with new technologies (Calvello 2017). Different previous LEWSs are discussed below.

4.2.1 Kathmandu-Trishuli Road, Central Nepal

Water Induced Disaster Prevention Technical Centre (DPTC), Government of Nepal, installed rain gauge, piezometer, moving pegs, tiltmeter, and extensometers in the Km-19 landslide along the Kathmandu-Trishuli road, central Nepal, in 1993 (Poudel et al. 2001). The landslide damaged more than a 100 m long section of the road and affected 0.015 km^2 of land uphill side of the road. Many tension cracks and inclined trees were monitored with the help of simple and automatic extensometers. The displacement data recorded using simple and automatic extensometers showed a direct relationship with rainfall. This is the first recorded landslide monitoring system to understand the mechanism of a particular landslide in the Nepal Himalaya.

4.2.2 Bhanu VDC, Tanahun

Practical Action, UK, with co-funding from the European Commission Humanitarian Aid and Civil Protection (ECHO) in coordination with the Government of Nepal installed community-based LEWS in 2012 in the Bhanu Village Development Committee (VDC), Tanahun, Nepal, to monitor small-scale landslides (Malakar 2014). More than eight landslides occurred in 2008 in the red to light brown colluvial soil along with residual soil on the top. These landslides destroyed more than 0.057 km^2 arable land, partially damaged houses, and lost livestocks. The project installed both automatic rain gauge (tipping bucket) and manual rain gauge for rainfall measurement. The automatic system was connected to an electronic display board via mobile SIM cards. The alert system was

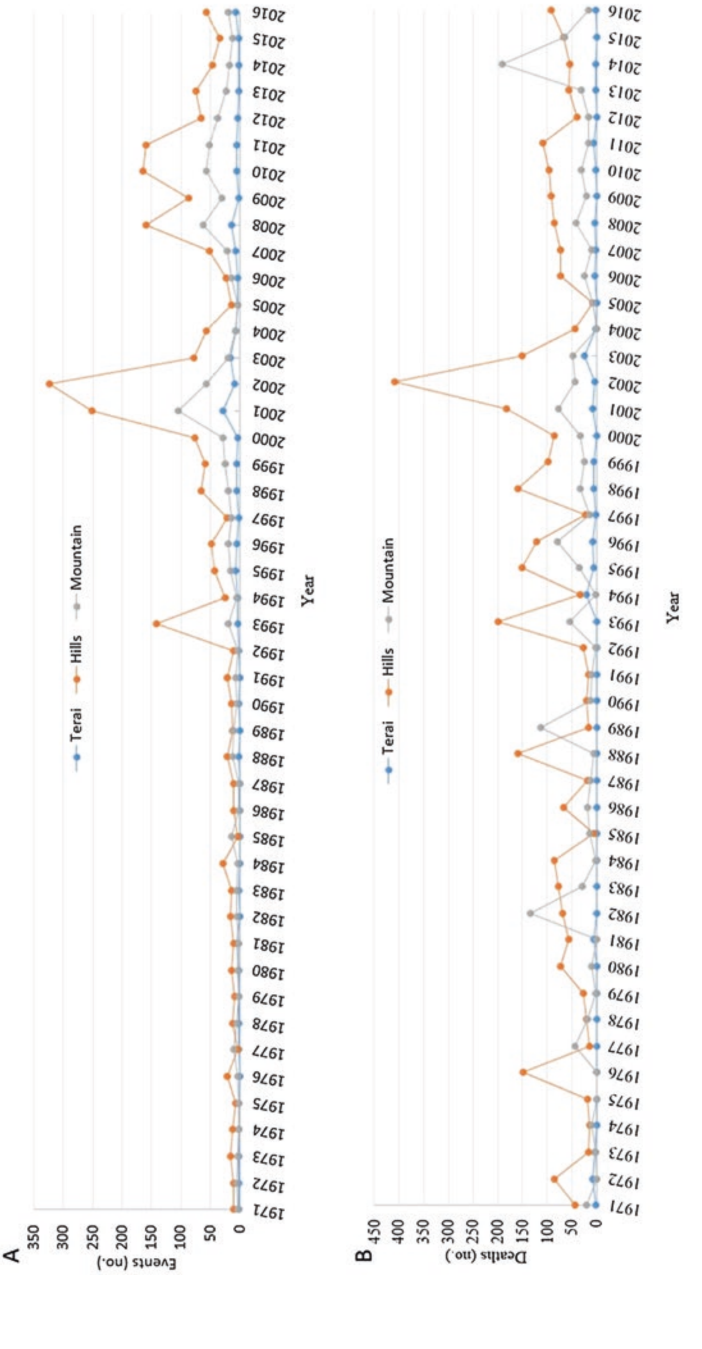

Fig. 20.5 Distribution of events and deaths in three ecological regions of Nepal. **(a)** Number of landslide events vs Year; **(b)** Number of death vs year

placed with hand-operated sirens and megaphones to communicate with the local community. This alert system was based on rainfall durations in 1 and 24 h. The system recorded rainfall from 2012 to 2013. The maximum recorded rainfall was 44.2 mm (1 h and 128 mm (24 h) in July 2013. However, the system did not alert the message because the rainfall was below the threshold (200 mm/24 h) during the project period.

4.2.3 Massey Village, Kailali

Landslide monitoring system (moving peg method) was established in 2014 in the Massey village, Kailali, by Mercy Corps with technical assistance from the Institute of Engineering, Tribhuvan University, Nepal, in coordination with the Government of Nepal (Adhikari and Sitoula 2017). The landslide was 120 m long and 50 m in width making eight houses vulnerable. This system consists of wooden posts longitudinally installed in two series at the interval of 10 meters from the crown to the toe of the Massey landslide (Fig. 20.6a). This landslide monitoring project trained LEWS task force for the regular measurements of the distance between two pegs, which were geo-referenced to the stable points. The maximum rainfall (144.8 mm/24 h) was measured in a nearby station (Sandepani, Kailali) on 14th of August 2014; however, there was no landslide movement during the project period (August 2014–July 2015). Therefore, this rainfall amount can be the rainfall threshold of that area, yet the landslide does not only depend on rainfall but also on local geological and geomorphological conditions.

4.2.4 Nigali VDC, Kailali

Community-led rainfall monitoring was established by Mercy Corps and Practical Action in coordination with the Government of Nepal in Sahajpur and Nigali VDCs of Kailali district in 2012 (Phaiju et al. 2012). This system was installed after the occurrences of large numbers of landslides due to heavy rainfall in September 2008. The system considered both manual rain gauges (200 mm diameter) and automatic rain gauge stations (tipping bucket). The system was able to record data with the help of a data logger, and those data were displaced in the digital board (Fig. 20.6c and d). Rainfall accumulated in 1 h, 12 h, and 36 h were shown by the display board and used for both short- and long-term rainfall monitoring. The community focal person was able to send the warning message after receiving the alert message from that system. Hand-operated sirens and megaphones were used to send the warning to the community.

Fig. 20.6 Some examples of landslide early warning systems in Nepal. (**a**) Measuring landslide displacement by moving peg method; (**b**) LEWS installation in Bijulikot, Ramechhap (Source: Shreelal Poudel); (**c** and **d**) automatic rain gauge and rainfall display board in Kailali; (**e**) LEWS in Sundrawati village, Dolakha; (**f**) LEWS installation in the Khani Gau, Gorkha. (Source: Lalu Sinjali)

4.2.5 Upper Bhote Koshi Valley, Nepal

The National Society of Earthquake Technology (NSET) established a landslide monitoring system with the help of Durham University, UK, in the upper Bhote Koshi valley of central Nepal in 2017 (Durham University 2017). This area is the worst-hit area due to the Gorkha earthquake 2015 and triggered many landslides (Gnyawali and Adhikari 2017). This project installed ten automatic extensometers, with rain gauge equipped with mobile SIM cards and data directly transferred to the Durham University server. The details status of the web-based monitoring system can be accessed from http://community.dur.ac.uk/nepal.2015eq/. This system was developed mostly for scientific research, and there was no warning mechanism and community involvement in the ground.

4.2.6 Ramechhap, Nepal

Mission East Nepal has installed an automatic rain gauge and display board in the Bijulikot, Ramechhap, Nepal, with help from Durham University, UK, to monitor the landslide for the LEWS establishment in 2017 (Oven and Rosser 2017). The Bijulikot landslide, 300 m wide and 400 m long, was located on a dip slope of the laminated schist providing the smooth surface for material move downward. The sliding material consists of saturated silt and clay. This project has installed a strain-based monitoring system using a low-cost moving peg method, and communities were trained for the effective implementation of the LEWS (Fig. 20.6b).

4.2.7 Sundrawati, Dolakha

The Department of Forests and Soil Conservation, Government of Nepal, with the help of Food and Agricultural Organization (FAO) installed automatic rain gauge, soil moisture sensor, and extensometer for LEWS in the Mehele landslide, Dolakha, in 2018 (Thapa and Adhikari 2019) (Fig. 20.6e). The landslide is about 160 m in length and 40 m wide and covered with grassland. Many cracks are present in the upper and middle parts of the slide. Geologically, this area is mostly dominated by mica-schist, augen gneiss, gray phyllites, and quartzite (DMG 2011). The system was connected to a mobile SIM card to provide an alert message and siren. The threshold value was assigned for 24-h accumulated rainfall, which was equal or more than 50 mm and crack opening equal to or more than 30 cm. The LEWS orientation program was conducted in rural municipality/ward office, Local Disaster Management Committee (LDMC), and district soil conservation officers for effective communication of the warning and response. The LEWS worked perfectly during the landslide occurrence on 23rd of August 2018, and more than 400 people were saved.

4.2.8 Khani Gau, Gorkha

The National Academy of Science and Technology (NAST) has installed LEWS in Khani Gau, Gorkha, in 2019. The system installed the Global Positioning System (GPS) to record the movement of the landslide and the mobile SIM card to transfer the data to the control station (Fig. 20.6f). The landslide occurred in colluvial deposits and mostly composed of silt, gravel, and boulders. Communities were involved during the installation and got training for operation and rescue during the landslides.

5 Discussions

The landslide trend analysis from 1971 to 2016 shows the positive relationship between landslide and geographical distribution. The landslide occurs on the slopes of the mountains which destroys many lives and property as most of the settlement are residing in the paleo-landslides. The number of deaths is higher in hills compared to mountains and Terai, which might be due to high population density (186) in hills compared to mountains and Terai (CBS 2011). For example, the 1993 cloud burst event in central Nepal killed 52 people and destroyed many houses in Phedi Gau, Makawanpur district (Dhital et al. 1993). Besides this, the number of landslides increased significantly after the Nepalese government prioritized road construction after 1992. Therefore, almost all Village Development Committees (VDCs) and municipalities spent most of their annual budget for road construction. Unfortunately, most of those road constructions were not fully engineered. So, many landslides were triggered in the following monsoon. This change in fatalities coincides with the Maoist civil war (1996–2006) because the conflict had increased the vulnerability due to the constant migration from Maoist-controlled rural areas to government-controlled urban areas (Petley et al. 2007). McAdoo et al. (2018) have reported that the new road construction in the Nepalese mountains has severely hindered the socioeconomic developments and contributes to loss of life. Even these days, roads in rural areas are being constructed without considering engineering norms and values. If the road construction continues in a similar approach, then there will be more landslide in the future. People migrated toward the road corridor from the rural areas for economic opportunities and started to build houses along the road. Such migration increases the vulnerability in the mountain slopes. The increasing number of landslide events in the database in recent years might be related to a global increase in mobile technology and the Internet. Gorkha earthquake 2015 has triggered many coseismic landslides (Gnyawali and Adhikari 2017; Roback et al. 2018) in central Nepal. These landslides were reactivated by the monsoon in the next years. Anthropogenic activities such as slope modification, improper agricultural practice, and deforestation are also playing an important role in landslide generation (Froude and Petley 2018).

The rapid and informal house construction in the landslide hazardous zone after the earthquake is mostly due to low income or lack of awareness. Therefore, the Government of Nepal should emphasize proper planning on construction, safe area identification, and awareness raising about landslide hazards. Currently, the government mostly focuses on mitigation of landslide using high-tech engineering construction, i.e., retaining walls and bioengineering to control major landslide in the mountains. However, it is important to install LEWS where mitigation options are not feasible and very expensive. Some installed LEWSs are project basis and do not work for a longer period after the project termination. Therefore, the preparation of a nationwide landslide hazard map and web-based landslide recording system for future prediction should be implemented urgently. It is also recommended that the proposed system should be connected with existing weather stations of the Nepal Himalaya.

6 Summary and Conclusions

The landslide trend analysis identified the landslide hotspot districts in Nepal. The analysis shows that the number of deaths not only depends on number of landslides but also depends on size and extent of landslides and location of settlements from the landslides. Hilly districts of central and western Nepal are the most affected areas due to fragile geology and concentration of population. The trend shows that the number of landslides is increasing almost every year since 1992 due to nonengineered road construction, rural-urban migration, increased population, and heavy rainfall. There are some existing landslide early warning system (LEWS) practices in the Nepal Himalaya, but most of them vanished after the completion of the project. Low-cost community-based LEWSs are the most effective methods in the rural parts due to its easiness to handle and operate, and therefore they should be replicated in other parts of Nepal. Nepal government should start to build a nationwide dynamic landslide inventory database system connected with weather stations for the monitoring and forecasting of the landslide.

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