Saeid Eslamian
Faezeh Eslamian *Editors*

Disaster Risk Reduction for Resilience

Disaster Economic Vulnerability and Recovery Programs

Springer

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Editors
Saeid Eslamian
Department of Water Engineering
Isfahan University of Technology
Isfahan, Iran

Faezeh Eslamian
McGill University
Montréal, QC, Canada

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To Professor David Herbert Pilgrim (1931–2015), my late PhD supervisor, having more than 300 technical papers on flood hazard estimation

Preface

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

The United Nations System Chief Executives Board for Coordination (CEB), at its 2011 Spring Session, committed to mainstreaming Disaster Risk Reduction in the programs and operations of the UN system through the development of a common agenda, and to raise disaster risk reduction to the highest political support. UNISDR (United Nations Office for Disaster Risk Reduction) Strategic Framework 2016–2021 is guided by supporting countries and societies in its implementation, monitoring, and review of progress, 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 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, by 2030.

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

The Seven Global Targets could be summarized as follows:

(a) Substantially reduce global disaster mortality by 2030
(b) Substantially reduce the number of affected people globally by 2030
(c) Reduce direct disaster economic loss in relation to GDP by 2030
(d) Substantially reduce disaster damage to critical infrastructure, among them health and educational facilities
(e) Substantially increase the number of countries with local disaster risk reduction strategies by 2020
(f) Substantially enhance international cooperation to developing countries through adequate and sustainable supports
(g) Substantially increase the availability of the access to multi-hazard early warning systems by 2030

The Four Priorities for Action for Sendai Framework 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 book series **Handbook of Disaster Risk Reduction for Resilience (HD3R)** attempts to fill theory and practice gap in the Sendai Framework through publishing the six proposed books. There is a big hope that learning primary and secondary audiences of HD3R helps to meet several Sendai targets and priorities for action, and book series publications on HD3R could be continued beyond publishing these six books up to 2030.

For assisting the UN objectives in disaster risk reduction, the 2022 Handbook Series of Disaster Risk Reduction for Resilience (HD3R-2022) have been contracted by Springer. This volume's chapter titles are given below:

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

This book is part of a six-volume series on disaster risk reduction and resilience. The series aims to fill in gaps in theory and practice in the Sendai Framework, and provides additional resources, methodologies, and communication strategies to enhance the plan for action and targets proposed by the Sendai Framework. The series will appeal to a broad range of researchers, academics, students, policy makers, and practitioners in engineering, environmental science and geography, geoscience, emergency management, finance, community adaptation, atmospheric science, and information technology.

The current handbook, as the fourth book of this series, on vulnerability and recovery programs of disaster risk includes 15 chapters as summarized below:

This volume focuses on the concepts of economic and development vulnerability, and discusses the roles of physical, social, cultural, political, economic, technological, and development factors that contribute to disaster impacts and threat levels on vulnerable populations. This approach explores how the resilience of individuals and communities can be increased in the face of future hazard threats, and how post-disaster efforts are planned for and implemented to manage risk reduction and the potential outcomes of hazard threats. Topics addressed in the book include disaster recovery reform and resilience, recovery and development programs, place-based reconstruction policies, resilient and sustainable disaster relief and recovery programs, sustainable community development, and disaster recovery and post-hazard recovery strategies.

Students in all three levels (and also short courses) and instructors, lecturers, and professors are the primary audiences.

The secondary audiences include industry members (earthquake industries, pollution control industry, chemical factories, construction industry, and transportation Industry); policy makers; consulting engineers; researchers (civil engineering, geosciences, natural geography, environmental science and engineering, hydrologic engineering, atmospheric sciences, environmental sanitation, applied sciences, statistics, and information technology); National Hazard Centers; National Weather Services, IPCC members; insurance companies; International Bank for Reconstruction and Development; UNDRR; UNEP; Community Resilience Centers; emergency management agencies; and disaster risk managers.

Isfahan University of Technology — Saeid Eslamian
Isfahan, Iran
McGill University — Faezeh Eslamian
QC, Canada

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About the Editors

Saeid Eslamian is 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. 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 1000 publications in journals, books, and technical reports. He is the founder and chief editor of the *International Journal of Hydrology Science and Technology* (IJHST). Eslamian is now associate editor of five important publications: *Arabian Journal of Geosciences* (Springer), *Eco-Hydrology and Hydrobiology* (Elsevier), *Water Reuse* (IWA), *Journal of the Saudi Society of Agricultural Sciences* (Elsevier), and *International Journal of Climate Change Strategies and Management* (Emerald). Professor Eslamian is the author of more than 50 books and 300 book chapters.Dr. Eslamian's 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*, *Eco-Hydrology*, *Journal of American Water Resources Association*, and *American Water Works Association Journal*. UNESCO has also nominated him for a special issue of the *Eco-Hydrology and 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 the 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 distinguished national researcher in Iran. Dr. Eslamian was 2019 Nomination "High" Score for UNDP Equator Prize. He also was Stanford World Top Researcher 2% in 2019 and 2020.He has also been the referee of many international organizations and universities. Some examples include the U.S. 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 took admission at 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 26 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 the Center of Excellence for 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 late Professor Eric F. Wood at the School of Engineering and Applied Sciences for 1 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 14 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), *Handbook of Irrigation System Selection for Semi-Arid Regions* (2020), *Urban and Industrial Water Conservation Methods* (2021), and the three-volume *Flood Handbook* (2022). The two-volume *Handbook of Water Harvesting and Conservation* (2021) has been awarded New York Academy of Science. His books *An Evaluation of Groundwater Storage Potentials in a Semiarid Climate* and *Advances in Hydrogeochemistry Researc*h by Nova Science Publishers (USA) were also published in 2019 and 2020, respectively.The six-volume series Handbook of Disaster Risk Reduction and Resilience is also one of the Saeid Contribution to knowledge that four volumes have been published so far.

Faezeh Eslamian holds a PhD in bioresource engineering in 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 across the world on 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.

Part I
Economic Vulnerability in Disaster Environments

Chapter 1
Systemic Risk and Mitigating Economic Disasters in the Arctic: Cases of Oil Spills, Cruise Ships, and Pandemics

David Cook and Lara Johannsdottir

Abstract The Arctic constitutes a significant geopolitical and economic region, becoming increasingly globalized in the recent decades. Considerable economic opportunities are observed, such as growth in hydrocarbon and mineral utilization and tourism. However, the vulnerabilities of the Arctic – especially its remoteness, environmental sensitivity, cold climate, sparse population, and limited infrastructure – ensure that the potential for systemic risk events to unfold is of greater likelihood than elsewhere on the planet. This chapter provides a synthesis of three recent studies on systemic risk in the Arctic, which focus respectively on the issue of oil spills, cruise ships, and the COVID-19 pandemic. The three studies consider the economic implications of disasters in the Arctic from a systemic perspective, and this chapter explores commonalities, differences, and residual risks after mitigation methods. Disasters involving oil spills and cruise ship incidents exemplify systemic consequences, involving economic losses for the businesses directly involved, but also a chain of negative impacts to related industries, loss of trust in the industry, and often prolonged court cases to determine the extent of compensation claims and liabilities. The impacts of the COVID-19 pandemic are also demonstrative of interconnectedness, involving a cascade of impacts between sectors, with national governments acting as an insurer of last resort to sustain the incomes of businesses and individuals. The case studies provided in this chapter reinforce the need for risk mitigation strategies to consider the potential for systemic risk events to unfold in the Arctic. Risks are difficult to quantify in the Arctic, and insurance premiums are frequently calculated on a case-by-case basis. However, the insurance sector plays an important role in determining safety standards, often through alignment with fairly recent protocols such as the Polar Code.

D. Cook
Environment and Natural Resources, Faculty of Economics, University of Iceland, Reykjavík, Iceland

L. Johannsdottir (✉)
Environment and Natural Resources, Faculty of Business Administration, University of Iceland, Reykjavík, Iceland
e-mail: laraj@hi.is

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Keywords Economic disaster · Systemic risk · Mitigation · Oil spill · Cruise ship · Pandemic

1 Introduction

There are many definitions of the term "risk." For the purposes of this chapter, we will utilize the definition outlined by the Intergovernmental Panel on Climate Change, which describes a risk as "the potential for adverse consequences from a hazard for human and natural systems, resulting from the interactions between the hazard and the vulnerability and exposure of the affected system" (IPCC, 2018, p. 33). This definition affirms that there are connections between risks and systemic consequences for human and natural systems. Often the concept of systemic risk is applied to describe disastrous events of such severity that they involve the unleashing of a cascade of negative economic consequences (Burkholz et al., 2018; Schwarcz, 2008). Schwarcz (2008, p. 198) also depicted systemic risk as involving "significant losses to financial institutions or substantial financial-market price volatility." Based on these understandings, Schwarcz (2008) considered systemic risk to constitute a risk *to* a financial system rather than a risk *within* the system. A similar distinction has been made by the London School of Economics, whereby shocks from outside (exogenous to) a system are distinguished from shocks within the system (endogenous to) (Danielsson & Shin, 2002). Schwarcz (2008, p. 204) proceeds to set out the following definition of systemic risk that will be relied upon in this paper:

> The risk that (i) an economic shock such as market or institutional failure triggers (through a panic or otherwise) either (X) the failure of a chain of markets or institutions or (Y) a chain of significant losses to financial institutions, (ii) resulting in increases in the cost of capital or decreases in its availability, often evidenced by substantial financial-market price volatility.

It is useful to consider the incidence of systemic risk within a scale of risk. The pyramidic scale of Thurm et al. (2018) considers the following risks: nano (to individuals and careers), micro (to enterprises), meso (to portfolios), systemic (macro), and cosmic (existential). Much of the focus of the risk literature has been on the meso level, focusing on investment portfolios, albeit the issue of systemic risk has been garnering increased attention in recent years (Thurm et al., 2018; Cook & Jóhannsdóttir, 2021; Johannsdottir & Cook, 2019; Johannsdottir et al., 2021). This has perhaps been due to increased public awareness of systemic risk events that lead to financial volatility, significant financial losses, and/or market and institutional failure. A classic example was the Icelandic banking collapse of 2008, where the nation's entire banking system collapsed (Árnason et al., 2010). Other, highly visible, examples are megaprojects such as infrastructure projects, for example, airports, cruise ships, mines, offshore oil and gas extraction platforms, and so on (Flyvbjerg, 2014; Johannsdottir & Cook, 2019; Salonen, 2021). These are projects that are inherently risks for a number of reasons, with difficulty estimating the duration and costs of delivery (Flyvbjerg, 2014), and significant consequences of disasters linked to infrastructure failure, such as in the cases of the Piper Alpha oil platform explosion in 1988 (Hill et al., 2021) and BP Deepwater Horizon oil spill in the Gulf of Mexico in 2010 (Ebinger, 2016; Chamberlin, 2014).

One region where the topic of systemic risk has been a focal point is the Arctic. Although remote and sparsely populated, with a total population of approximately four million, the Arctic has become geopolitically and economically significant, not least due to the potential for further utilization of fossil fuel and mineral resources and emerging transportation routes, such as the Northwest Passage and Northern Sea Route, and the growing importance of tourism, especially involving cruise ships (Hausner et al., 2021). If the region's resources are to be further utilized, infrastructure development is needed (Kaiser et al., 2018), with Guggenheim Partners (2016) estimating that the Arctic's investment needs over the 15 years up to 2030 amassed to around USD one trillion. However, such developments are inherently risky in a region with limited existing infrastructure in some parts (Kruke & Auestad, 2021) and critical care and search and rescue facilities (Johannsdottir et al., 2021), an often extreme climate (Avila-Diaz et al., 2021; Christensen et al., 2021), and a largely pristine marine ecosystem that provides multiple ecosystem services of significance to human well-being (Malinauskaite et al., 2019; O'Garra, 2017).

The topic of systemic risk in the Arctic has recently received considerable attention in three publications on oil spills (Johannsdottir & Cook, 2019), cruise ship incidents (Johannsdottir et al., 2021), and the COVID-19 pandemic (Cook & Jóhannsdóttir, 2021). The studies on oil spills and cruise ship incidents considered the economic and sustainability implications of such events unfolding in the Arctic, using examples from the region and consideration of how worst-case examples from elsewhere in the world might materialize there. In the case of the COVID-19 study, which focused on impacts specific to Iceland and Greenland, economic and sustainability impacts were identified across all affected industries. The aim of this chapter is to provide a synthesis of the economic impacts of system risk events identified in these three studies, with a view to identifying common themes in mitigation measures that can reduce the extent of the negative, macro-scale impacts. Three research questions (RQ) are explored, as follows:

1. What are the economic implications of systemic risk events in the Arctic with respect to oil spills, cruise ship disasters, and the COVID-19 pandemic?
2. What mitigation measures have been adopted by governance institutions and relevant authorities to reduce the effects of systemic risk events?
3. What residual risks and information needs remain after mitigation measures?

Section 2 of this chapter is split into three sections with respect to oil spills, cruise ships, and pandemics. In each case, a brief summary is provided concerning the recent history of developments and systemic risk events in the Arctic, before the specific economic implications are described with respect to market/institutional failures and financial volatility. This provides the response to RQ1. In Sect. 3, the mitigation measures and some of the residual risks are explored, responding to RQ2 and RQ3, respectively. For reasons of confined space, this chapter does not describe the methodologies that were adopted in the studies on which this synthesis is based; however, these are described in detail in the respective journal articles.

2 Economic Disasters Related to Oil Spills, Cruise Ships, and Pandemics

2.1 Oil Spills

Although there has been interest in developing Arctic hydrocarbon resources for many decades, this has reduced more recently due to lower resource prices, technical challenges of operations in the Arctic, falling demand for fossil fuels in the midst of the COVID-19 pandemic, and the climate change policy agenda (Gulas et al., 2017; Hausner et al., 2021). However, there remains considerable potential for expansion in the activities of extractive industries in the Arctic, with the US Geological Survey estimating in 2008 that the Arctic included around 90 billion barrels of oil, 1669 trillion cubic feet of gas, and 44 billion barrels of natural gas, with 84% of these combined resources located offshore (Bird et al., 2008). To date, five Arctic states have explored, extracted, or extended their exclusive rights to oil and gas resources in the region: Canada, the US, Russia, Norway, and Denmark (Hausner et al., 2021). Most Arctic hydrocarbon resources remain to be explored and are located on continental shelves and/or international waters beyond continental shelves (Gulas et al., 2017). In the future, Arctic hydrocarbon production is likely to include developments in remote and environmentally sensitive regions, including Norway's Lofoten Islands (Mohn, 2019), Alaska (Hansen & Ipalook, 2020), and Russia's continental shelf (Carayannis et al., 2019; Poussenkova, 2019).

Although oil spills in the Arctic have been rare to date, they have the potential to induce market failures and financial volatility in several industries dependent on the abundance and relative pristineness of marine resources. The Exxon Valdez oil spill in Prince William Sound, Alaska, in 1989 is the most significant and largest to date in Arctic waters. Running aground on the Bligh Reef, 11 million gallons of Prudhoe Bay crude oil was spilled, some of which remains present to this day (Barron et al., 2020). Systemic economic consequences unfolded with respect to Exxon and the oil industry and indirectly in relation to other industries in Prince William Sound. As outlined by Perry (2010), Exxon incurred nearly USD 2.1 billion in clean-up costs; pleaded guilty to several criminal violations leading to fines; settled a civil action by the United States and Alaska; paid USD 303 million in voluntary settlements, mainly to fishers; paid out USD 287 million in civil litigation damages to commercial fishers; and paid out a little over USD 500 million in punitive damages. With regard to indirect impacts to tourism, visitor spending alone reduced by USD 19 million the following year (McDowell Group, 1990).

The burden of responsibility held by Exxon for the disaster led to economic damages which at the time were unprecedented for any oil spill. Johannsdottir and Cook (2019) discuss how the oil spill led to considerable spillover effects and job losses in related industries, which persisted for many years after the disaster. The negative publicity and loss of trust linked to the disaster and resultant litigation lasting for decades entailed direct implications for Exxon but also the oil industry in general, especially with respect to public and institutional perceptions concerning the riskiness of oil projects in Arctic waters. Other economic consequences of the Exxon Valdez oil spill were less visible and quantifiable, but nevertheless significant for those affected. Stress-related impacts on survivors, plus physical and psychological health effects on survivors, locals, and/or children, including post-traumatic stress, anxiety, or depression, have been consequences reported in relation to clean-up activities or loss of economic status (Palinkas et al., 1992; Skinner & Reilly, 1989). Additionally, strain on publically funded infrastructure and negative social externalities were reported in connection with clean-up activities in remote and sparsely populated Alaskan communities due to the considerable expansion in the local population (Taylor, 2014). Green et al. (2016) reported on how local housing availability was insufficient, social organizations were put under immense pressure, crime rates spiralled, and the health, sewer, and garbage agencies could not keep up with the massive upscaling in activities. The economic costs associated with the need for long-term health surveillance and longitudinal studies on those involved in clean-up activities and exposed residents are unlikely to ever be recoverable and are highly likely to be passed on to taxpayers (Lichtveld et al., 2016).

2.2 Cruise Ship Incidents

In the period prior to the COVID-19 pandemic, Arctic tourism grew considerably, with expansion centered on Iceland, the Faroe Islands, Alaska, and parts of Arctic Fennoscandia, with Greenland, the Russian Arctic, and Canada likely to be emerging hotspots in the future (Runge et al., 2020). Seaborne tourism, in particular the cruise ship industry, has been one of the fastest-growing segments of Arctic tourism (Bystrowska & Dawson, 2017; Palma et al., 2019). In the space of 2 years from 2015 to 2017, the number of cruise ship visitors to Iceland increased by 65% from 265,935 to 402,834 (Icelandic Tourist Board, 2018). Ports in northern Norway experienced a 33% uplift in cruise ship visitors in the 5-year period from 2014 to 2019 (Bystrowska & Dawson, 2017), with the number of visitors to Svalbard increasing by 62% over the period 2008–2017 (AMAP, 2018). Overall, the number of cruise ship visitors to the High Arctic increased by 57% from 67,752 in 2008 to 98,238 in 2017 (Palma et al., 2019). There are likely to be many reasons why tourists choose to visit the Arctic, many of which can be bracketed under the motivation of "last chance tourism" (Lemelin et al., 2013; Veijola & Strauss-Mazzullo, 2019). This is perhaps something of a misconception, since this notion reflects the dynamic changes brought about by climate change – tourists perceive it as their last chance to see the region in its current form (Hausner et al., 2021).

Although Arctic cruise ship incidents are relatively rare, as a proportion of total cruise ship journeys, they seem as common in this region as anywhere else and perhaps more likely to occur in the future due to the increased number of cruises into the Marginal Ice Zone (Hausner et al., 2021). Johannsdottir et al. (2021) detail six major incidents in the Arctic over the period 1989–2019, which have included groundings, engine failure in bad weather, and collisions with icebergs. Although none of these incidents resulted in loss of life, which was seemingly by luck, the most significant incident involving the Viking Sky in the Norwegian Sea in 2019 resulted in a need to evacuate and rescue 1373 passengers. Following an iceberg strike close to Svalbard, 953 passengers had to be rescued from the TS Maxim Gorky in 1989. Other cruise incidents around the world have frequently resulted in loss of life, even capsizes very close to shore, such as the Costa Concordia, and if replicated in Arctic waters could result in even graver outcomes.

There are some clear parallels between the economic implications of oil spills and cruise ship incidents in the Arctic. Both types of disaster led to negative impacts for the company involved and spin-off effects on its industry. In the case of the former, there were reduced profits and negatively impacted financial performance, largely linked to sizable liability claims and clean-up or salvage costs, such as wreck recovery and disposal. The costs of wreck recovery were incurred by the companies involved in the MS Explorer and MV Clipper Adventurer incidents. Industry-scale impacts related to job losses and negative effects on businesses reliant on cruise ship visitors, such as gift shops, cafes, and restaurants. There can also be a palpable loss of trust in the whole cruise ship industry, locally and further afield, when incidents involve the rescue and emergency of many passengers and receive critical international press coverage (Johannsdottir et al., 2021).

In some cruise ship incidents, prolonged litigation has occurred as survivors seek compensation. This was the case in relation to the MS Explorer incident, following which survivors pursued damages of close to 41 million euros based on the perception of "intentional fault." The case of the MV Clipper Adventurer in 2010 led the Ottawa Government to pursue claims for environmental damages after the incident led to fuel and sludge spills. The owners of the cruise ship, Adventurer Owner Ltd., were required to pay CAD 500,000 in environmental costs to the government after a court verdict in February 2017. Another cruise ship incident involving legal claims is the Viking Sky. Although still to be resolved, a class action lawsuit was filed against Viking about the on-board emergency in March 2019, during which the ship lost all power and had to be evacuated in rough seas. This would seek compensation beyond that already paid out by Viking, which has already encompassed the costs of the cruise, air fares, and other expenses during the trip.

As per the overburden sometimes placed on remote Arctic communities during oil spill clean-ups, the social costs of cruise ships may place strain on local communities, with considerable demands placed on limited critical infrastructure. In the case of cruise ships, this can also include the costs of search and rescue, including the coastguard, and hospital treatment for any injured individuals. Insufficient infrastructure was evidenced in the case of the M/V Clipper Adventurer that ran aground in Nunavut, Canada, in 2010, where there were not enough local medical services to cope with an incident involving the rescue of 197 passengers. This deficit entails significant logistical challenges and additional costs – compared to less remote locations – for search and rescue and emergency services (Johannsdottir et al., 2021).

2.3 Pandemics

The impacts of the COVID-19 pandemic have been experienced the world over, with, at the time of writing in August 2021, nearly 4.5 million deaths and 215 million cases across the planet (Worldometer, 2021). The recently published article by Cook and Jóhannsdóttir (2021) focused on the impacts of the pandemic on the Arctic island nations of Iceland and Greenland, which were chosen because they exemplified the challenges and risks specific to many Arctic nations – a low and scattered population (circa 368,000 in Iceland and 56,000 in Greenland) with close knitted communities, reliance on natural resources for livelihoods and income, and limited critical response capacity in cases of crises (Cook & Jóhannsdóttir, 2021). Iceland had its first COVID-19 infection in February 2020, and by 26 August 2021, the total number of cases was 10,341 of whom 9402 had recovered. A total of 31 deaths had occurred (Worldometer, 2021). Greenland's first infection was confirmed in March 2020. Since then, a total of 313 cases have been reported, of whom 243 have recovered. No deaths have been ascribed to COVID-19 (Worldometer, 2021).

The COVID-19 pandemic differs somewhat from oil spills and cruise ship incidents since it directly impacted several economic sectors simultaneously. Cook and Jóhannsdóttir (2021) report on how national unemployment rates in Iceland reached as high as 12%, the highest for nearly 10 years. In some regions, rates were much higher – on the Reykjanes peninsular, unemployment rates soared to as high as 26% and have been as much as five times higher among women than men. In addition, unemployment rates in the region were reported as being 6% higher among immigrants (20%) than their 14% share of the national population. Much of the unemployment in Iceland related to the decline in the tourism industry – foreign visitors in 2020 numbered only 478,510, a 75.9% reduction on the 1,986,153 visitors in 2019. The cruise ship industry was hit harder still, with the number of visitors to Iceland reducing by 99.6% from 549,000 in 2019 to 2300 in 2020. Macro-economic hardship has also befallen Greenland. Cook and Jóhannsdóttir (2021) summarized several negative impacts on the tourism and transportation sectors, particularly in relation to reduced air and cruise ship traffic. Overall tourism revenues were projected to be down 67–90% in 2020 compared to 2019, and the cruise ship industry was in abeyance throughout the summers of 2020 and 2021. This has had consequences for fly-in fly-out workers, especially Danes and other foreigners, who have been used to working in the Greenlandic tourism sector during previous summers (Economic Council of Greenland, 2020).

Other economic sectors afflicted by the COVID-19 pandemic include fisheries and fish processing and raw materials and energy (Economic Council of Greenland, 2020). These impacts were associated with falling resource prices and reduced demand for commodities. Export prices for Greenlandic fish products reduced by up to 20% in 2020, which was projected by the Economic Council of Greenland (2020) to reduce public revenue directly by DKK 232 million (USD 38 M), of which resource rent taxes would be down by DKK 113 million, income taxes by DKK 92 million, and corporate taxes by DKK 27 million. Systemic consequences have been evident in relation to supply chain disruptions in both Greenland and Iceland. Fish markets were affected early in the COVID-19 pandemic due to transportation restrictions on air freight and closures of global markets (Deloitte, 2020; SeafoodSource, 2020). The need for fresh fish and shellfish products was also greatly reduced in these nations because of the near cessation of the tourism sectors, with negligible demand from the hospitality and food service sectors (Economic Council of Greenland, 2020; Cook & Jóhannsdóttir, 2021).

Economic impacts on the tourism industries in Iceland and Greenland were severe (Economic Council of Greenland, 2020; RÚV, 2021). Cook and Jóhannsdóttir (2021) cite several examples from Iceland. The company Arctic Shopping, which owned the subsidiary gift shops of Lundinn, Óðinn, Thor, and Jólahúsið, closed all its shops in spring 2020. Subsequently, one of the leading gift shops in Iceland, Geysir, was forced to shut in February 2021, and all employees were laid off just prior to the company being declared bankrupt. A survey in October 2020 of businesses on Laugavegur, the main shopping street in the capital city of Reykjavík, reported that nearly 40% of all ground floor businesses were closed (Iceland Monitor, 2020). There have been highly negative spillover effects on the profits and viability of tourism-dependent operations, such as museums, cafes and restaurants, art and design stores, and book shops.

Other costs in Iceland and Greenland have included increased national government expenditures on furlough schemes, especially to keep tourism-dependent businesses afloat, additional investment in healthcare and education, and targeted investment in infrastructure projects to assist the vitality of the recovery. The need for governments to borrow money to finance such endeavors increases the likelihood of higher future tax rates which may constrain macroeconomic performance, all other factors being equal (Economic Council of Greenland, 2020; Icelandic Chamber of Commerce, 2020; OCED, 2020).

3 Discussions

3.1 Summary of Economic Impacts

The three examples of oil spills, cruise ship incidents, and pandemics may differ characteristically; however, there are many commonalities in terms of negative economic implications, which are highlighted in Table 1.1. All disasters entail

Table 1.1 Negative economic implications of Arctic disasters

Negative economic implications	Oil spills	Cruise ship incidents	Pandemics
Direct loss of revenue and profits for "guilty" and/or affected parties	✓	✓	✓
Economic losses for related local industries, e.g., fishers and tourism actors	✓	✓	✓
Direct and indirect job losses in affected industries	✓	✓	✓
Loss of trust in the industry and the quality/safety/reliability of local produce and supply chain functionality	✓	✓	✓
Need for increased government expenditure to maintain the viability of industries and companies			✓
Need for intervention by governments and government agencies (e.g., law enforcement, military, rescue services) to minimize consequences	✓	✓	✓
Industry uncertainty, increased resource prices, reduced share/stock prices, and diminished investor confidence	✓	✓	✓
Costs of compensation – Fines, voluntary payments, settlement funds, court and legal fees, etc.	✓	✓	
Costs of salvage/clean-up	✓	✓	
Increased costs of healthcare (including hospitalization) linked to exposure and/or clean-up	✓	✓	✓
Stress, psychological, and other health impacts with economic and productivity implications	✓	✓	✓
Strain on limited public infrastructure, care and rescue facilities, and evidence of need for increased investment	✓	✓	✓

industry-specific consequences over the short, medium, and longer term, but there are considerable spillover effects to related sectors, exemplifying the systemic and interconnected nature of consequences.

3.2 Approaches to Risk Mitigation

3.2.1 Current and Potential Role of Insurance and Risk Management Policies

Thus far, there has been a fairly limited discussion in the Arctic concerning the role of insurance in mitigating systemic risk in the Arctic. Insurance is undoubtedly relevant in the context of oil spills and cruise ship incidents, not least with respect to physical damage or loss of equipment, covering during and after construction of a project, business and income interruption, operator's expenses, workers' compensation in cases of injuries or death, and environmental/pollution-related liabilities (Johannsdottir & Cook, 2019; Johannsdottir et al., 2021). The insurance sector also has a role in loss prevention and claims settlement, both in cases of oil spills and cruise ship incidents; however, it has been recognized that the energy industry needs greater standardization with respect to the design and execution of drilling in such extreme, ice-laden environments, and insurers need greater knowledge concerning their accumulative exposure to systemic risks (Johannsdottir & Cook, 2019; Johannsdottir et al., 2021). Emmerson and Lahn (2012) voiced that in cases of pollution events, such as oil spills, it can be difficult to allocate liabilities due to the presence of several companies involved in the disaster. In addition, PwC (2014) recognized that there were limits in the extent to which insurance mechanisms can mitigate due to uncertainty and lack of data, lack of understanding, reactive pricing, regulatory issues, and the limits of insurability.

Nevertheless, Cook and Jóhannsdóttir (2021), Johannsdottir and Cook (2019) and Johannsdottir and Wallace (2020) identify several roles for insurers with respect to oil spills and cruise ship incidents, which are exacerbated in importance due to the additional riskiness of operations in Arctic waters. These include the following:

- Product and service offering, underwriting and risk management, loss prevention and claims settlement, and investments.
- Bridging the gap between heterogeneous stakeholders and, as institutional investors, influencing company behavior and market trends, e.g., by insisting that environmental-economy risks are incorporated into the strategic and resilience planning of oil and cruise ship companies (Eslamian et al., 2021).
- Communicating with regulators and governments, collaborating with other insurers and reinsurers, and participating in industry initiatives to share knowledge.
- Reviewing investment portfolios, identifying opportunities with respect to securing competitive advantages, and assessing underwriting guidelines to ensure they consider systemic risks.

These pursuits are especially important in the context of the Arctic, where uncertainties and potential liabilities are very high. In fulfilling the roles outlined in the bulleted list, insurers will have greater capacity to (1) assess risks relative to objectives or interests (what should be avoided and what is the likelihood); (2) assess what are the biggest risks (worst-case scenarios); (3) consider the full range of probabilities (low probability in the Arctic might result in high risks and high costs); (4) use best available information (could be science or expert judgment or, in the case of the Arctic, include indigenous knowledge); (5) take a holistic view, including systemic risk and direct risk; and (6) be explicit about value judgments (Johannsdottir & Cook, 2019). Fulfillment of these objectives is likely to result in the minimization of risks because it will induce the further development of systemic crises management and contingency strategies which consider training, equipment, financial, logistics, infrastructure, clean-up methods, communication, and response aspects (Johannsdottir & Cook, 2019; Johannsdottir et al., 2021).

Several strategic and risk management initiatives have already been developed for the Arctic with contributions from the insurance sector. These include the Polar Code of the International Maritime Organization, and the International Union of Marine Insurance supported the development of the Arctic Marine Best Practice

Declaration (Backman et al., 2013), which cultivates "common ice regime guidelines in the Arctic that would support the Polar Code (IMO, 2015) and improve safety standards," and POLARIS (Polar Operational Limit Assessment Risk Indexing System) (Stoddard et al., 2016). In addition, the Nordic Association of Marine Insurers (NAMI) has prepared a checklist for underwriters and managers for assessing risks associated with voyages in Arctic waters, the aim being to raise awareness of risks associated with such journeys (Cefor, 2012; Johannsdottir et al., 2021). This list addresses accident scenarios across various levels of seriousness, highlighting that infrastructure limitations and limited search and rescue resources, especially in the case of cruise ship incidents, mean that even minor casualty events can become very costly. In order to minimize risks of a systemic and direct nature, the NAMI checklist advocates for logistical and meteorological preparedness, enhanced crew training and competences in order to fulfill contractual and safety-related duties, the taking of steps to ensure the suitability and robustness of vessels (e.g., an adequate Ice Class for anticipated conditions), and awareness and completion of necessary documentation to adhere to national regulations across the Arctic (Cefor, 2012; Johannsdottir et al., 2021).

With regard to the cruise ship sector, the systemic risk analysis summarized in this chapter provides a strong argument in favor of the adoption of robust preventive measures and comprehensive risk management. Cruise ship incidents have considerable potential to tarnish the reputations of the cruise ship operator and industry alike. In a similar vein to the Polar Code, the Association of Arctic Expedition Cruise Operators (AECO) sets out various guidelines for operators and visitors, several of which are mandatory, including operational safety guidelines for tour operators that are members of the organization (AECO, n.d.). However, it is important that cruise ship operators consider risks not only specific to their company but also passengers. This is because search and rescue coverage may be limited dependent on the age of passengers or the regions in which a cruise ship is going to operate. Given this, ship owners should purchase sufficient search and rescue cover for all passengers on board (Trantzas et al., 2018).

The approach to mitigating risk in the case of the COVID-19 pandemic has been somewhat different since this involves simultaneous impacts to multiple sectors of the economy and an ongoing health crisis. Emphasis has been placed by the national governments of Iceland and Greenland on ensuring that a cosmic-scale event with existential risks does not materialize, with two main focuses (a) making sure that there is provision of sufficient healthcare services, especially critical care infrastructure, to handle the number of severe infections and (b) maintaining and improving important infrastructure, industry viability, and skills to underpin a targeted post-pandemic economic recovery. In the short to medium term, throughout 2020 and the first half of 2021, item (a) was prioritized, which entailed the near cessation of the tourism industries in these nations. As Cook and Jóhannsdóttir (2021) discuss, a buoyant tourism sector in this period would have led to the greatest risk of a cosmic-scale event unfolding. In the case of Greenland, very strict domestic policies have been enforced concerning restrictions on domestic movement, while border policies have for the most part prevented international entry apart from for key workers. In Iceland, domestic movement has rarely been restricted, but border controls have been stricter and included double testing and quarantining.

Economic approaches in Greenland and Iceland have involved national governments taking on the role of insurer against direct and systemic risks through the provision of economic support schemes to businesses and individuals (Economic Council of Greenland, 2020; Icelandic Chamber of Commerce, 2020; OCED, 2020). Three financial aid packages were introduced in Greenland in the early months of the pandemic, two for the business sector and one for employees. The support package for the business sector was comprised of two components: emergency and general packages. The former was focused on private companies – hotels, restaurants, and the service industry. The latter targeted potential spillover effects to sectors other than tourism, including fishing, building and construction, and transportation. Wage compensation was provided in the aid package for employees in Greenland, a form of furlough scheme whereby the national government covered all the wages of employees who were placed into sabbatical rather than made redundant (Economic Council of Greenland, 2020).

In Iceland, the national government, municipalities, and credit institutions provided an array of economic support measures to help businesses and individuals to survive the pandemic. Measures included the extension of deadlines for taxes, temporary reliefs for tourism businesses, support of part-time workers of up to 75% of salary, VAT refunds, state-backed bridging loans for businesses, support loans for small- and medium-sized enterprises, subsidies for closed businesses, and allowing 2020 losses to be offset against 2019 tax liabilities (Icelandic Chamber of Commerce, 2020). The interconnectedness of sectors was recognized in the Icelandic response. Part of the economic vulnerability of the nation, regardless of the pandemic, was its overreliance on the tourism sector; however, it was acknowledged in the national government's response that the sector would be crucial for generating economic recovery and avoiding the systemic and society-wide implications of a bankruptcy event akin to the one experienced in 2008. Thus, in 2020, there were periods when restrictions were temporarily lifted in addition to a sustained and international marketing campaign focused on attracting visitors from nations with high vaccination rates (especially the USA and UK), which continued throughout 2021 and so far has appeared to lead to a faster than anticipated economic recovery (Cook & Jóhannsdóttir, 2021; RÚV, 2021).

3.3 Residual Risks and Information Needs

Despite the importance of systemic risk and megaprojects, such as oil production platforms, for Arctic economic development, limited information about this subject is available on the Arctic Council's website. Considerably greater information exists on oil spills, and it is evident that increased oil and gas exploration, as well as shipping and cruise ships, is a growing concern and that there is a need for more knowledge on these topics (Hausner et al., 2021) Additionally, it is evident that more can be done to prevent oil spills in Arctic waters and to enhance adequate response capacity to spills across the Arctic (Benz et al., 2021; Dalaklis & Drewniak 2020; Hausner et al., 2021). Increased traffic in the Arctic is expected to increase the likelihood of more incidents, which will in turn increase direct and systemic risk. In relation to oil activities, collaboration is needed, including via risk assessment/analysis, increased emergency preparedness and response resources, and the engagement of indigenous peoples.

Despite the risk mitigation advancements made by the Polar Code, several shortcomings remain to be addressed. These include data gaps, such as the non-inclusion of fishing and leisure vessels, insufficient attention to pollution risks, and the non-mandatory advanced training required for all crew members. In addition to these concerns, enforcement of the Polar Code is challenging given the leeway of Arctic Council governments, maritime agencies, and ship owners in defining the breadth and applicability of its advocated safety standards. These are governance failings that exemplify long-lasting problems concerning the level of authority held by the International Maritime Organization over maritime operators' compliance (Helgason et al., 2020) and Arctic Council powers over member states, weaknesses that are compounded by the governance and logistical challenges when dealing with disasters unfolding in international waters in the High Arctic.

One area where information is particularly lacking is the extent of financial losses, especially in cases of cruise ship incidents, that have been absorbed by insurance companies, but this type of information is very difficult to find. Nevertheless, it is important to bring forth information regarding the terms and conditions under which Arctic oil projects and cruise ship voyages are covered, so that possible gaps in coverage in cases of worst-case scenarios may be identified. In scenarios of maritime casualties, costs are generally absorbed by a complicated system of insurance underwriting and protection and indemnity clubs. Much less is known about other types of consequences, or insurance terms and conditions, such as for Arctic shipping or energy development/operation projects, as this information is seldom disclosed by insurance companies, although it is known that insurance companies impose stricter requirements and higher premiums on Arctic shipping contracts than for other shipping contracts (Sarrabezolles et al., 2016). Assessing the precise cost of insurance in the Arctic is difficult given the non-disclosure of such information, but it is known that the final price tends to depend on the ship, the route, and the proximity to ice-breakers, among other criteria (Reuters, 2020). Certain Arctic-specific risks linked to the navigation of ice-laden waters are not yet modelled and are rather assessed on a case-by-case basis (Sarrabezolles et al., 2016; Trantzas et al., 2018). A study by Reuters (2020) on ten insurance companies or brokers offering insurance to Arctic shipping companies found to date that they were paying out more due to ship damage than they were collecting in premiums, with some now pulling out of the industry altogether. Insurers were forced to improvise when setting premiums, conducting case-by-case assessments and then adding 40% to a basic premium of USD 50,000–125,000 for a single Arctic journey. It is known that higher insurance premiums for sailing in Arctic waters can be constrained if certain conditions are met, such as ice-class certification, risk and safety management policies and past behavior, training and experience of shipmaster and crew, and contingency plans, and thus adherence to all of the mandatory and voluntary guidelines set out in the Polar Code can likely convey economic advantages with regard to the affordability and availability of insurance. Such conditions, though, can make it difficult for newcomers to enter the Arctic shipping and cruising markets.

4 Summary and Conclusions

The chapter aimed to explore three research questions concerning the economic implications of systemic risk events in the Arctic, the mitigation measures that are adopted, and the residual risks and uncertainties after mitigation. A synthesis of the findings in three recent studies on the systemic risks of oil spills, cruise ships, and the COVID-19 pandemic was used to highlight the interconnection of economies in the Arctic and potential for cascading negative impacts to unfold in cases of disasters, far beyond the companies that are directly involved. Industry-wide impacts, including job losses, negative publicity, and a decline in trust, are likely to result. The insurance industry plays a collaborative role in the development of protocols, such as the Polar Code, that can enhance safety standards and reduce the riskiness of operations in ice-laden waters; however, there remain limits in the extent to which premiums can be accurately modelled. Many insurers of Arctic shipping projects are paying out more in damages than they obtain in premiums. Insurance mechanisms have also been central to the management of the COVID-19 pandemic in the island states of Iceland and Greenland, with national governments acting as a ballast of last resort through furlough schemes that have supported the incomes of individuals and businesses. This has helped to prevent a collapse in these tourism-dependent economies that would have been difficult to rebound from in 2021 and beyond.

The Arctic acts as a barometer of global risk, with environmental impacts experienced earlier and to a considerably greater degree than the rest of the planet. Although not the main focus of this chapter, the issue of climate change and related effects in the Arctic, such as reduced sea ice and the opening up of remote regions for potential transportation routes, cruise ship exploration, and hydrocarbon exploration, is indicative of the globalized nature of modern economies. In the Arctic, such opportunities can support economic security and growth but occur alongside the cost of greater exposure to risk, which is systemic – even occasionally cosmic – in scale, and disasters can lead to a spiral of negative economic consequences. Moreover, although this chapter has predominantly focused for reasons of space on the economic dimension of systemic risk, the broader sustainability-themed implications of disasters also need to be recognized and mitigated by policymakers. The COVID-19 pandemic in Iceland and Greenland highlighted an array of negative social consequences – for example, increased domestic violence and anti-immigrant sentiments – deriving from the crisis, impacts that were only ever partially mitigated, at best. Equally, oil spills in the Arctic can negatively impact sensitive marine and coastal ecosystems for decades, simultaneously undermining food security, environmental sustainability, and recreational amenity in the region.

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Chapter 2
Assessing Loss and Damage of Low-Exposed Sudden-Onset Disasters: Evidence from the Marginal Salt Cultivators of Kutubdia Island, Bangladesh

Mohammad Mahbubur Rahman and Mizanur Rahman Bijoy

Abstract In recent years in Bangladesh, there has been regular cyclonic event, flooding and erratic pre-monsoon precipitation, that has hampered production greatly and forced Bangladesh to import salt from abroad to manage market deficiency. There is much uncertainty about the effects of climate change on the frequency and intensity of small-scale, sudden-onset weather phenomena such as heavy rainfall and subsequent loss and damage (L&D). But, several studies indicate that an obvious strong relationship exists between irregular rainfall and associated L&D. Nowadays, severe changing rainfall patterns are observed in Bangladesh, which is rapid onset in nature, but low exposed in terms of response. The current study explored a “double-exposed” burden combined of both climatic (e.g., uneven rainfall) and non-climatic governance factors (e.g., imperfect trade policy, the absence of risk transfer mechanisms) which are hindering salt production and pushing the country from the aspiration of salt exporting to the net buyer. This chapter mainly assesses the impacts of L&D due to climatic events that are causing overwhelming effects on the well-being of marginal salt farmers at Kutubdia Upazila of Bangladesh. Data were mainly collected through participatory vulnerability analysis (PVA), key informant interviews (KII), and sample surveys (SS). This study would provide insights for improved disaster management policy and an appropriate adaptive measure to address such extreme events as well as to initiate a further study for understanding the nexus of “nature and market” in building resilience among the marginal salt farmers.

M. M. Rahman (✉)
Network on Climate Change in Bangladesh, Dhaka, Bangladesh

Department of Sociology, Lancaster University, Lancaster, UK
e-mail: m.m.rahman@lancaster.ac.uk

M. R. Bijoy
Network on Climate Change in Bangladesh, Dhaka, Bangladesh

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1 Introduction

The coastline of Chittagong and Cox's Bazar is the central hub of crude salt production in Bangladesh (National Salt Policy, 2011). Typically, these areas are very "exposed" to sea and hugely "sensible" to various hydrometeorological hazards such as cyclone, heavy rainfall, tidal surge, and sea level rise (SLR). Climate change poses an existential threat, and the salt-producing areas in Bangladesh are recognized as the most vulnerable areas to potential losses of livelihood (Toufique & Yunus, 2013).

Favorable weather conditions (low rainfall and available daylight) are the apparent preconditions for salt production. Thus, winter and the pre-monsoon season between November and May are the most suitable periods for the production of salt. In recent years, the salt-producing areas have experienced a frequent cyclonic surge, tidal inundation, and uneven rainfall in the salt cultivation period. Such incidents hugely hampered the salt production and forced the country to import about one million tons of salt in repeated 3-year period (from 2015 to 2017) to manage the market shortfall (BSCIC, 2018).

Several reports and studies identified unfavorable weather conditions that had reduced the number of salt beds (Hossain et al., 2003, 2006), low market price (Hossain et al., 2006), and also the import of salt from foreign countries. These are the main causes of failure to achieve production targets. The field investigation explores a "double-exposed" burden combined of both climatic (e.g., uneven rainfall, cyclonic surge) and non-climatic governance factors (e.g., unfavorable trade policy, lack of risk transfer mechanisms) which are hindering salt production and pushing the country from the aspiration of salt exporting to a net buyer. Given the complex scenario, this study mainly attempts to assess the loss and damage due to climatic events increasing overwhelming effects on the well-being of "marginal salt cultivators[1]" at Kutubdia Upazila of Bangladesh.

There is significant suspicion regarding the impacts of climate change on the frequency and severity of small-scale, sudden-onset weather phenomenon (e.g., heavy rainfall, storm, hailstorms, etc.) and subsequent loss and damage. However, several studies indicate that an obvious strong relationship exists between uneven rainfall events, high tide, and associated loss and damage (IPCC, 2014; Putnam & Broecker, 2017). Therefore, from a climate change point of view, this study is an attempt to texture the feature of loss and damage of "double-exposed" less adaptive

[1] The definition of "marginal farmer" refers to a farmer cultivating (as the owner, tenant, or shareholder) inland less than 0.049 acres, as stated by the Bangladesh Bureau for Statistics (BBS).

(in terms of financial instruments or physical measures) salt cultivation. This chapter explores a "double-exposed" burden combined with climatic (e.g., uneven rainfall, cyclonic surge, etc.) and non-climatic factors (e.g., unfavorable trade policy, lack of risk transfer mechanisms) that are hindering salt production. As a result, the country had pushed from the aspiration of salt exporting to the net buyer. Therefore, the study mainly seeks to assess how the impacts of climate change (weather anomalies) affect salt production and to what extent the livelihoods and well-being of marginal salt farmers are affected by increased loss and loss of salt yield.

First, this chapter began with a summary of the concept of loss and damage (L&D) and described its relationship to climate change. Later, we discussed the background of salt cultivation in Bangladesh as well as its situation in the context of the changing nature of the global climate change. After that, we presented the methodology that we followed in this study and discussed the findings and results accordingly. Lastly, the chapter ended with summary and concluding remarks.

1.1 Understanding Local Level "Loss and Damage"

In the global negotiation, "loss and damage (L&D)" is commonly conceptualized as the impacts of climate change that are "beyond adaptation" limits and unavoidable through adaptation as usual mitigation efforts (Roberts et al., 2015; Verheyen, 2012). But at the local level, "L&D" has been specified as the impacts of climate change that households and communities cannot adapt within their existing capacity (Warner et al., 2012, 2013). Correspondingly, this argument has reinforced calls for increased mitigation ambition and incremental financing for adaptation (Huq et al., 2013; Kreft et al., 2013; Roberts & Huq, 2013; Roberts & Pelling, 2018). L&D also presents a range of ethical and global political issues as it narrates the questions of liability and compensation for climate change-induced losses and damages (James et al., 2019). Despite growing scientific advancements, the debate is currently more extensive and prolonged, while the strong policy direction and norms of compensatory justice remain unclear and disputed (Mechler et al., 2019). It is essential to develop a separate definition to assess the local level loss and damage incurred from a particular climatic event by considering the diverse global and local context (Van der Geest, 2018). In this regard, Lopez et al. (2019) and Van der Geest (2018) focused on the convergence among climate change adaptation (CCA) and disaster risk reduction (DRR). They emphasized the need to assess coping capacity and adaptation measures for conducting local empirical work.

Analyzing available literature (O'Brien & Leichenko, 2000; O'Brien et al., 2004; Warner & Van der Geest, 2013; Van der Geest, 2018), this pilot study focused on the climate impacts that affect the vulnerable people and community in particular; tried to identify traditional practices to deal with such consequences within their limit (coping); and explored the possible options (technical, financial, social, and policy support) to avert harmful impacts (adaptation). This study is also an attempt to assess the particular role of extreme events and volatile market price (the "double stress") threatening the small salt farmers from "both ends" (nature and the market).

1.2 Climate Change Attribution

Nowadays it has become a debatable issue among the international climate scientists (e.g., Huggel et al., 2015; Hulme, 2014; James et al., 2014) whether the loss and damage (L&D) is attributable to climate change or more generally to any climate-related impacts (Warner & van der Geest, 2013). However, this attribution matter is debatable as it is linked with blame and liability (James et al., 2014). Nevertheless, biophysical and social determinants influencing L&D, including climate change, need to be recognized to address the associated risks (Huggel et al., 2013). The consideration of attribution evidence may help inform and facilitate policy discussions (Huggel et al., 2015). To what extent can particular, extreme events, such as landslides, erratic or heavy rainfall, etc., be attributed to anthropogenic climate change is a crucial question in international climate change negotiations (Parker et al., 2017; Van der Geest, 2018) though solid evidence exists correlating to slow-onset events, such as the sea level rise and glacial retreat, to climate change (Bindoff et al., 2013). But, links between climate change and specific extreme weather events, such as heatwaves and particularly floods and droughts, were found more uncertain due to the larger role of natural variability. It is not likely to prove whether an event would have appeared in a stable climate (Parker et al., 2017). However, all the previous IPCC's Assessment Reports (AR) (e.g., AR3, AR4, AR5, etc.) mentioned that due to increased global greenhouse gas emissions (GHG), the global temperature would be increased which will influence the intensity and distribution of several extreme weather events. For example, the IPCC (2018) special report on the impacts of global warming of 1.5 °C above pre-industrial level shows that trends in intensity and frequency of several climate and weather extremes will be influenced to a large extent. The report pointed that several regional changes in climate are predicted to occur with global warming up to 1.5 °C compared to pre-industrial (1850–1900) (average warmth in between 12 and 15 °C) levels, including warming of extreme temperatures in many regions (high confidence); increases in frequency, intensity, and amount of heavy precipitation in many areas (high confidence); and an increase in intensity or frequency of droughts in some regions (medium confidence) (IPCC, 2018).

2 State of Salt Cultivation in Bangladesh

Salt-producing areas in Bangladesh are very exposed to open sky, adjacent to the sea, thus facing all the hazards approaching from the sea. Sometimes the whole production is washed away by heavy rain and tidal surge because of lack of protection and storage facility. Despite being seasonal goods, salt farming generates many employment opportunities in Cox's Bazar and Chittagong districts of the country. About five hundred thousand people are directly or indirectly engaged in salt production, refining, preservation, storing and marketing, etc. (National Salt Policy, 2011). This sector contributes about 35.5–41.5 million USD each year in the national economy. In Cox's Bazar district, around 15% of total rural households within the community are involved in salt farming. This area meets the bulk of the demand for raw salt in the country (Al Mamun et al., 2014). Nevertheless, the government has also taken the initiative to bring alternative areas under salt production in the Khulna-Satkhira region. The salt cultivation program has already started in Shyamnagar Upazila of the Satkhira district.

3 Salt Cultivation Under a Changing Climate

The global demand for salt is increasing, especially in developing countries, due to the large chemical manufacturing market. Climate and weather conditions are affecting salt production, particularly in developing countries, and are likely to be hard hit by climate change over the coming decades (Bhat et al., 2015). A study (Roland et al., 2018) on the Songor salt project in Ghana finds a correlation between climate change and yield of salt production by running a linear multiple regression model. Therefore, soon, the climate shocks may directly decline the salt productivity in the developing countries and shall increase dependency on importing salt from the industrially developed and growing economies, such as the leading greenhouse gas emitters China, USA, and India.

In the case of Bangladesh, a significant increasing trend of annual and pre-monsoon rainfall (March–April-May) has been observed with a growing trend in heavy precipitation days and decreasing trends in consecutive dry days (Shahid, 2011) which may lead to reduce the salt-producing season, hamper production, influence to change livelihood, and increase loss and damage. The IPCC's Report (2013) anticipated that the Indian summer monsoon circulation will be weakening, but leading to more rainfall within the small period. Though the monsoon is the most important climatic phenomenon which is directly related to crop production and livelihood of billions, flood and landslide due to heavy monsoonal rain are also common catastrophes in the South Asian countries which have been reported to increase the loss of lives and assets and lead to displacing million in recent years.

Not only change in monsoonal rain but also the frequency and intensity of tropical cyclones have also been reported to increase in recent decades. Several studies (Girishkumar & Ravichandran, 2012; Dasgupta et al., 2014; Balaguru et al., 2014; Chowdhury & Ndiaye, 2017) anticipated that the El Niño/La Niña events will further intensify the threat of cyclonic activities in Bangladesh and could double in the future due to global warming. Considering the increasing risk of weather extremes, insurance as a risk transfer mechanism could be supportive of reducing the chances of loss and damage from extreme weather events. However, in Bangladesh, the insurance sector is rather on an initial stage to think about a new package for transferring the risks of the natural catastrophe like cyclones, rainfall variability, drought, etc. Therefore, the study's overall goal is to assess the impact of sudden-onset but low exposure (in terms of response from government and non-government agencies and media attention) disasters on the climate-sensitive economic activities of the poor and marginalized people living in Kutubdia Island.

4 Methods

4.1 Study Area

Cox's Bazar in the southeastern coastal district of Bangladesh is a hub for salt farming activities, consisting of production activities in the fields and refining and marketing activities of the industries. The different parts of Cox's Bazar and the adjacent offshore islands, including the islands of Kutubdia, Ramu, Ukhia, Teknaf, Chokoria, Pekua, Moheshkhali, and Kutubdia, produce seawater salts mainly from the solar process. In this study, salt production data for the whole district of Cox's Bazar and the precipitation data for the three separate rainfall stations Cox's Bazar Sadar, Teknaf, and Kutubdia Island have analyzed to explore interconnection with salt production and precipitation. Besides, as the case, we have taken Kutubdia Island to investigate the loss and damage of salt cultivation at a local level due to various weather anomalies (Al Mamun et al., 2014).

Kutubdia Island is located in between 21°43′ and 21° 56′ northern latitudes and in between 91°50′ and 91°54′ east longitudes. This small island is surrounded by the Bay of Bengal on the north, west, and south and Kutubdia channel on the east (Fig. 2.1). With an average width of about 3 kilometers, the channel divides the island from the mainland. The elevation of the island differs between 0.1 m and 7.6 m above sea level. Kutubdia is threatened by sea erosion, which compressed the island with an area of 433 km^2 in 1880 to at present 151 km^2. At the current rate of decay, Kutubdia Island will cease to exist within the next 30 years (Vidal, 2013; Rahman et al., 2015). According to the trend analysis (CCC, 2016), the range of sea level rise (SLR) on the Bangladesh coast over the 30 years is between 6 and 21 mm/year. The study also identified higher trends of SLR in the Chittagong and Cox's Bazar coast compared to the previous study findings of SMRC (2003), which could also reduce the salt cultivable land in this region. Moreover, this area is also under increasing cyclonic risk. Chowdhury (2018) identified the southeastern coastal (Southern Chittagong, Cox's Bazar and Teknaf) belt as the most impacted and more exposed to cyclonic events during the pre-monsoon season, further threatening the salt farming in this area.

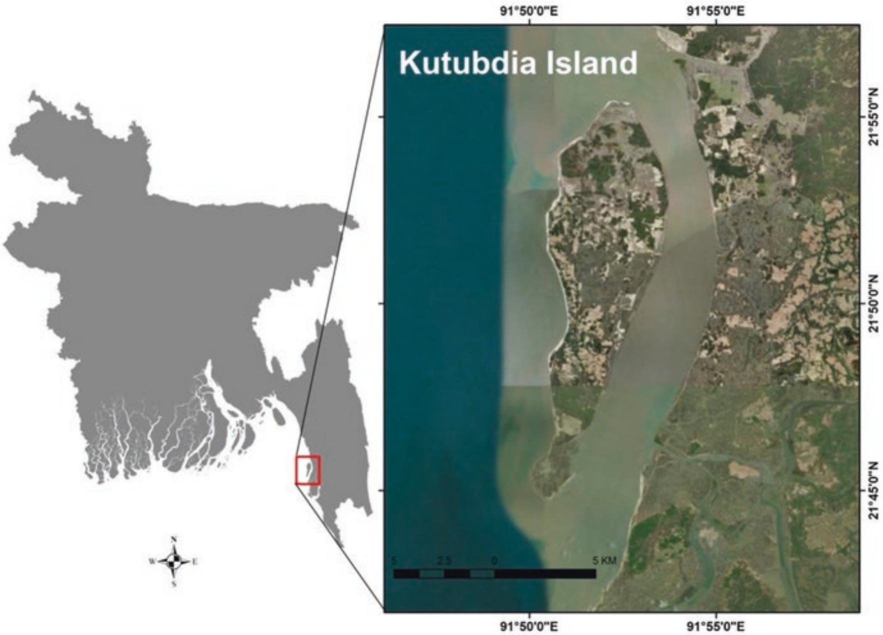

Fig. 2.1 Study area (Kutubdia Upazila)

4.2 Data Collection

This study also attempted to collect data on the pricing of raw salts at producers and refined salts at the consumer's standard. This approach intended to assess the particular role of extreme events and volatile market price (the "double stress") threatening the small salt farmers from "both ends" (nature and the market). Thus, the study made use of both qualitative and quantitative techniques. The qualitative part was anchored in participatory vulnerability analysis (PVA), key informant interviews (KIIs), and case study method. At the same time, quantitative data were collected by conducting the sample questionnaire survey. A set of questions and checklists were developed based on literature review, analysis of the study proposal, field test, and frequent consultation with relevant experts. This study used data from a questionnaire administered to inhabitants of six unions[2] (Ali Akbar Deil, Uttar Dhurung, Kaiyarbil, Dakshin Dhurung, Baraghop, and Lemsikhali) of Kutubdia Upazila. The unions were selected based on their location and proximity to rivers,

[2] Unions (also known as Union Parishads or Union Councils) are the oldest and smallest administrative units in Bangladesh. There are nine wards in each union. Normally, one village is named as the ward.

their vulnerability to natural disasters, and the number of households involved in salt cultivation. However, the secondary information was collected through direct communication with Bangladesh Small, Cottage Industries Corporation (BSCIC). Historical data were analyzed from the available evidence obtained from the Bangladesh Meteorological Department (BMD), published and unpublished scientific journals and media reports, etc.

4.3 Data Analysis

A simple random sampling (also referred to as a random sampling) method was applied to investigate the targeted population. This method is used when the whole community is accessible, and the investigators have a list of all subjects in this target population (Elfil & Negida, 2017). A total of 52 respondents were randomly selected from a list of 248 salt farmers in Kutubdia, provided by the Bangladesh Small and Cottage Industries Corporation (BSCIC). If the chosen randomly farmer was unavailable at the time of the survey, the next available farmer within the list was interviewed. The study consisted of both open- and close-ended questions. The survey was conducted in October 2018. This survey would be considered as a pilot survey for a detailed study in the future. Questionnaire survey data included respondent's household, livelihood and vulnerability information, information on loss and damage from climate-related events, and existing adaptation and coping measures against those extreme events. The data was analyzed using Microsoft Excel (2010). The analysis was carried out in two stages: the information was first tabulated in a Microsoft Excel sheet, and then frequency distribution and percentage were calculated. Finally, descriptive analysis, including both textual and tabular formats, described the study results. Respondents were asked about their age, ownership of house and salt farming land, access to electricity, income source, experience on natural hazards, loss and damage, available adaptation and coping options, etc. The overall goal was to explore the impact of various rapid-onset extreme climatic events on the livelihood of marginalized salt farmers.

5 Results and Discussion

5.1 Respondents' Profile

The selected demographic and socioeconomic characteristics of the respondent are presented in Table 2.1. The age of the respondents ranged between 18 and 85 years. The age distribution pattern shows that the salt farming activities in the study area are highly involved with the people aged between 41 and 50 years (36.5%). All of the survey participants were male, which reveals that males are mostly engaged in

Table 2.1 Respondents' certain characteristics

Characteristic	Number	Percentage
Age (in years)		
18–30	14	26.9
31–40	14	26.9
41–50	19	36.5
51–60	4	7.7
>60	1	1.9
Gender		
Male	52	100
Female	0	0
Is the respondent household head?		
Yes	52	100
No	0	0
Do you own the house you live in?		
Yes	52	100
No	0	0
Type of the living house		
Jhupri (hut)	13	25
Kacha (mud-built house)	35	36.5
Semi-Paka (semi-building)	2	3.8
Tin shade	0	0
Paka (building)	2	3.8
Access to electricity		
Yes	47	90.4
No	5	9.6
Source of electricity		
Power grid	2	3.8
Solar	45	86.5
Both	0	0
No electricity	5	9.6
Major income source		
Salt farming	52	100.0
Others		
Paddy	16	30.8
Livestock	14	26.9
Fisheries	2	3.8
Vegetable garden	2	3.8
Remittance	1	1.9
Small grocery/medicine shop	4	7.7

(continued)

Table 2.1 (continued)

Characteristic	Number	Percentage
Day labor	2	3.8
Boat rent	1	1.9
Fishermen	2	3.8
None	8	15.4
Major crops		
Salt	52	100
Others		
Paddy	30	57.7
Vegetable	3	5.8
None	19	36.5
Type of salt cultivated land		
Borga (borrowing)	13	25.0
Ijara (lease)	16	30.8
Own + *Borga* (borrowing)	13	25.0
Own + *Ijara* (lease)	10	19.2

this profession. The farmers also play the role of household head, and they take major decisions on family issues. The respondents stayed at their own house, a mostly mud-built house (*Kacha*) (36.5%). Most of the people have access to electricity (90.4%). The survey results revealed that the highest number of respondents (86.5%) used solar as a primary source of electricity. Only a few people had access to the national power grid (3.8%). Salt farming is the primary occupation of all the respondents. The other supporting income-generating activities (IGA) are paddy cultivation (30.8%), livestock (26.9%), small business (7.7%), fisheries (3.8%), vegetable gardening (3.8%), day labor (3.8%), fishermen (3.8%), remittance (1.9%), and boat rent (1.9%). Salt (100%) and paddy (57.7%) are the major cultivable crops in that area. The people mostly cultivate salts in a lease (30.8%) and taken and borrowed (25%) land, and at the same time a good portion of the respondents cultivated in the mixed type of lands (e.g., own and borrowed (25%) and own and lease taken (19.2%) land).

5.2 Trend of Rainfall in Kutubdia, Cox's Bazar, and Taknaf

The linear trend analysis of the monthly rainfall for April in three coastal locations, including Kutubdia, Cox's Bazar, and Teknaf, is the key hub for salt farming and salt production in Bangladesh which shows an increasing trend for the last 16 (from 2003 to 2018) years. The highest rainfall for Kutubdia, Cox's Bazar, and Teknaf was found in 2017 (270 mm, 361 mm, and 163 mm, respectively), and the lowest rainfall was found in the year 2008 (0.5 mm, 0.4 mm, and 0 mm, respectively) (Fig. 2.2).

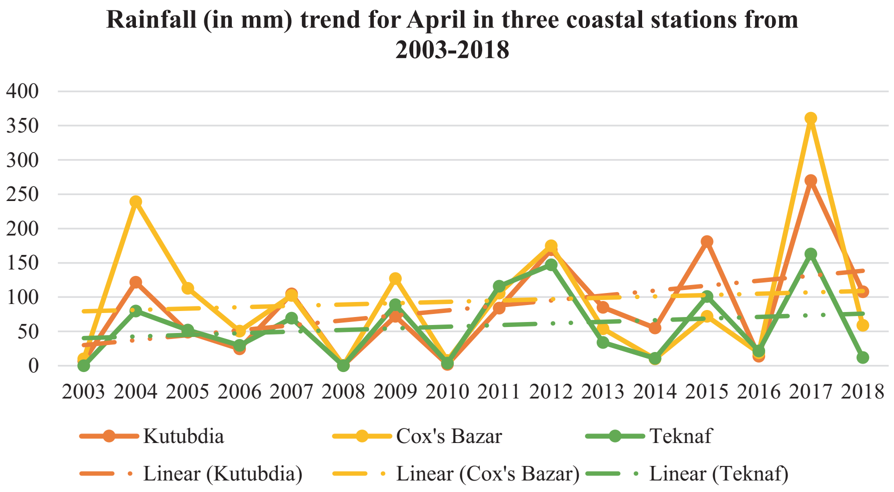

Fig. 2.2 Rainfall (in mm) trend for the month of April in Kutubdia, Cox's Bazar, and Teknaf from 2003 to 2018

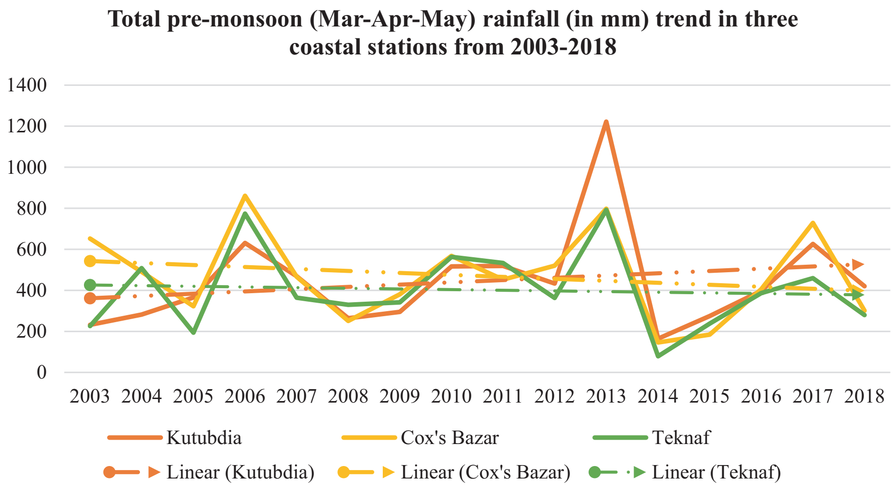

Fig. 2.3 Total pre-monsoon rainfall (in mm) trend in Kutubdia, Cox's Bazar, and Teknaf from 2003 to 2018

Figure 2.3 shows that the total rainfall during March, April, and May also shows an erratic pattern in these locations. At the same time, total rainfall in April is rising, especially (Fig. 2.2). The highest total rainfall for the pre-monsoon season (Mar-Apr-May) was found in the year 2013 for Kutubdia (1222 mm) and Teknaf (792 mm) and in 2006 for Cox's Bazar (860.6 mm). However, the lowest was found in the year 2003 for Kutubdia (232 mm) and in the year 2014 for Cox's Bazar (146 mm) and Teknaf (78.7 mm).

5.3 *Trend of Salt Production in Cox's Bazar*

Availability of raw material (seawater) and squeezing scope for cropping (paddy) due to salinity and better-earning opportunity are the main factors that encouraged coastal people to engage in salt production. In the season 2017–2018, nearly 27,528 salt cultivators operated on 59,563 acres of land in the Cox's Bazar district (Table 2.2). Salt is both an agricultural and manufacturing product. Production of crude salt from seawater is a traditional practice involving land, labor, and weather, while the refinement and crushing are manufacturing activities involving men, machines, and money (Quaiyum, 2019). It should be noted that the favorable weather condition for salt production prevails when there are low rainfall and high daylight. In Bangladesh, such weather condition prevails only during winter and pre-monsoon season (between November and May), while over the last few years, uneven pre-monsoon rainfall, cyclonic surge, and tidal inundation have reduced salt-producing area and hindered production. As a result, the country has failed to reach the production target and bound to import nearly one million metric tons of salt during the 2015–2017 periods worth 120 million USD roughly (Table 2.2).

Table 2.2 shows a decreasing trend in salt production, especially from the 2014–2015 periods. The number of salt farmers and land indicates a huge fluctuation, influenced by unstable market price and inappropriate import policy of the government. In 2017–2018, the number of salt farmers had decreased by nearly 38% compared to 2005–2006. Salt-productive areas also reduced significantly in this period, almost 15% reduction compared to 2005–2006 (Table 2.2). Bumper

Table 2.2 Scenario of salt production in Cox's Bazar from 2014 to 2018

Salt cultivation season	Total number of salt cultivators	Area (in acres)	Demand (Lakhs M.T.)	Production target (Lakhs M.T.)	Net production (Lakhs M.T.)	Import (Lakhs M.T.)
2005–2006	44,574	70,050	11.70	11.70	15.74	–
2006–2007	45,000	70,754	12.20	13.00	10.54	–
2007–2008	43,000	67,743	12.20	13.00	12.02	–
2008–2009	44,000	69,415	13.00	13.20	13.58	–
2009–2010	43,353	67,751	13.33	13.45	17.04	–
2010–2011	38,582	55,637	13.70	13.90	9.56	–
2011–2012	43,390	62,718	14.36	14.50	11.68	–
2012–2013	44,761	64,151	15.06	15.20	16.34	–
2013–2014	42,484	59,960	15.80	16.00	17.53	–
2014–2015	29,508	51,970	16.58	18.00	12.82	2.00
2015–2016	40,380	60,130	16.58	18.00	15.55	2.50
2016–2017	43,102	64,140	15.76	18.00	13.64	5.00
2017–2018	27,528	59,563	16.21	18.00	14.93	–

Source: BSCIC (2018)

production in early 2016, the country envisaged it as a salt exporting nation (Dhaka Tribune, 2016). But, soon after the shock of cyclone "Roanu" in the same year (2016) and cyclone "Mora" in the following year (2017), the government had decided to import 5 lakh and 2.5 lakh metric tons of crude salt from abroad (Kallol, 2017).

It should be noted that in the previous year (2014–2015), Bangladesh was also bound to import two *lac*[3] metric tons of salt from exporting countries (57% from India and 35% from China) after the shortfall in production (Table 2.2). Though the National Salt Policy (2011) emphasized on various actions to protect local industries and farmers, the salt farmers have been deprived of many agricultural subsidies as salt was recognized as industrial goods, rather than a farming crop. Therefore, the smallholder salt producers are exposing double burden, reducing their yield due to unpredictable weather events, and then unable to sell the product in the market when "low-cost imported salt" is available in the market.

5.4 Critical Stress Moment

Though the normal monthly rainfall for Cox's Bazar for April was estimated as 99.3 millimeters (Khatun et al., 2016), for several years, the rain in April was found much higher than the normal monthly range. For example, the monthly precipitation of April was 102.4 millimeters, 127 millimeters, 106 millimeters, 175 millimeters, and 361 millimeters for 2007, 2009, 2011, 2012, and 2017 respectively (Fig. 2.4). However, it is observed that the years in which the monthly rainfall for April exceeded the average monthly normal rain resulted in a shortfall of production target, except 2008, 2015, 2016, and 2018 when tidal surge and inundation associated with cyclones such as Nargis (in 2008), Komen (in 2015), Roanu (in 2016), and Titli (in 2018) washed the salt fields (Fig. 2.4).

5.5 Major Climatic and Non-climatic Stressors for Salt Cultivators in Kutubdia

It is observed from the field survey that heavy rainfall (33%), cyclone (22%), flood/inundation (17%), and storm (16%) are the most devastating hazards in the entire Kutubdia Upazila (Fig. 2.5). Among the other natural hazards, thunderstorm/lightning (8%), continuous rainfall (2%), hailstorm (1%), and irregular rainfall (1%) pattern have found comparatively less destructive (Fig. 2.5). All of the respondents (100%) said that they had experienced the impact of erratic or heavy rainfall in their

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[3]A *lac* (also written as *Lakh*) is one hundred thousand (100,000) in the Bangladeshi numbering system.

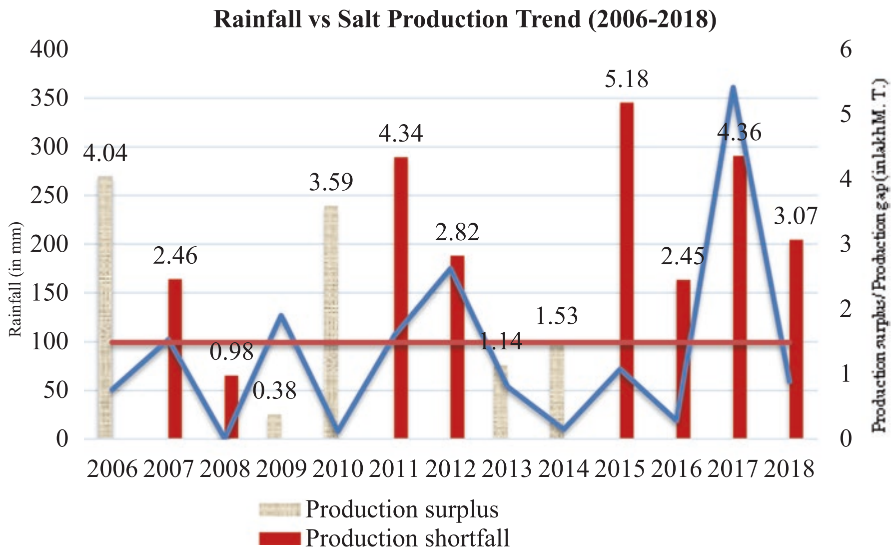

Fig. 2.4 April rainfall vs. production surplus or shortfall in Cox's Bazar

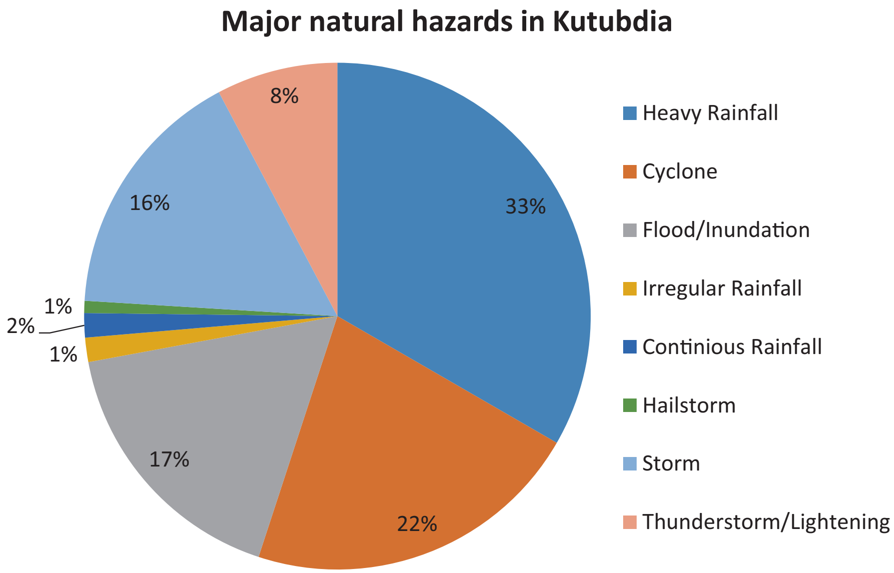

Fig. 2.5 Major natural hazards in Kutubdia Upazila

community. It is also found that in the last 10 years and 5 years, the number of erratic and heavy rainfall incidents increased significantly, e.g., increased a lot (17.3%) and increased a bit (73.1%). People (59.6%) also noted that rainfall has occurred during April, which is a peak season for salt farming. Also, Kutubdia is threatened by continuous erosion. Moreover, the dense foggy weather is another threat to the salt cultivators. In addition to climatic stress, non-climatic factors such as fluctuation of salt price, lack of financial capital, changing government regulation, lack of support (e.g., insurance), and weak implementation of policy also affect the "marginal salt farmers" of Kutubdia island.

5.6 Outcomes of Hazards on Salt Cultivators in Kutubdia

Several natural hazards, including erratic and heavy rainfall patterns, caused both economic and non-economic loss and damage of life and belongings of the salt cultivators of Kutubdia Island. In the case of economic loss, reduced salt production, reduced income, damaged properties, and reduced livelihood opportunity are the key concerns. Besides, key non-economic concerns are children dropping out of school, breaking social cohesion, psychological stress, and displacement. The respondents said that they had experienced long-term impacts of the erratic and heavy rainfall events. Such events have affected salt production (100%), livestock (e.g., cow, hen, duck) (9.6%), trees (7.7%), housing (11.5%), and health and well-being (5.8%). Moreover, salt cultivators informed that a significant portion of their produced salt was damaged in their land in 2018. However, the amount of loss varied from farmers to farmers, e.g., 1–15 metric tons (69.2%), 16–30 metric tons (21.2%), 31–45 metric tons (5.8%), and 46–60 metric tons (3.8%). In terms of money, the loss was also found noticeable among the respondents, such as 40,001–60,000 BDT (21.2%), 80,001–100,000 BDT (19.2%), and 20,001–40,000 BDT (13.5%) in the year 2018.

5.7 Salt Cultivation in Kutubdia Is in Peril!

Repeated embankment breaching, tidal inundation, and unusual rainfall patterns hamper salt production, reducing salt production area and season. Cyclone Roanu that struck on 21 May 2016 killed four and made nearly 20,000 people homeless. The cost of damage was around BDT 200 crores (25 million USD) only in Kutubdia (DDM, 2016). Approximately 18 km of embankment in Kutubdia was reported to be damaged (BWDB, 2016), and tidal wave that overflowed the earthen barrier washed shrimp *gher,*[4] crop, and salt fields in association with heavy rain. Financial and technical support was very limited from both government and non-government agencies or, in some cases, absent to reduce and manage unexpected losses (Field Survey, 2018).

[4] A pond commonly dug into a rice field to use for fish farming.

Internal displacement and changing traditional occupation have also been reported by the local authorities (e.g., local government representatives), which also increases, particularly after any sudden disaster events or frequent crop failures, while low-exposed, but both the slow (e.g., salinity intrusions, degradation in soil quality, etc.) and sudden-onset events (e.g., low-scale cyclone, embankment bleaching) are also forcing people to become displaced over time (Field Survey, 2018). These types of events are reasonably covered by news and reports in the national and local news media. The heightened degree of media coverage reveals that the frequency and severity of this rapid- or sudden-onset, but low-exposed disasters have increased at an alarming rate in this area in the last few years. However, the issues come to the surface just after the event, and follow-up investigation and assessment on the long-term impacts were not noted. Also, loss and damage due to heavy rainfall are less discussed. These unusual weather events cause loss and damage to the lives and properties of millions of people in Bangladesh. But, no support was visible from both the government and non-government agencies in response to such localized, small-scale disasters. Besides, these types of disasters are not covered by government safety net programs (Field Survey, 2018). With the growing concerns over supporting the smallholders with risk transfer and recovery facilities, very few insurance companies are developing such products (Rahman, 2018).

Nevertheless, some initiatives are practiced to a limited scale to support smallholders to recover crop loss caused only by sudden-onset disasters. For instance, in Bangladesh, crop insurance was introduced in 1977 through the state-owned insurance company Sadharan Bima Corporation (SBC) as a pilot project. Due to a shortage of policy support and partnership, expertise, and monitoring and methodological problem, this project was not sustained, and the scheme was closed in 1996 (Habiba & Shaw, 2013). Later on, Pragati Insurance Company Ltd., a privately owned venture established in 2000, introduced a crop insurance scheme in Sirajganj district in 2013 to support loss recovery caused by monsoon floods. However, that initiative was a periodic attempt, not eventually conceptualized as a “business product” and didn’t consider its operational sustainability; therefore, it didn’t sustain. This project was led by several national and international organizations with differentiated roles and responsibilities. For example, Oxfam Bangladesh was involved in planning, Swiss Development Agency and Corporation (SDC) in the financing, and Manob Mukti Songstha, a local NGO, in the implementation (Rahman, 2018).

Moreover, CRM India was involved in providing technical support; the Institute of Water and Flood Management (IWFM), respectively, in data collection; and Swiss Re as the reinsurer. Unfortunately, this initiative also didn’t last long (Rahman, 2018). But, still, risk transfer and insurance mechanisms could be an effective strategy to deal with such loss and damage due to rapid-onset extreme events if properly implemented.

5.8 Coping and Adaptation Measures

Field survey (2018) and Hussain et al. (2017) identified that the salt farmers are smallholders who use manually operated local equipment and lease the land from landowners or the government every year. Community-focused land leasing systems, sufficient credit facilities, mechanical equipment (water pump, leveler, etc.), and reliable weather forecasting can enhance salt production. Moreover, the formation of salt farmer's cooperatives can ensure bargaining power and maximize economic return (i.e., salt price) for their living (Hussain et al., 2017).

Though there are very limited opportunities for initiating adaptive measures to save the yield from cyclone surge, tidal inundation, or heavy rainfall, the salt cultivators are mainly using polythene or plastic sheets to cover stacked salts to protect from the fog in winter and rain during the pre-monsoon season. But it is very temporary and not even enough to protect salts from unpredicted rain, which may arise quickly from the Bay and will not allow the necessary time to cover the field (Field Survey, 2018). At the same time, as a traditional technique, salt farmers used to store salts under the salt fields by digging a deep hole or well, deposit salts in the well, and finally intensely filled the top few feet with soil (Fig. 2.6). Using polythene or plastic sheet to cover the top of the dug well before filling it with the earth is traditionally very popular. This technique allows the water to flow over the tight hole easily during the rainy season and left the salt in useable condition. After the rainy season or in the late monsoon, the holders remove the earthen few feet from the top

Fig. 2.6 The traditional method for storing the salt by digging a deep hole or well in the cultivation field

of the well and collect their salt from the deposit. But, sudden cyclone, unexpected tidal inundation, or heavy rainfall during the productive period remains a subject of "key risks" for achieving production targets (Field Survey, 2018).

The salt cultivators have not received any support from the government organizations (GOs) or non-government organizations (NGOs) to reduce the loss of salt farming caused by any natural hazards like heavy rainfall or tidal inundation. However, people had taken loans with a higher interest rate from the local money lenders, landlords, or land lease providers immediately after the loss. Even many were bound to sell their bonds and withdrawn savings from the bank or cooperatives. Few smallholders had taken loans from government programs such as "Ektee Bari Ektee Khamar[5] Project." Unfortunately, there were no visible supports from the government or the aid agencies, particularly for the salt cultivators, to address their loss (PVA, 2018).

Moreover, dams are not built properly. Thus silts enter into the salt fields, and salt quality and price decrease. As heavy rainfall and inundation are natural events, those are unavoidable, and farmers can't do much by working under an open sky without observing the stored salts being washed out. More importantly, a week-long rain can easily overflow the embankments. Hence, it is mandatory to increase the dam's height and repair the damaged embankments in due time. Due to the domination of the third parties in the salt industry from the field levels to mill owners, the farmers don't get a reasonable price. For that reason, they had to keep the salts in the fields without selling in some cases. Moreover, local government representatives, such as the Union Parishad members and chairmen, are often corrupted (PVA, 2018). Nonetheless, people faced various types of difficulties such as having no alternative options (11.5%), lack of skills or knowledge (38.5%), absence of government or private support (5.8%), etc. to adopt effective measures to prevent the impacts of extreme events on salt farming and reduce the loss (Fig. 2.7).

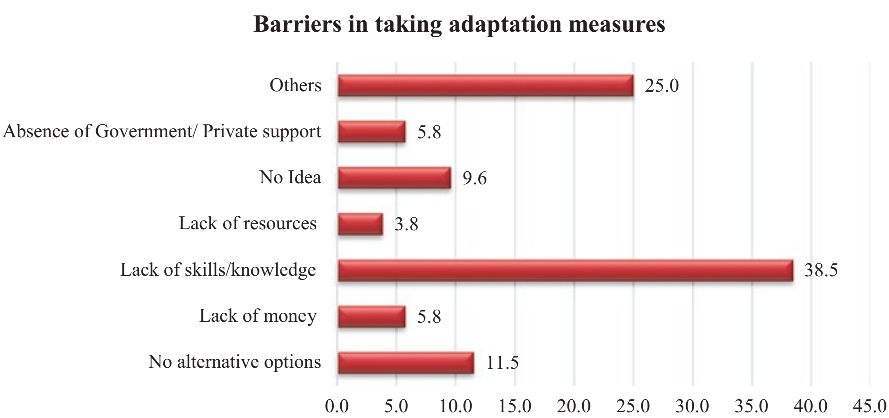

Fig. 2.7 Key hindrance in taking effective adaptation measures

[5] A project runs by the government of Bangladesh to reduce poverty in rural areas.

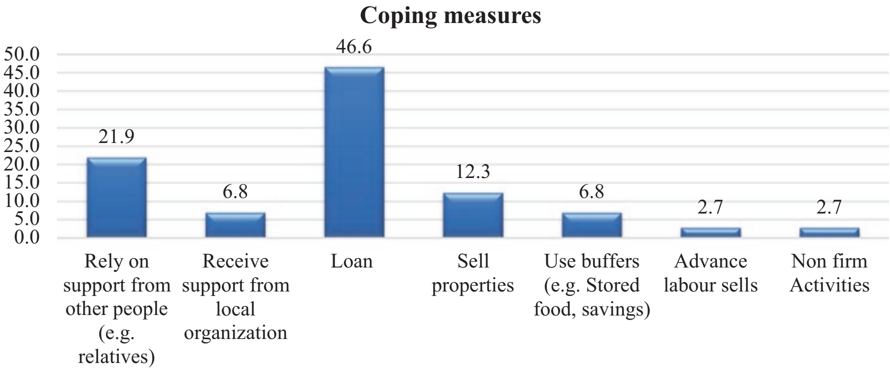

Fig. 2.8 Coping measures taken by the marginal salt cultivators

To cope with the adverse situation, people took different measures, including taking support from people (21.9%), getting loans (46.6%), selling properties (12.3%), using buffers (e.g., stored foods, savings), receiving support from local organizations (6.8%), etc. (Fig. 2.8).

It is very much unlikely that none of the local or national level organizations (including the government institutions, NGOs, cooperatives, etc.) has not initiated any research or piloted technical support (such as using solar energy for drying up the salt or indorsed local weather forecasting system) which may contribute to support the salt farmers in adapting with adverse weather events. Additionally, there are no insurance or compensation programs that exist for the marginal salt farmers (Field Survey, 2018).

5.9 Additional Burden on Smallholders Due to Low Market Price!

It is perceived from the field survey (2018) that along with loss and damage due to the frequent visit of different natural catastrophes, the smallholder salt producers are also facing a massive loss due to low market price of crude salts. The average production cost for the per hectare of land is approximately 1399 USD which includes expenses such as land lease, water supply, polythene, and labor charge (Table 2.3).

On the other hand, the current selling price of crude salts at the field level is around 920.1 USD only. Therefore, the farmers undergo a loss of approximately 478.4 USD per hectares of cultivated land. And per metric ton of production, the financial loss is around 23 USD (Fig. 2.9).

Imports of ordinary refined, bouldering, or other salts are restricted in line with the government's import policy order (2015–2018). However, salt can only be imported as the primary raw material for the industry and the recognized industrial,

Table 2.3 Salt production cost per hectare

Type of cost	Amount (in BDT)	Amount (in USD)
Land lease (for 6 months)	83,333	981
Water supply cost	10,417	123
Polythene use cost	12,500	147
Labor cost	12,500	147
Total cost	**118,750**	**1399**

Note: In Bangladesh, the local salt cultivators use the land measurement unit named *Kani*. The author has collected data on the local unit and converted it into the international unit. 1 *Kani* = 120 decimals = 0.48 hectares
Source: Field Survey (2018)

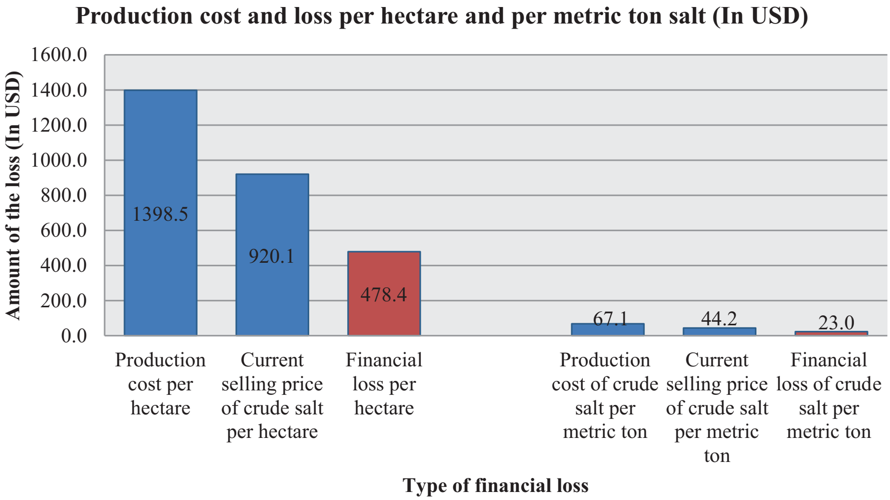

Fig. 2.9 Production cost of salt and financial loss. (Source: Survey, 2018)

pharmaceutical company by its recognized industrial unit producing chemical products (Barua & Eslamian, 2022), approved by the Directorate of Drug Administration (GoB, 2016). By abusing this act, crude salts are being illegally smuggled and imported by some salt mills at a low price in Dhaka, Chittagong, Cox's Bazar, Khulna, and Jhalokati, as opposed to a local market (Al Mamun et al., 2014). Such activity creates an added burden and damages from natural disasters on marginal salt farmers. In addition, the raw salt price is comparatively low in comparison to the retail price of the refined salt sold in the local market. Hence, the salt producers are facing injustice in the pricing of salts.

6 Conclusions

In the last 4 fiscal years, the country has failed to reach the salt production target due to adverse weather conditions such as unexpected heavy rainfall and tidal inundation. Consequently, Bangladesh had to import nearly one million metric tons worth of 120 million USD, and therefore, this country could claim equivalent compensation from the international loss and damage fund! In spite of the absence of such financing authority, governments in vulnerable countries have started developing their mechanisms for loss and damage. For example, Bangladesh is already setting aside contingency funds for climate-related disasters and is now considering the development of a dedicated loss and damage mechanism. Other countries have developed regional risk pooling solutions – such as the Caribbean Catastrophe Risk Insurance Facility (CCRIF) – or national insurance mechanisms.

Most importantly, these mechanisms need to reach those most in need of support: poor households with a high dependency on natural resources for their livelihoods (Kreienkamp & Vanhala, 2017). However, in Bangladesh, there is still an absence of such risk insurance mechanisms or policies that would be useful for addressing the loss and damage of marginal salt farmers due to the low-exposed sudden-onset events, including erratic or heavy rainfall events. Hence, this study urges the policymakers and other relevant stakeholders to come forward to take necessary steps in developing essential policies and introducing adequate adaptive measures (such as using the removable cover, community storage facilities, enhancement of early warning system, and dissemination through mobile technology) and efficient response measures (such as well-targeted safety net program, a soft loan, or insurance facilities). At the same time, the researchers and academicians should initiate a comprehensive study for exploring solutions to save the marginal farmer from the unfavorable nexus of "Nature and Market."

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Chapter 3
Disaster Economic Vulnerability and Recovery Programs Experience from Tanzania

Neema Penance Kumburu

Abstract Disaster risk is described as "the probable damage of life, injury, or demolished or spoiled properties that might happen to a network, organization, or a communal in a particular time, influenced probabilistically as a role of hazard, exposure, vulnerability, and ability," while economic recovery program is a means by which a community advances and competently executes its ability to engross an early tremor using extenuation and to counter-react and acclimatize subsequently so as to preserve activities and fasten rehabilitation and again to be in an improved situation to lessen fatalities from upcoming disasters. No organized examination has been endeavored to comprehend disaster economic vulnerability and recovery programs in Tanzania; thus there is knowledge gap in this area. It is for this reason that this section documents and shares knowledge on disaster economic vulnerability and recovery programs using Tanzania as a case under investigation. The development of this section was founded on the hypothetical and ancient work study. To ensure an extensive hypothetical and experiential foundation for this work, desk review has been carried out to gather information from numerous secondary bases. This comprised reports and project papers and registrations. Secondary databases have been gotten from writings regarding disaster, economic vulnerability, and recovery programs. Furthermore the desk review reviewed reputable journals related to the discipline. Finally, the information gathered were scrutinized, polished, and modified to match the requirement of this article. Concepts and frameworks on tragedy economic susceptibility and repossession agendas as well as indices that are used to measure susceptibility and pliability to natural threats are also offered; this is shadowed by econometric model: influences and measures of economic susceptibility. The chapter also illustrates disaster economic vulnerability and retrieval programs experience from Tanzania whereby efforts that have been made so far and economic recovering program, namely, macroeconomic stability, microeconomic market efficiency, governance, and social development, have been presented.

Keywords Disaster · Economic vulnerability · Recovery programs · Risk

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N. P. Kumburu (✉)
Department of Management, Moshi Co-operative University, Moshi, Tanzania

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1 Introduction

Among 1970 and 2012, the worldwide direct economic losses (DELs) triggered by climate-correlated disasters amounted US$ 2.4 trillion (in 2012 prices), and deaths surpassed 1.94 million (WMO, 2014). On the other hand, universally, 91% of altogether disasters throughout 1998–2017 were triggered by overflows, tempests, droughts, heatwaves, and other life-threatening incidents (CRED, 2018). These incidents caused death in human life and major harm to possessions, infrastructure, and the surroundings (Formetta & Feyen, 2019); additionally the events excessively influence people in emerging countries (UNISDR and CRED, 2015). Worldwide climate-linked disaster losses have realized growing tendency in the last decades, mostly due to increased manifestation of human being and properties caused by economic progress and populace increase (Wu et al., 2018). Moreover, the susceptibility to disasters also differs particularly along the development range (Tanoue et al., 2016). Although the developing and third-world countries contribute to up 65% of global natural tragedy deaths from 1985 to 1999 (Wu et al., 2018), the hostile economic growth effect of weather disasters is more apparent in less developed countries compared to first-world countries (Klomp & Valckx, 2014). Even though obviously correlated, disaster economic vulnerability and recovery programs remain elusive (Fatemi et al., 2022).

Over 2000 natural tragedies have pretentious 460 million persons, and murder over 880,000 since 1970 in Africa (Pusch et al., 2016). Overflows are the greatest recurrent, contributing for 42% of economic costs. Yet, droughts form 78% of the vulnerable populace. Other less common hazards such as hurricanes, tremors, landslides, volcanoes, and epidemics have broad-spectrum economic and growth penalties. Capitals needed for retrieval avert deliberate growth expenses, thus causing fiscal pressures. Disasters likewise have a macroeconomic cost, such as damage and deceleration growth of GDP (Pusch et al., 2016). Harm and fatalities triggered by natural disasters counting unhurried beginning ones such as droughts have produced an attrition of considerable percentages of GDP, and noticeable slowing down in GDP growth, in African economies over the last few years. Tragedy fatalities and people's contact to dangers are cumulative in Africa. This is attributed to quick development, unplanned dwellings frequently in dangerous areas, unmanageable land usage, infrastructure pressure, cumulative climate inconsistency, and increasing populace. Environmental dilapidation, deficiency, and battle further worsen the dangers and decrease the adaptability ability of communities.

Comparable to other nations in sub-Saharan Africa, Tanzania is principally susceptible to the influences of life-threatening weather, such as extensive floods, recurrent and lengthy droughts, and seaside storm surges (Watkiss et al., 2011). These incidents have been allied straight to substantial social and fiscal effects counting deteriorating harvest yields, augmented occurrences of produce pests and illnesses, loss of livestock, reduced water obtainability and upsurge in the last few years, and water-borne diseases (Msemo et al., 2021). Practices specify that communicable illness outbreaks habitually follow dangerous climate activities, as microorganisms, sources, and pool animal hosts exploit the troubled communal and ecological situations of dangerous weather (McMichael, 2015). Human health also is affected due to heat stress, changes in weather condition, and water-borne contagions, air impurities, and conflicts motivated by the utilization of scarce natural resources (Ncube & Tawodzera, 2019).

Feeble recovery ability and dependence on rainfed agriculture brand Tanzania tremendously susceptible to climate variation effects (Msemo et al., 2021). It is predictable that by 2100 Tanzania will realize upsurges in flows and sea level rise, exposing majority of persons at risk of seaside overflowing (Mkonda & He, 2018). Msemo et al. (2021) noted that the Tanzanian government has continuously devoted millions of US dollars circumventing the effects of unadorned weather and climate variation, but the efforts have never been successfully partly due to postponements and official drawbacks in integrating the healthier application of climate information (Pardoe et al., 2018). It has been forecasted that climate alteration might cause net fiscal charges that are equal to a cost of nearly 2% of GDP each year by 2030 (Watkiss et al., 2011). It is recognized that the government of Tanzania has enacted, designed, and implemented policies and programs supportive to disaster and economic vulnerability. These policies and programs include Disaster Relief Coordination Act No. 9 of 1990. The Act was also reviewed in 2015. Among others, the Act recognized an Inter-Ministerial Committee, namely, the Tanzania Disaster Relief Committee (TANDREC), to superintend, organize, and control the general release processes and disaster administration functions in the republic.

Despite the efforts, the study by Msemo et al. (2021) found that a sum of 498 tragedies were noted in the tragedy records from the Prime Minister Office Disaster Management Department (PMO-DMD) amid 1872 and 2019, out of that 363 happened among 2000 and 2019 whereas 135 arose in the period of 1872 and 1999. Weather-linked disasters amounted for 250 (69%) of the 363 detected tragedies in Tanzania. The span of 2000–2019 has an alike occurrence of tragedy type as the entire time of 1872–1999. Flooding is the greatest happening occurrence, ascribing to 35% to the entire-natural tragedies in both periods. Strong winds amount to 8.1%, and drought contribute to 4.4% of the whole catastrophes, during the 2000–2019 period. With regard to actions often linked to bad climate (directly or indirectly), speats and maritime fates accounted for 21.2 and 16.2%, respectively, of entire-natural tragedies in the last 20 years. Climate influences are observed as a fundamental feature in a number of speats such as cholera, dengue, and plague (Chersich et al., 2018; Fadda, 2020), although bad climatic actions and deprived attention to climatic circumstances are among the determinants contributing to naval accidents (Fig. 3.1).

It was further revealed that the magnitude of occurrence of flood is in the northeastern part of the country, Lake Victoria washbowl, northeastern uplands, and the middle parts of Tanzania. Disasters related to deficiency of water are high in Arusha, Mara, Shinyanga, Dodoma, Tanga, and Lindi regions. On the other hand, strong winds are prevalent in Dar es Salaam, Pwani, and Mafia Island; Lakes Tanganyika, Rukwa, Njombe, Ruvuma, and Mtwara; Dodoma; Lake Victoria basin; and Mara, Mwanza, and Kagera regions. Coastal areas of the Indian Ocean are more affected

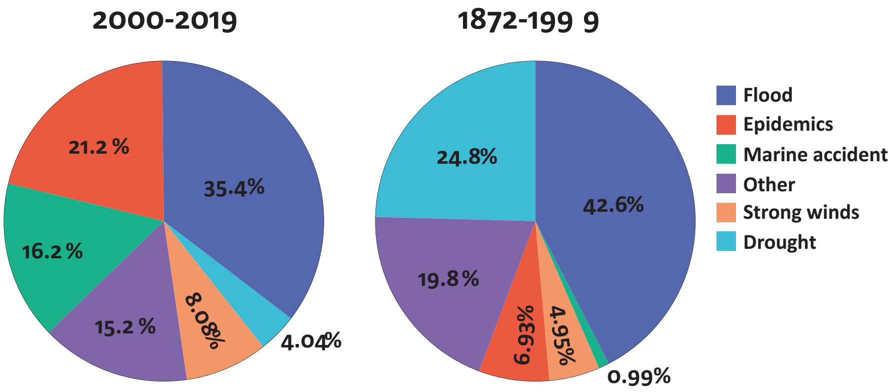

Fig. 3.1 Classification of weather-related and other non-meteorological disasters in Tanzania for the period of 2000–2019 and 1872–1999. (Source: Msemo et al. (2021))

by disasters because of amalgamation of many factors like population density, poor infrastructure, land usage variations, and poverty (Anande & Luhunga, 2019). Substantial precipitation is prevalent in Dar es Salaam, Pwani, Mtwara, Mara, Mwanza, Kagera, and Singida regions, while landslides were common in Kilimanjaro and Mwanza. Nautical fates were reported over Zanzibar Island and single occurrence in Mwanza (Lake Victoria).

Over 20.5 million dollars were spent by the government to control major disasters that destroyed over 35,700 habitats and 1000 critical infrastructures (roads, bridges, schools, and hospitals), displaced over 572,600 people, and resulted in over 240 damages and 450 deaths. See Fig. 3.2 for further information.

While these statistics are correct, there is currently little research on Disaster Economic Vulnerability and Recovery Programs in the third-world countries, particularly in Tanzania. CRED (2018) used the CRED's Emergency Events Database to examine the worldwide position on economic fatalities, deficiency, and catastrophe in the period of 1998–2017 (EM-DAT). The document grouped disasters, based on the kind of danger that activates them where hydrological, climatological, and atmospheric incidents were cooperatively labelled weather-linked plus geophysical disasters (CRED, 2018). Furthermore, the document compares the effects among developed and developing countries with emphasis on human impact rather than pecuniary effects. On the other hand, Msemo et al. (2021) on their study What Do Weather Disasters Cost? An investigation of climate influence in Tanzania uncovers the space spreading of climate-associated disasters and their impacts and proposes mechanism to advance creation and acceptance of climate data by climate delicate sectors. No organized scrutiny has been attempted to understand disaster economic vulnerability and recovery programs in Tanzania; thus there is knowledge gap in this area. It is for this reason that this chapter will document and share knowledge on disaster economic vulnerability and recovery programs using Tanzania as a case under investigation.

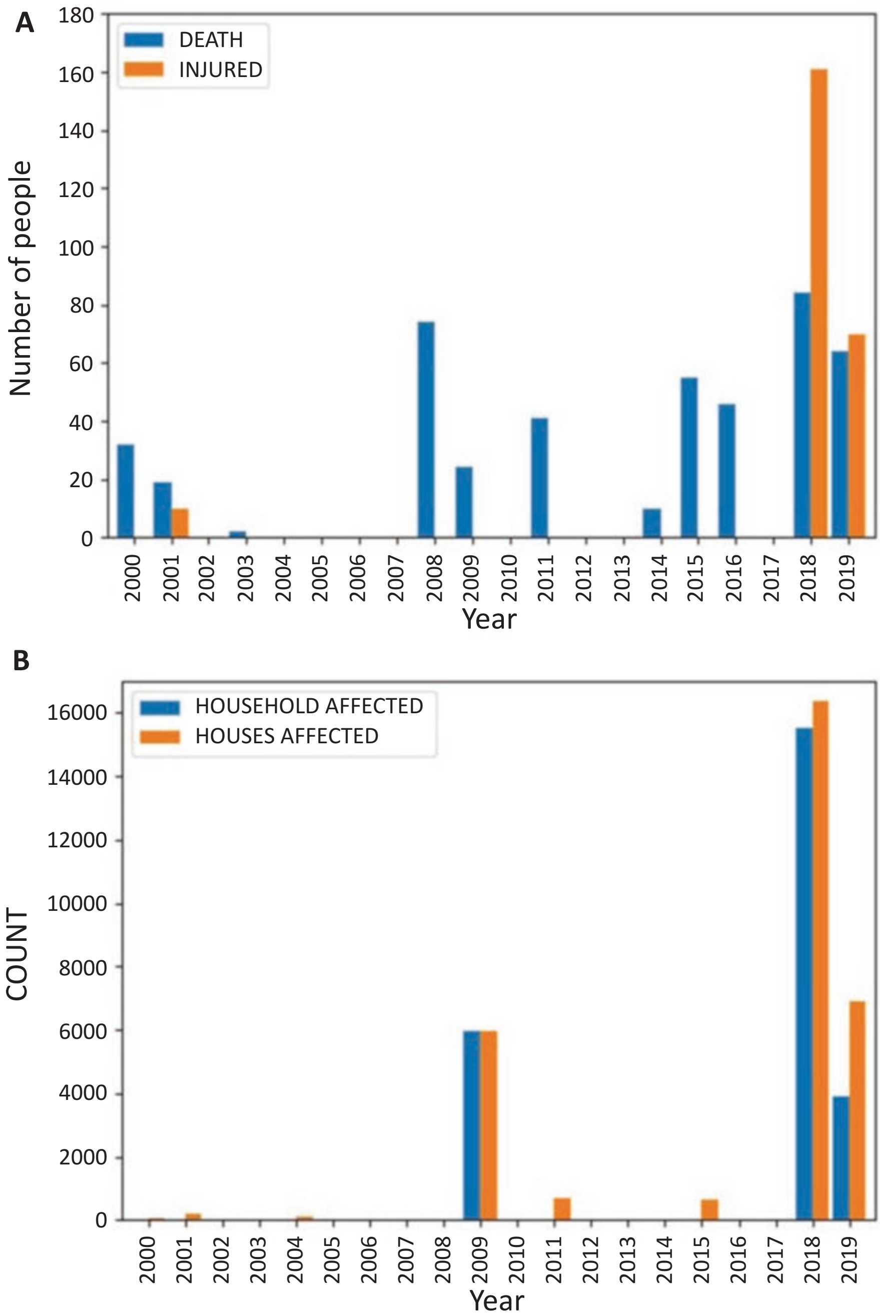

Fig. 3.2 (**a**) The yearly number of deaths and injuries. (**b**) The yearly number of persons impacted and homes destroyed or damaged by weather-related catastrophes. (Source: Msemo et al. (2021))

Development of this work was based on the hypothetical and pragmatic literature study. To ensure extensive hypothetical and empirical foundation for this study, desk review has been carried out to obtain data from numerous secondary foundations. This included reports and project documents and policies. Secondary data sources have been gained from literatures about disaster, economic vulnerability, and recovery programs. Furthermore the desk review reviewed reputable journals related to the discipline. Finally, the information gathered were scrutinized, polished, and modified to match the requirement of this article.

2 Overview of Key Concepts and Frameworks on Disaster Economic Vulnerability and Recovery Programs

2.1 Conceptual and Theoretical Frameworks

What is described as disaster today was not there 10 years past; the dissertation on tragedies was mainly concerning natural threats and their faces. Disasters were regarded as outcomes of procedures of the geophysical biosphere (Cavallo & Noy, 2011). In such situation governments' recovery programs were largely mechanical, in particular hazard defense actions such as flood resistance (Van Westen et al., 2009). The mechanical approach provided inadequate solution to the changing effects of disaster on individuals and community (Noy & Yonson, 2018). Over the years, using the practices of third-world nations, the notion of susceptibility arose in the disaster treatise. Disasters activated by natural threats have been extensively regarded as unnatural incidences invited by a convergence of communal influences sideways these natural hazards (Van Westen et al., 2009). Based on that, that disasters were the outcome of the interface among natural threats and societal issues seemed as early as in the 1970s (Noy & Yonson, 2018); however the opinion has not voluntarily gain extensive recognition at that moment. Consequential to this transformation is the keen curiosity by an array of disciplines in attaining adeptness of the vital fundamental issues that permit hazards to convert to disasters. From this thoughtful of vulnerability arose a similar recognition of the dissimilar role of resilience in determining the effects that tail from the subsequent disaster impacts.

At the moment enormous theoretical and pragmatic works on susceptibility and resilience to natural dangers are available. Though mainstream of these literature are from varied social disciplines, the economic measurement of susceptibility and of resilience is typically covered. Scholars in economics began later, principally in 2000 (Noy & Yonson, 2018); nevertheless the inventive description on the economics of disasters arose much earlier by the works of Dacy and Kunreuther (1969) and Albala-Bertrand (1993). On their study Dacy and Kunreuther (1969) assessed the factors of long-run recovery, such as infrastructure networks, insurance, and public policy. Meanwhile, Albala-Bertrand (1993) designed a framework for examining disasters in third-world countries and contends that in the sphere of progress influences the prevalence of a disaster, disasters are not impediment toward development. Thus, it can be said that economic susceptibility and adaptability, interacting with the hazard and the revelation of populaces and physical possessions, are regarded as crucial elements of the resulting disaster damages and losses. As a matter of fact, disasters are determined mostly by economic forces, so that existence of disasters is an economic event (Cavallo & Noy, 2011).

Innumerable research adopts numerous procedural approaches within and external the economics discipline. Complex adaptive system is one of the prominent methodology which offers sympathetic increasing effects of natural dangers by captivating an evolutionary approach (Holland, 2006). Other relevant and crucial approaches include the general equilibrium methods and the partial equilibrium analysis.

Complexity theory is about unpredictable associations in altering, chaotic systems whose steadiness is transitory (Norberg & Cumming, 2008). It tries to comprehend how multifaceted behavior changes or arises from fairly modest resident connections amid system parts over time. Complexity theory thus brings into line well with the context of susceptibility studies assuming that, distinct to conservative systems theory founding, intricacy approach hypothesizes that frameworks are not in a persistent state of symmetry and are created relationally (Preiser et al., 2018).

This avoids the stationary characterization of interconnected procedures and outcome by concentrating on determinants including expansion of feedback circles, the crossing of verges, and the variety of performers and procedures utilized. To comprehend the system as a whole as well as how its parts fit together, it is thus crucial to scrutinize changing associations on different foundations of a system with time and the movement of stocks and flows among its sub-parts. Complex systems appeared to be utilized in continuous sciences and the examination of human-environment connections by the eye of Complex Adaptive System (CAS) (Preiser et al., 2018). CAS and complexity theory often utilize together a number of assumptions in such both contend that systems are made up of varied parts that are autonomous but whose small connection and possessions advance to emergent wider behaviors (Cairney, 2012). CAS, however, are attentive, upon adaptation, and have the capacity of systems to self-organize and adjust their behaviors; as a result, they can acclimatize to deviations in their surrounding and establish co-evolutionary capacity. Furthermore, CAS theory declares that systems are integrally managed by economies of scale and that minor relations are frequently ruled by greater-scale trends. Main ideas inside CAS theory are modulation (i.e., the extent to which bulges of a network can be dissociated into comparatively separate parts and reconvened), redundancy (i.e., the extent to which bulges can substitute for one another), ranked endogenous-exogenous interface (i.e., the system is exposed and can interrelate with outside factors), and emergence (the source and growth of unforeseen or erratic phenomena) (Naylor et al., 2020.) CASs are too understood to have the aptitude to not only acclimatize but also study, know, and respond to reactions both institutionally and ecologically. CAS theory is built upon some surrounds of risk and some elementary doctrines which are not comprehensively sufficient to fit within practically any susceptibility approach or framing. Examples notion that a system can self-organize after a perturbation to recur its initial role when a stressor is applied, which reduces its subsequent susceptibility through an increase in its coping range. Figure 3.3 presents the details.

A general equilibrium approach (GEA) is a valuable framework to assess the economic impact of disaster and its policy response at micro and macro levels (Huang & Hosoe, 2014). The model is a multi-market simulation approach based on the optimization behavior of individual households and firms, as well as competition in markets following the GEA developed by Hosoe et al. (2010). Overall, the aim of the GEA approach is to estimate a community's regional economy at a particular point in time (e.g., a "snapshot" of the economy after investing in resilience) and to examine how the community responds to exogenous changes (or "shocks") to the economy relative to that particular point in time. For that matter GEA is an ideal option for discovering the effects of large disruptive events, such as recessions and natural disasters, on a community's economic activity and the impact of resilience planning on reducing these effects. GEA imitates the working of a market economy in that prices and amounts supplied and demanded are regulated to clear all markets (Helgeson et al., 2018). The economy is assumed to be in equilibrium when markets are clear. Figure 3.4 presents the typical associations in the economy as prescribed by a CGE. Households increase their welfare, firms boost their profits, the state is assumed to have a balanced budget, and resources are scarce but again costly. Effectively, a GEA stipulates the probable behavior of enhancing consumers and producers; the community and government (e.g., taxes) are included as an agent to capture transactions in the circular flow of income (Shultz & Elliott, 2013). GEA models allow for a geographic distribution of the impacts from shocks to an economy. Thus, GEAs are ideal for exploring the distributive effects (in particular, the

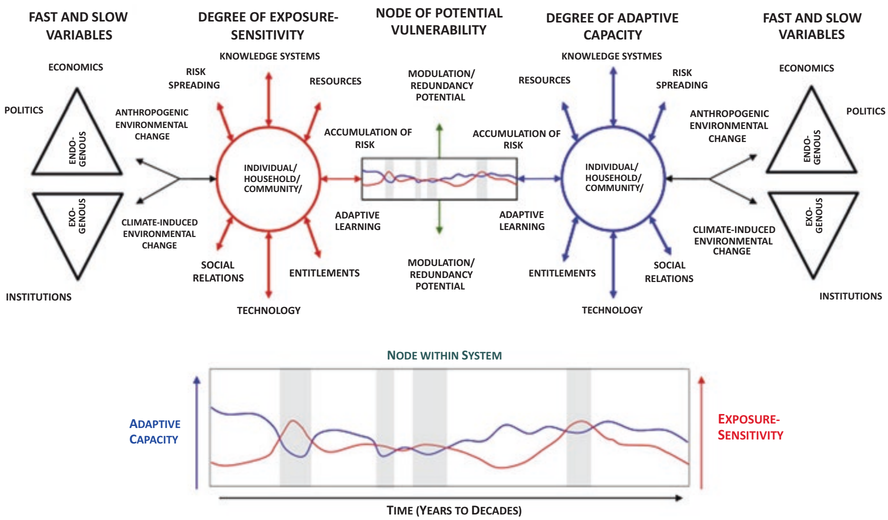

Fig. 3.3 Complex adaptive system and vulnerability. (Source: Naylor et al. (2020))

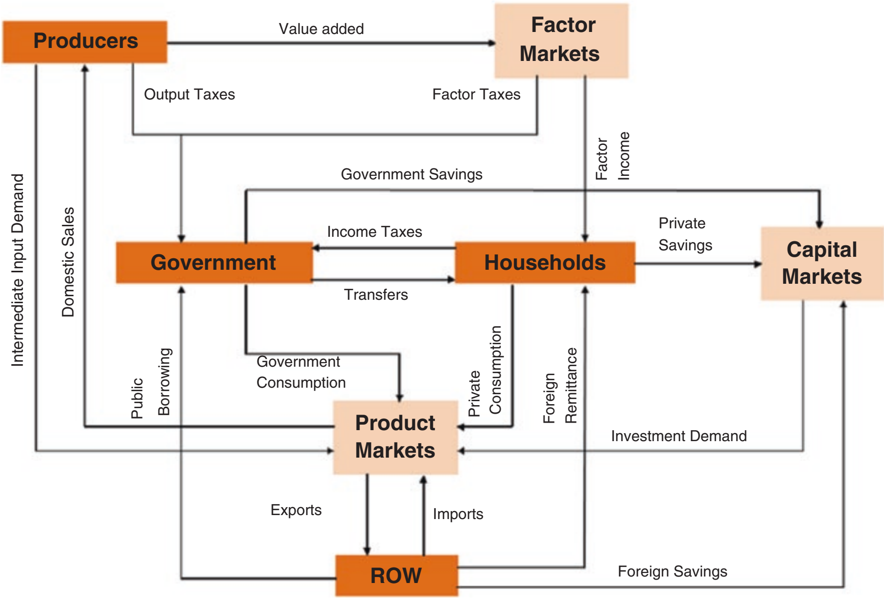

Fig. 3.4 Main components in a GEA. (Source: Helgeson et al. (2018))

resilience dividend) of resilience planning against large-scale shocks across a community such as floods and drought.

The partial equilibrium technique associates supply and demand in single or multiple marketplaces in order that prices are steady at its symmetry level. Utilizing this method, the prices convert endogenic in difference to the demand purposes. This method is differentiated from GE models for the reason that it fails to reflect all production and consumption state in an economy. It also fails to reflect all markets and prices in an economy and fails to capture the influence of variations in one market on additional main markets in the economy. Fractional symmetry analysis is more appropriate for assessing sectoral improvements. Precise equipment for fractional equilibrium includes “multi-market models” and “reduced form methods.” The multi-market models approximate mechanisms of demand and supply relations and assess the influence of regulations in subdivision which can be interpreted into other linked segments. Multi-market models are applied in a numeral of settings to scrutinize the well-being effect of mechanical vicissitudes in farming, e.g., input grants in India (Binswanger & Quizon, 1984) and receivers and losers in business reorganization in Morocco (Ravallion & Lokshin, 2004).

Condensed form practices are applied to activate the influence of dissimilar regulation parameters on social consequences, such as deficiency and nourishing condition. A situation of reduced form technique for Tanzania was realized in quick per capita GDP advance between 1995 and 2001. Yet, domestic surveys displayed the weakening in poverty was comparatively minor. Understanding this state, Demombynes and Hoogeveen (2004) contended that a conceivable clarification for this consequence was because poverty augmented through beginning of the 1990s, whereas economic progress might only counterbalance a portion of the initial increase in poverty.

They presented that, underneath a diversity of situations, poverty occurrence first enlarged to above 40% at the beginning of the 1990s and then deteriorated to less than 36% by 2000–2001. Their sectoral imitations recommended that the poverty reduction influences economic growth in Tanzania which was more important in town than in villages. Their sectoral rottenness of the poverty consequences designated that a minor portion (11.6%) of the weakening in headcount poverty at the country might have been clarified by a change in the populace from the inferior village areas to the rich town areas. They decided that attaining the Sustainable Development Goals would thus need altering designs of growth in the village areas. More recently, Holmes and Dharmasena (2016) utilized the monthly national US data for the period 1997–2012 to investigate the connections among macroeconomic tremors and involvement in food support programs. Their modelling included polynomial dispersed lags, vector autoregression methods, and directed acyclic graphs. Such methods can be applied to develop improved forecasts of involvement rates in food support programs at the time of shocks persuaded by macroeconomic parameters, can help in better valuation of the costs involved in food support programs, and can save government capitals through creating the intervention cost-effective.

2.2 Synthesis of the Findings from Econometric Studies

Synthesis of the findings from econometric studies is presented in order to offer comprehensive understanding of disaster economic vulnerability and recovery programs. In this context a model specification of the four-component disaster risk formulation is specified as:

$$\text{Disaster Risk} = f\left(\text{Hazard, Exposure, Vulnerability, Capacity}\right)$$

This equation was approved by the United Nations General Assembly as fragment of the worldwide effort to create parameters for the Sendai Framework for Disaster Risk Lessening 2015–2030; in addition the variables are in line with the pointers for the Sustainable Development Goals (UN, 2016) According to UN (2016), disaster risk is likely demise, damage, or demolished or spoiled assets that might happen in a certain period of time to an organization, culture, or community, as influenced probabilistically as a function of hazard, exposure, vulnerability, and capacity." A technique, object, or human deed that may result in loss of life, injury, or other health effects, property damage, social and economic disruption, or environmental degradation is defined as a hazard in this context.

On the other hand, exposure is when individuals, infrastructure, habitat, production capacities, and other palpable human assets are exposed in hazard-prone environments, whereas vulnerability refers to situations exacerbated by physical, social, economic, and environmental influences or procedures that increase an individual's, a community's, assets, or systems' defenselessness to the effects of hazards. Finally, capacity is a combination of all the high-caliber attributes and properties accessible inside an organization, community, or society to manage and reduce disaster risk while also strengthening resilience (UN, 2016).

In this context, capacity refers to both adaptive and coping capacities, as defined by the IPCC (1996) and the UN (2016) and the UNISDR, respectively (2006). The capacity of an organization, neighborhood, or community exposed to catastrophe to fight, engross, host, change, and recuperate from the impact of a hazard in a right time and effective manner, applying the conservation and refurbishment of its vital elementary structures and purposes using risk management, is referred to as resilience.

2.3 Frameworks on Vulnerability and Resilience

There is distinct operationalization of susceptibility and pliability apiece of the disciplines and societies intricate in the discussion of natural threats (Birkmann, 2006; Thywissen, 2006). Villagran de Leon (2006), on the other hand, shows how a range of different activities have resulted in a shift in sympathy, if not misconception, toward these beliefs (Miller et al., 2010). That's why individually discipline is probable to preserve its exact meanings and disciplinary contexts when investigating natural hazards and disasters, without creating the alterations and contextualization to line up with other disciplines. Regardless of the contributions of numerous academic disciplines (e.g., sociology, geography, economics, planning, or public health), the meanings and frameworks of disaster risk reduction (DRR) and climate change continue to evolve as a result of their application within the DRR and climate change communities. Before the four-item disaster risk formulation described in Sect. 2.2, the disaster risk community's most common and longest stand-up disaster risk formulation was as follows:

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability}.$$

The dual-items risk formulation, i.e., Risk = Hazard × Vulnerability, is added variant. It seizures the two contrasting mechanisms under the Pressure and Release (PAR) framework (Wisner et al., 2004). Concentrating on individuals, vulnerability is described in this context as the features of an individual or cluster in terms of their ability to antedate, contend with, counterattack, and recuperate from the impact of a natural hazard (Blaikie et al., 1994). In this operationalization, it is true that vulnerability includes exposure. This description imitates what usually are regarded to be the parts of resilience, as demarcated by UNISDR (2006) and UN (2016). Notwithstanding this clarification, the system touches the means that disaster happens when a natural menace comes close to the weak. The PAR framework is also shown in the Evolution of Vulnerability Framework. This concept distinguishes between three stages of vulnerability development: the economic and social networks that determine the ways by which capitals, prosperity, and authority are dispersed, governance ideologies, and antiquity and culture are all examples of "root causes." "Dynamic pressures" are defined as shortages in society's economic, social, and political processes, as well as macro-forces such as rapid population growth and urbanization, desertification, and a decrease in soil throughput, to name a few (Noy & Yonson, 2018). These serve as the means by which the origin gives rise to a result in delicate livelihoods in dangerous sites that is the last level in the advancement (Wisner et al., 2004). There are a slew of other previous definitions of vulnerability that contain either or both familiarity and pliability. Pelling (2012), for example, recognizes three types of vulnerability: exposure, resistance (the ability to withstand hostile impact), and resilience (i.e., the ability to cope and acclimatize).

Sensitivity, exposure, and adaptive capability are all factors that influence vulnerability (IPCC, 1995). It divides the advantageous and disadvantageous characteristics that influence susceptibility into binary groups: sensitivity and resistance. Furthermore, the IPCC (1995) proposed that resilience is the polar opposite of vulnerability. Meanwhile, Holling (1973) describes the resistance of ecological systems' scenery to shocks. He defines resilience as a system's ability to absorb vagaries and persevere in the face of them. Similarly, the capacity to survive the occurrence of the danger while suffering only tolerable amounts of losses is articulated in the geoscience disciplines (Mileti, 1999). The length of time it takes to recuperate from the harmful effects of a tremor is emphasized in engineering (Correia et al., 1987). Pimm (1984) defined resilience as the speed with which a disorder is recovered in an ecological context, which is analogous to engineering. Apart from disasters, the idea of vulnerability is used in economics to describe tetrad extents of concern: poverty, food security, asset vulnerability, and sustainable development (Alwang et al., 2001). Vulnerability is regularly assessed in the dynamics of poverty, with a focus on the "risk of slipping into poverty" (Moret, 2014). Resilience is also applied in three different sections of the research: economic tremors, sustainability, and organizations (2009).

Briguglio et al. (2009) are among the first to examine the association amid economic susceptibility and economic pliability, hypothesizing that the two influence a country's danger of being amplified by outside earthquakes. Economic vulnerability is demarcated as a country's exposure to external disturbances as a result of intrinsic economic features such as economic openness, export concentration, and reliance on strategic imports. These are considered structural and so hard to alter by intelligent strategies. Economic resilience, on the flipside, denotes to the economy's capacity to cope, which might be changed by policy (Briguglio et al., 2009). Policies that promote and encourage recovery programs improve macroeconomic constancy, upsurge market efficacy, advance administration, and enlarge social progress. Rose (2009) noted numerous extents of economic recovery programs that are given scant attention and that are ignored in the current operationalization. They argue that, despite everything, there is a necessity to discriminate among injury to stocks (i.e., property damage) and destruction of flows (i.e., destruction of production of goods and services). While stock losses are felt completely at the time of the shock, flow losses begin almost immediately after the danger occurs and endure to be felt until the complete retrieval is realized. As a result, according to Rose (2009), flow damages are more pertinent to the economic retrieval apprehension.

3 Assessment of Economic Vulnerability and Economic Recovery Programs

There are various efforts that have been made by researchers and academicians to translate these theoretical approaches into applied tools to analytically recognize the elements of the numerous scopes of economic susceptibility and retrieval program.

3.1 Indices of Vulnerability and Recovery Program

The index methodology is one of the most commonly used methods for assessing vulnerability and adaptability to natural disasters. These scales are designed to capture a wide range of susceptibility and pliability, as well as their economic components. The most well-known economic metric includes outcome (GDP or regional output), revenue, employment, price increases, consumption, expenses, savings, local and international financial transfers, public money, and trade (Rose & Krausmann, 2013). These scales differ in terms of motivation (e.g., assessment of susceptibility and/or pliability), geographic scope (e.g., global, provincial, local), examination scale (e.g., governments, resident authorities, enterprise-level, household), and methodological approach (e.g., government, resident authorities, enterprise level, household) (e.g., deductive, inductive, econometric). The recognition of gauges is based on relevant theoretical frameworks and/or recognized essential factors in the preceding pragmatic literature, and the majority of these measures use an inductive method. The most common methods for combining indications into a merged scale are spontaneous arithmetic or regular mean, and calibration is usually done before the combination. When weights are used, they are often based on expert judgment, participatory procedures, or a combination of the two. Econometric algorithms, such as data-reducing techniques like principal component analysis (PCA) and factor analysis, are another ordered tool for recognizing relevant indicators and allocating weights (FA). One of the first indexes to use the PCA was Cutter et al.'s (2003) social susceptibility index (SoVI). In sectoral level investigation, the SoVI and its offspring are commonly used. Two global indices are presented in the following subsections.

(a) **The Disaster Risk Index**

The Disaster Risk Index (or DRI) is the first index to use an arithmetic technique to try to validate the mechanism by which human sensitivity and disaster risk are affected by growth (Pelling, 2012). The DRI is handled on a global scale and has a national level of examination. The DRI was custom-made by the United Nations Development Program to be used by global and national policy formulators to make direct choices. The DRI used an inferential technique to identify a variety of economic, social, and environmental variables that were examined for their relationship to disaster deaths (Pelling, 2012). The basic risk equation is reflected in the DRI equation:

$$R = H \times \text{Pop} \times \text{Vul}$$

where
R = is the disaster risk, calculated in the form of quantity of deaths
H = is the proxy for hazard, calculated in the form of incidence of happening
Pop = is the amount of persons staying in the part affected by hazard
Vul = is the vulnerability

Vulnerability is a type of risk that explains why people who are exposed to the same amount of danger have different levels of risk (Peduzzi, 2006). As previously stated, the DRI only uses statistics on deaths attributed to hazard. For each danger type, a total of 32 socioeconomic and ecological pointers were evaluated as potential important susceptibility factors. Depending on the findings of different regression requirements, the final collection of susceptibility indicators varies among dangers. The GDP per capita for tropical cyclones, droughts, and floods and town growth for tremors are among the economic metrics that have emerged as critical. The results show that while growth does have an impact on susceptibility to natural dangers, the aspects of development that have an impact on each hazard differ. For example, the level of advancement as measured by per capita GDP affects vulnerability to hydro-meteorological hazards, whereas vulnerability to earthquakes is induced by the growth procedure.

(b) **InFORM**

The InFORM risk management index is designed for a global examination of charitable risk, with philanthropic groups, donor agencies, country governments, and development shareholders as target operators (De Groeve et al., 2015). Despite the fact that the InFORM considers the four mechanisms in the UN’s (2006) definition of risk, risk is not “probabilistically determined” here. The InFORM, like the DRI, uses a multiple risks framework. InFORM, unlike the DRI, which only protects against natural hazards, also protects against man-made dangers. The DRI uses a deductive approach to variable selection, whereas the InFORM uses an inductive method. The InFORM is a composite index comprised of more than 50 parameters that are classified and calculated as follows:

$$\text{Risk} = \text{Hazard \& Exposure}^{\frac{1}{3}} \times \text{Vulnerability}^{\frac{1}{3}} \times \text{Lack of copingcapacity}^{\frac{1}{3}}$$

The InFORM defines vulnerability as people's sensitivity to hazards, as defined by the UNISDR (2006) and the UN (2016), and it is represented in two classifications in the index's creation: socioeconomic vulnerability and vulnerable groups (De Groeve et al., 2015). Economic vulnerability is measured by socioeconomic class, which is based on a mathematical average of variables measuring growth and denial, disparity, and reliance on aid. It is renowned that pliability is apprehended, nevertheless not in its sum, under absence of surviving ability that denotes to the existing capitals that aid individuals to "engross the tremor" (Mechler, 2009). Governance, institutional, and infrastructure parameters (such as access to health systems) are used for this element. Although both scales offered overhead are at the macro-level, there are also micro-level scales that are designed to assess economic susceptibility or pliability at the household or business level. In Cutter et al. (2003) and Rose and Krausmann (2013), several helpful appraisals of the macro- and micro-level scales may be instituted.

3.2 Determinants and Measures of Economic Vulnerability: An Econometric Approach

Cross-section or panel data frameworks are the most commonly used in the economics sector to rigorously recognize the underlying farces that define vulnerability and resilience. Deductive econometric frameworks are the most common, according to Pelling (2012), since they are more practical than inductive frameworks. These methodologies are used in two types of studies on the economics of tragedy. The first component aims to assess the influences that determine disaster effects on individuals and properties. The models can be described in the following way:

$$Y_{it} = \alpha_0 + \beta_1 H_{it} + \beta_2 E_{it} + \beta_2 X_{it} + \varepsilon_{it};$$

where:

Y_{it} = is the estimate of real effects either on persons or on possessions in spatial unit i at time t

H_{it} = is a vector of hazard features

E_{it} = is an estimate of the acquaintance of persons or properties

X_{it} = is the vector of the features of the exposed components, including the social, economic, and physical environments

These experiential models produce understandings on the factors underlying the susceptibilities of the discovered by controlling for hazard aspects and the familiarity of individuals and properties. The second component aims to examine the financial impacts in the short term (months to years) as well as the long term (at least

3–5 years). These researches also try to comprehend the issues that drive these influences in order to provide insight into the elements of economic pliability. According to Cavallo and Noy (2011), most models have the below specifications:

$$Y_{it} = \alpha + \beta X_{it} + \gamma \mathrm{DIS}_{it} + \varepsilon_{it};$$

where:

Y_{it} = is the effect of a spatial unit i on economic flows at time t. These effects are quantified, among other things, in terms of GDP (or growth), GDP per capita, the human development index, poverty, and employment.

DIS_{it} = is the disaster's immediate effect on properties and/or people. This provides the hazard features in various researches.

X_{it} = is a vector of control variables that influence Y_{it}.

As previously stated, resilience means the ability to reduce health-related losses (Wu et al., 2018). This drive necessitates the selection of appropriate wellness indicators to employ. The use of production and output variables, such as GDP and its variants, as a substitute for well-being is common, while consumption is debatably a healthier proxy. There exists economic work that argues on numerous welfare assessments. One of the prior recommendations on the limits of production and development parameters as welfare measures comes from Nordhaus and Tobin (1972). Overall, production refers to how much is made available, whereas consumption refers to amount that actually spent (expended). As a result, the economic conceptions of utility and way of life are seized by the healthier. Consumption, rather than work and production, is important to utilitarians (Cavallo and Noy) (2011).

4 Disaster Economic Vulnerability and Recovery Programs Experience from Tanzania

Tanzania, officially the United Republic of Tanzania, is a country in East Africa. In 2018, its population was estimated to be 54.2 million, including a considerable proportion of people residing in rural areas (68%). The annual population growth rate has been over 3%, and the population is expected to grow even more to 129.4 million in 2050. The services sector accounts for the largest portion of Tanzania's economy (47.6%), followed by the industries sector (28.6%). However, the agricultural sector, with a share of 23.4%, employs the majority of the workforce, accounting for roughly 67% of the total employment (Delloitte, 2017; URT, 2019). Tanzania's gross domestic product (GDP) in 2018 was $58.0 million, and the economy has seen rapid growth in recent decades, averaging 6.76% between 2002 and 2018 and continuing to expand steadily (5.4% in 2018). Naturally, fiscal incomes account for between 10% and 12% of national GDP. Budget deficits have been decreasing in recent years. In most industrialized republics, disaster attentiveness and response are well established pre-disaster, with strong plans of deed advanced by a team representing multiple sectors. Contempt misery from some of the fatal disasters, disaster planning is often absent in most developing countries. In Tanzania, the quantity of disasters has augmented considerably in the past decade. These disasters have costed the life of numerous people, leaving some with enduring incapacities and causing disturbance of infrastructure and settlement.

Responsibility for Disaster Risk Management

Tanzania DRM began with the Disaster Management Department (DMD), in the Prime Minister's Office (OPM). The National Disaster Management Policy of 2004, the Disaster Management Act (DMA) No. 7 of 2015, and the Disaster Management Regulations of 2017 are the driving forces behind it. The Tanzania DMA formed the Tanzania Disaster Management Council to supervise the department's functions (Fig. 3.5). The DMA again establishes a legislative structure for the formation of a state Podium for Disaster Risk Reduction and disaster management committees at all levels.

Though the Act was launched in 2015, it is important to note that it has yet to be completely implemented. Inadequate capitals mean that the government failed to carry out all of the Act's functions, such as the functioning of functional disaster management committees. The National Forums are formed by the DMD. Despite the efforts, there is urgent necessity to advance DRM capability and competences, particularly at the grassroots level, where disasters are most likely to occur. In its areas of operation, a Regional Secretary, as defined by the Regional Administration Act, operates as a Regional Disaster Management Committee. Meanwhile, Council Management Committees are recognized as District Disaster Management Committees in their areas of operation under local government acts. Ward Management Squads, created under the Local Government Act and acting as Ward Disaster Management Committees, and Village Management Teams, acting as Village Disaster Management Committees, are responsible for disaster management at the local level.

The council is in charge of ensuring that DRR is aligned with pertinent government guidelines and regulations. The National Disaster Management Fund (NDMF)

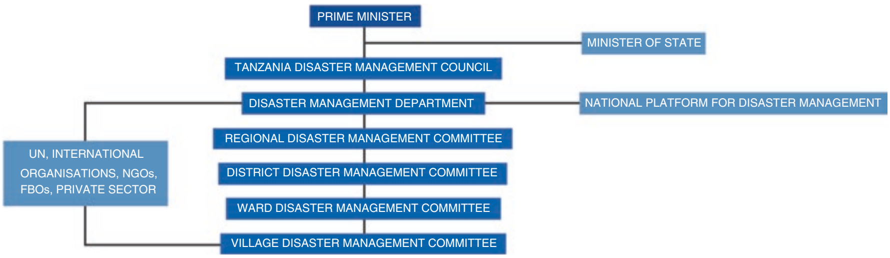

Fig. 3.5 Disaster management governance structure in Tanzania (Source: Disaster Management Department, Government of Tanzania (2019))

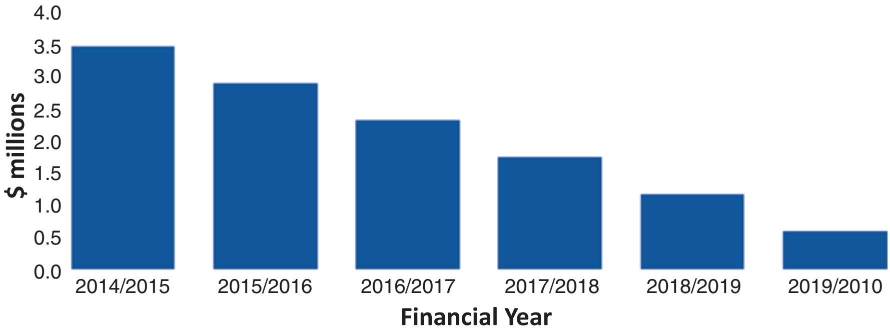

Fig. 3.6 Budget allocations to the NDMF, 2013/2014–2019/2020 ($ millions). (Source: Office of the Prime Minister (2019))

was established by the Act to carry out DRR and humanitarian assistance. The country budget is the primary source of funding for the NDMF.

The quantities allotted for the years 2013/2014 to 2019/2020 are shown in Fig. 3.6. The money allocated to NDMF has deteriorated over time, which could be linked to changes in government policy in response to the country's economic difficulties. Many intrinsic economic topographies, such as high degrees of economic openness, export concentration, and reliance on strategic imports (Briguglio et al., 2006), as well as disasters activated by natural hazards such as drought and floods, are thought to contribute to a country's susceptibility to exogenous shocks.

Economic Openness The ratio of international commerce to GDP determines economic openness. A high level of economic openness exposes a country to external economic conditions over which it has no direct control. Economic openness is a more intrinsic feature of an economy, determined mostly by a country's ability to properly generate the diversity of goods and services required to meet its collective demand. If a country's productive base is limited to a small number of products, it will have to rely on imports to meet a large portion of its spending needs and on exports to pay its import bill. Tanzania economy is highly import dependence especially on strategic import, thus is highly susceptible to the obtainability and price of those imports. For economies that most rely on exports, the instability in both export earnings and economic growth allied with economic tremors exposing Tanzania tremendously defenselessness. Tanzania's terms of trade have been growing over time since 2014, demonstrating augmented competitiveness with key business partners. Subsequently, the economy has been opening up persevering with the transaction share of external trade be around 43.0% of GDP between 2000 and 2017, having augmented from 33.5% in 2000 to the peak of 53.3% in 2011 before weakening to 32.0% in 2017. The mounting motion of importations and exportations chiefly since 2002 describe the trade openness. However, the trade openness index has sustained underneath average of 50.0% globally, 49.0% for East Asia, and 70.0% for sub-Saharan Africa, partially elucidated by a substantial deterioration in global product prices, chiefly for coffee, tea, tobacco, and gold. On the other hand, amplified use of domestic natural gas has substantial lower oil import bill. This is supported by Peduzzi (2006) who use GDP per capita as a proxy for economic progress and discover that it is adversely correlated with fatalities from tropical cyclones, droughts, and floods. Similarly, Kahn (2005) found that first-world countries have fewer earthquake fatalities than emerging ones. As a result, he contends that economic expansion acts as a "implicit blanket" that protects people from the negative effects of disasters.

Export Concentration Reliance on a limited range of exports exposes growth to risks associated with a lack of divergence, worsening susceptibility associated with economic openness. This situation is, once again, largely the result of inherent traits in the Tanzanian economy's manufacturing foundation. The UNCTAD scale on merchandise trade can be used to assess export responsiveness. Briguglio and Galea (2003) invented a substitute scale which accommodates services. It is vital to note that in Tanzania, complete utilization of some of the profits given by the global connection like the new worldwide economic retrieval was affected by a number of mechanical problems. These are in association to attentiveness of export markets to insufficient destinations (mainly India and South Africa), thin exports base, low value adding, and reliance on instable transfers/official development aids (ODAs) as the main exterior sources of finance.

Reliance on Strategic Imports Another aspect of the exposure dispute is the reliance on strategic imports, which may cause an economy to tremor due to the obtainability as well as price of such imports. The ratio of energy, food, and manufacturing supply imports to GDP can be used to measure this variable. This scenario is intrinsic and so dependent on country size, resource availability, and import replacement capability.

There are various disaster economic vulnerability and recovery programs that can be and are used in Tanzania to ensure that Tanzania recuperate rapidly from a tremor; endure the effect of a shock; and evade the shock. Furthermore, the financial recovery programs circumvent from nation's proneness to exogenic shocks emanating from intrinsic financial features, such as high notches of economic openness, export attentiveness, and reliance on strategic imports as well as disasters activated by natural hazards such as drought and floods. The recovery programs are discussed hereunder.

4.1 Macroeconomic Stability

The interface between an economy's total demand and total supply is referred to as macroeconomic consistency. If an economy's total spending moves in lockstep with total supply, the economy can be classified as having both interior and exterior balance, as evidenced by a stable fiscal position, low inflation, and an unemployment rate close to the natural rate. These can be measured as characteristics that are heavily influenced by economic laws and may serve as a legitimate variable in an economy's recovery program when faced with negative shocks. The macroeconomic stability component of the flexibility scale is thus based on a trio of indicators: the fiscal shortfall to GDP ratio, the rate of unemployment and inflation, and the external debt to GDP ratio. The government budget position is acceptable for inclusion in the pliability index because it is the result of fiscal policy, which is one of the most important tools available to government, and it denotes shock-absorbent pliability. This is because, in the event of a negative shock, a strong fiscal position would allow for modifications to taxing and spending policies. The fiscal shortfalls, as a percentage of GDP, price inflation, and unemployment, are all appropriate measures of pliability, and they may also contribute additional data to the fiscal discrepancy parameter. This is because additional types of fiscal policy, such as monetary and supply side measures, have a significant impact on price rises and unemployment. They are linked to pliability because when an economy already has high unemployment and inflation, opposing tremors are likely to charge significant prices on it. If on the other side, the economy has low levels of inflation and unemployment, then it may endure adverse tremors to these indicators without extreme welfare costs. In this regard, consequently, unemployment and price rises designate pliability of a shock-ingest nature. Taking Tanzania as an example, the shove of economic policy has been to withstand macroeconomic constancy by upholding comparatively solid financial progress; following fiscal steadiness by cumulative national income enlistment; governing the growth of comprehensive money supply reliable to economic development and price rise targets; and upholding satisfactory levels of forex reserves. Real GDP development, which is around 4.6% in 1996–2001, increased to 6.2% in 2002 and is projected at 5.2% in 2003. The estimate for 2004 is for 4.8% and 4.7% in 2005. The constancy in growth between 2004 and 2005 is predictable to be sponsored by robust export performance of mutually agricultural exports and gold, also through constancy in economic administration. Tanzania has preserved judicious financial policies that have produced constancy in budgetary results, little and steady price rises, and the steadying of lending rates. The exterior payments state again endured mainly steady, with vicissitudes in the structure of export configuration leading to augmented export revenues. This is supported by Noy and Yonson (2018), results that disclose that nations with an advanced income per capita, superior trade openness, and literateness rate increased state of public spending, and healthier institutions are capable to endure the early influences of tragedies and are too capable to avert spillovers. They further subscribe this to the ability for resource deployment to execute the essential rebuilding.

4.2 Microeconomic Market Efficiency

Markets, and their effective operation via the pricing device, were pinioned as the best means to allocate capitals in the economy by the study of economics. If markets change quickly enough to achieve symmetry, the effects of shocks like floods and droughts may be easily absorbed into the system, and comparable modifications can be made willingly ostentatious. If, on the other hand, market imbalances persist, particularly in the form of unfriendly shocks, capital will not be allocated properly in the economy, resulting in welfare costs, as evidenced by wealth discharges, jobless resources, waste, or shortages in the product markets. Consider the state of Tanzania's financial markets, for example. If markets reply effectively in the face of an opposing tremor with higher interest rates and lower asset values, capital may be reserved in the economy, causing the opposing tremors to be reproduced in price parameters. If, on the other hand, prices in the monetary markets fail to properly regulate, capital may be more likely to flee the economy during a hostile tremor, affecting economic conditions and employment. Similar considerations might be made regarding the approach of balancing the economy's labor and goods markets. These difficulties may have substantial implications for the shock-absorbing type's pliability.

4.3 Good Governance

For an economic plan to function properly and to be resilient, good governance is required. The term "governance" refers to topics such as the rule of law and property rights. Contrary tremors may be comparatively easy to cause economic and social unrest and discontent if such devices are not available. The impact of susceptibility would be exacerbated in the future. Good governance, on the other hand, can strengthen an economy's adaptability. The Global Economic Liberty Index features an element that focuses on the legal structure and protection of property rights. This is said to be useful in determining present workout in the origin scale of good governance. The scales protect judicial independence, court neutrality, intellectual property rights defense, rule of law, partisanship, and the legal system's authenticity. In Tanzania good governance and institutional failure are the origin cause for underdevelopment and susceptibility to disasters. While there are well-established structures and governance mechanism to ensure effective resilience and recovery programs, the established governance mechanisms are not functioning properly, for example, disaster management in Tanzania is guided by the National Disaster Management Policy of 2004, the Disaster Management Act No. 7 of 2015, and the Disaster Management regulations of 2017. But they were established contingent upon a country's governance structure permits the application and execution of public policies favorable to a republic's economic and social growth that can sustainable attained livelihoods and vulnerability to tragedies be condensed. Accountability, participation, predictability, and transparency are recognized as crucial factors of a governance structure that nurtures growth and braces risk decrease. This is supported by Briguglio et al. (2006) who noted that on the contrary, economic pliability denotes to the economy's managing capability that may, in distinction, be prejudiced by policies. Policies that persuade and fostering pliability are the ones that improve macroeconomic constancy, upsurge market efficacy, advance governance, and enlarge social advancement. Singapore that was among the most adaptive economies on economic standards positions 14th in rapports of governance. Susceptible economies incline to get inferior positions on this matter; nonetheless it still seems to be the situation that the susceptible economies relishing an advanced per capita GDP also incline to have healthier schemes of ascendency.

4.4 Social Development

Social development is an added vital constituent of economic resilience. This influence designates the degree to which social relatives in a community are correctly established, allowing an actual working of the economic device with absence of the interference of civil unrest. Social consistency may too designate the degree to which real social discussion happens in an economy, which in turn facilitates cooperative methods in responsibility of remedial measures in time of hostile tremors. It is thus conjectured that social growth is straight connected to social cohesion, though this declaration can't be verified analytically due to absence of data. Social growth in a republic may be assessed in a diversified means. Parameters linking to revenue such as its dispersal and the amount of populace staying in poverty; immortal unemployment rate, showing the quantity of people with little skills and insufficient engagement prospects; and amount of the people having low level of education might be valuable parameters. Still additional conceivable tactic might be to assess the amount and degree of cases of industrial or civil unrest. This is reinforced by Noy and Yonson (2018) who documented that admittance to finance such as microfinancing, global transmittals, and social payments is regarded as a noteworthy contributor to pliability. Yet, in communities with whichever more equal allocation of spending (as estimated by a commune's Gini coefficient of expenditures) or advanced level of mean per capita spending, families are realized as more pliable. Additionally, families with high level of schooling are also more adaptable to the bad impact of overflows and aridity.

5 Conclusions

A disaster is a solemn disturbance of the functioning community or society that has far-reaching human, material, economic, or ecological consequences that exceed the capacity of the current society or community to cope with using its own resources, while an economic recovery program is the procedure that a society establishes and competently executes its ability to engross early tremor through extenuation, responding, and acclimatization afterward in order to uphold function and speed retrieval, also to be in a healthier state to decrease sufferings from upcoming tragedies. Tanzania is principally susceptible to the influences of life-threatening weather, such as extensive floods, recurrent and lengthy dry period, and seaside hurricane flows. Reduced crop harvests, increased occurrences of yield vermin and illnesses, animal damage, reduced water accessibility, and rise in vector-borne and water-borne illnesses are only some of the societal and economic consequences of these episodes.

There has been no systematic analysis of catastrophe economic vulnerability and recovery initiatives in Tanzania, resulting in a knowledge gap in this area. It is for this reason that this chapter documents and shares knowledge on disaster economic vulnerability and recovery programs using Tanzania as a case under investigation. Concepts and frameworks on disaster economic vulnerability and recovery programs as well as indices that are used to assess vulnerability and resilience to natural hazards are also presented; this is followed by econometric approach: determinants and measures of economic vulnerability. The chapter also presents disaster economic vulnerability and recovery programs experience from Tanzania whereby efforts that have been made so far and economic recovering program, namely, macroeconomic stability, microeconomic market efficiency, governance, and social development, has been presented. Understanding disaster economic vulnerability and recovery programs experience from Tanzania has several implications to the attainment of Tanzania vision 2015 as well as Sustainable Development Goals. It is important to remember that 10 of the 17 Sustainable Development Goals (SDGs) contain particular targets connected to disaster risk reduction, including No Poverty, Zero Hunger, Good Health and Well-Being, and Climate Action. Quality education; safe drinking water; and sanitation, industry, innovation, and infrastructure; sustainable cities and communities; climate action; life below water; and life on land are just a few of the issues that need to be addressed. As a result, disaster preparedness and risk reduction are seen as key strategies for achieving the SDGs and Tanzania's development goal 2025.

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Chapter 4
Gendered Economic Vulnerabilities in Disaster Environments: The Case of the COVID-19 Pandemic

Tehmina Khan

Abstract The COVID-19 pandemic has demonstrated that entrenched and gendered economic disadvantages can become more pronounced in a disaster environment, especially when the disaster is a long-term situation, as with the pandemic. There is a large body of literature that has highlighted the existence of gender bias against women, in relation to their financial positions pre-disaster, which become more exacerbated during a disaster. Regional elements, including cultural factors, can become more pronounced, in increasing not only physiological and psychological vulnerabilities of women but also financial vulnerabilities during the disaster. A review of current literature (mostly media and academic literature, 2020–2021) has been undertaken to present a discussion of enhanced financial vulnerabilities of women during the COVID-19 pandemic. Recommendations for threat mitigation are also provided.

Keywords COVID-19 pandemic · Disaster · Threat · Financial gender equality · Economic impacts · Mitigation

1 Introduction

The COVID-19 pandemic has caused multiple negative social and environmental impacts since its global prominence in early 2020. Social impacts have included numerous physiological and psychological impacts due to the disease itself and due to the reactive steps undertaken to control the disease, including lockdowns and restrictions on movements. Perhaps one of the most prominent impact of the pandemic has been unprecedented economic and financial uncertainty (Greenfield, 2020). There have been multiple analyses of national-level and country-specific economic impacts including the costs associated with lockdowns on business and stimuli packages which have resulted in large deficits (IEA, 2021). Industry-specific

T. Khan (✉)
RMIT University, Melbourne, VIC, Australia
e-mail: tehmina.khan@rmit.edu.au

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and micro-region economic impacts have also been provided (see, e.g. Clein & Smith, 2021). Nevertheless, impact of COVID-19-related recession on women has been more pronounced than on men (Wood et al., 2021). As such, the pandemic continues to pose as a major threat to financial gender equality efforts and progress undertaken pre-disaster. Providing an understanding of the pandemic as a threat to financial gender equality serves as the key motivation for this chapter. Research questions addressed are as follows: "How does the COVID-19 Pandemic serve as a threat to financial gender equality"? And "What relevant threat mitigation actions can be undertaken by governments?"

In order to answer the research questions, a literature review of recent articles published on the subject has been undertaken. Based on the literature review, a detailed assessment of COVID-19 pandemic as a threat to financial gender equality has been undertaken. Recommendations for threat mitigation have also been derived from literature. The chapter is structured as follows: a brief description of research methodology is provided; next an understanding of financial gender (in)equality is provided, ensued by a background section on COVID-19 pandemic disaster economic implications. This is followed by an in-depth understanding of negative impacts of COVID-19 pandemic on financial gender equality. Recommendations for threat mitigation are discussed and conclusions are provided.

2 Research Methodology

An integrative approach to literature review (Snyder, 2019) has been adopted. Integrative approach involves a qualitative analysis of multiple sources including research articles and other published texts (Snyder, 2019). The purpose of an integrative approach is to synthesise literature on a topic to enable perspectives to emerge (Torraco, 2005). Integrative approach covers mature and emerging topics (Snyder, 2019), as is the case for this article. With emerging topics, the aim is not to cover all articles published but rather to combine perspectives and insights from different sources (Snyder, 2019). Thus, Google keyword search of three phrases, (a) global pandemic economic impacts (to understand general global impacts), (b) financial equality of women (to gather pre-COVID literature on (mostly inequalities) relating to women's economic positions and the factors contributing to these and (c) gendered COVID impacts (to understand differentiated pandemic economic impacts on women), was undertaken. Recommendations for threat mitigation were prevalent in the analysed literature, and these were derived as well. Google, a general search engine, serves as a tool most used for problem-specific information seeking; it serves as a widely used source for scholarly and non-scholarly literature (Jamali & Asadi, 2010). Principle of data saturation has also been applied, in that, for a small study (which this is), enough information (as articles) has been gathered and a point is reached when relevant factors seem to be repetitive (Fusch & Ness, 2015).

Key contribution from applying the integrative approach is to provide a detailed classification of a pandemic as threat to gender (economic) equality.

3 Literature Review

3.1 Financial Gender (In)equality

Prior to the pandemic, women were underrepresented in all aspects (including as depositors, borrowers, bank board members and regulators) in the global financial systems (Čihák & Sahay, 2018). Čihák and Sahay (2018) found that globally, only 2% of financial institution CEOs are women, and 20% of executive board members of financial institutions are women. Interestingly, this gender gap has contributed to more risks for the institutions (including greater risk of financial mismanagement, higher proportion of non-performing loans and less resistance to stress) for financial institutions (Čihák & Sahay, 2018). Such unequal distribution has been more prominent in countries with entrenched inequalities.

Another critical factor which pre-existed the pandemic is the gender pay gap. Gender pay gap measures the average earnings of men and women in the workforce (Workplace Gender Equality Agency, 2021). Gender pay gap is not the same as equal pay (which implies men and women getting the same pay for the same or comparable work). Rather it implies the existence of social and economic factors which reduce women's earning capacity over time (Workplace Gender Equality Agency, 2021). Key negative elements associated with factors which cause gender pay gap are reduced lifetime economic security, less career advancement, less superannuation and savings and higher risk of living in poverty in old age (Workplace Gender Equality Agency, 2021; Eslamian, 2012).

Ortiz-Ospina and Roser (2019) have summarised key factors which have contributed to financial gender inequality as women being generally under-represented in senior positions, women being overrepresented in low-paying positions, men being more likely to own land and control productive assets and women having limited influence in regard to household decisions including how their own personally earned income is spent. Prior to the pandemic, as Goldin (2014) found, women were still seeking jobs compatible with family responsibilities, and typically such jobs attract lower earnings per hour.

Nevertheless, prior to the pandemic, gender-equal inheritance systems, which were rare before, came into existence, and composite indices suggested that gender inequalities were shrinking (in some respects) in the last few decades (Ortiz-Ospina & Roser, 2019), before the pandemic.

McKinsey Global Institute (2015) have developed the Power of Parity Matrix in 2015. It maps 15 gender equality indicators, for 95 countries, over 4 categories: equality in work, access to essential services and enablers of economic opportunity, access to legal protection and political voice and physical security and autonomy.

Prior to the pandemic, McKinsey Global Institute (2015) found that progress toward gender parity was uneven. In 2015, 40 out of 95 countries were found to have high or extremely high levels of gender inequality. McKinsey Global Institute (2015) found these key areas requiring focus and attention to achieve gender parity (from women's perspective): unblocking economic potential, reducing time spent in unpaid work, enhancing legal rights, improving political representation, taking measures to reduce violence against women, increasing women's participation in high-income jobs, improving maternal and reproductive health, improving education levels for women, improving digital and financial inclusion for women and reducing girl-child vulnerabilities.

McKinsey Global Institute (2015) identified 75 potential interventions, tailored specifically to regions, depending on the severity of the issues in each region. The ultimate motivation for achieving gender parity, as identified by McKinsey and Company (2015), has been the attainment of US $28 trillion GDP in 2025 by achieving all interventions, globally.

Business case for achieving gender parity was established before the pandemic. Motivations and actions (to some extent) were being undertaken, and then the pandemic flung into action in early 2020, globally. As Madgavkar et al. (2020) have pointed out, prior to the pandemic, progress toward gender equality remained stagnant in aggregate between 2014 and 2019. Gender equality in work has lagged gender equality in society. Prior to the pandemic, female participation in the labour force stood at two-thirds of men. The pandemic continues to pose as a threat to gender equality (parity), and COVID-19 pandemic disaster as threat is discussed below.

3.2 COVID-19 Pandemic Disaster and Economic Implications

For the purpose of addressing the broader, global, economic implications of the pandemic, a coverage of recent literature (15 academic and media articles) is provided. COVID-19 has severely impacted the global economy and financial markets (Pak et al., 2020). Disaster mitigation measures have resulted in negative consequences which include material reductions in income, rise in unemployment and disruptions in transportation, services and manufacturing industries (Pak et al., 2020).

PWC (2020) undertook modelling for the next 12 months, of economic impacts, globally with the following key highlights. Based on the assumption of 50% of global population contracting the disease, 60% of people are in the workforce and are absent from the workforce for 5% of the year. This has been calculated as 1.5% reduction in global labour supply. A total of 0.5% mortality of global work force due to the disease equates to a further 0.1525% reduction in global labour supply. Breakdown in global supply chains' impact has been calculated as −0.57% reduction in global productivity of capital due to idle capacity. Government spending on health and public order is calculated to increase by 1%. A total of 1% to 5% increases in costs of supply chains integrated over borders and transportation, tourism, education and recreation are anticipated, respectively. Other factors have resulted in weak economic recovery for low-income and middle-income countries in 2021 (United Nations, 2021). These factors include the inability of low- and middle-level countries to provide fiscal support and stimulus, resulting in increase of debt distress. Most countries are not expected to return to the pre-pandemic GDP level before 2023 (United Nations, 2021). Conventional structural impediments including deep inequalities, weak governance, high levels of informality and low investment in human and physical capital continue to have a negative impact on productivity and growth (United Nations, 2021). United Nations' prediction is for developed countries' GDP to be 4% lower than pre-COVID times, for it to be 6.5% lower on average for economies in transition and 7.5% lower for developing countries (United Nations, 2021).

Increase in the number of COVID cases has had dramatic negative impact on world stock markets in 2020 (Jones et al., 2021). Recovery for some stock markets has been slow in 2021. Job loss has been dramatic, ranging from unemployment rates of 3% to 13% which went up for a large number of countries, during the pandemic (Jones et al., 2021). The authors have also pointed out that new job vacancies have been very low; for most countries it is in the negative. Travel, tourism and retail were severely hit by the pandemic in 2020 (Jones et al., 2021).

The International Labour Organisation (ILO) (2021) has assessed that global working hours in 2021 have been 4.3% below pre-pandemic levels. This is equivalent to 125 million full-time jobs. ILO has also warned that due to lack of technical and financial government support in developing countries, the gap regarding employment recovery will continue to widen. The two factors which have the most impact on this widening gap are the uneven vaccine rollouts and the major differences regarding fiscal stimulus packages. Eighty-six percent of global stimulus packages belong to high-income countries (ILO, 2021).

October 2021 projection of the International Monetary Fund (IMF) (2021) highlights that even advanced economies are not completely safe from economic downturn due to the pandemic. As the report points out, global economy is projected to grow by 4.9% in 2022, due to downgrade for advanced economies. Supply disruptions have a critical impact for advanced economies and what IMF (2021) refers to as worsening pandemic dynamics for developing economies. There are additional uncertainties relating to rapid spread of Delta and the emergence of new variants (IMF, 2021). Real GDP was all negative for advanced and emerging economies in 2020, 2021 saw re-emergence in the positive regarding GDP for all economies, while 2022 is projected to have more conservative estimates due to the factors mentioned (IMF, 2021).

3.3 COVID-19 Pandemic Disaster Negative Impacts on Financial Gender Equality

COVID-19's economic fallout is creating a regressive impact on gender equality (Madgavkar et al., 2020). Madgavkar et al. (2020) have made the following critical points to back this consideration: women's jobs are 1.8 times more vulnerable than men's during the pandemic. Fifty-four percent of job losses were associated with women. One of the main factors is the burden of unpaid care (which can be as high as 90% for women) being carried disproportionately by women. In some instances, the enhanced burden of unpaid care during the pandemic has resulted in an increasing risk of women permanently dropping out of the labour force. It has also had a negative impact on women's chances to participate in technical and professional jobs and assuming leadership positions. Women are disproportionately represented in sectors which face greater risk of job loss compared to men. These sectors include accommodation and food services, retail and wholesale and arts, recreation and public administration (Madgavkar et al., 2020).

N26 is a German Bank; it operates in multiple EU States and in the United States. N26 has developed a Female Opportunity Index which provides an analysis of gender equality in 100 countries and covers female leadership in government, corporations, STEM and entrepreneurship, as well as success enablers (N26, 2021). The Index has ranked the 100 countries, using its methodology which covers the mentioned factors. It has ranked Norway, Finland and Iceland as the top countries for female opportunity and Jordan, Egypt and Pakistan as the bottom ranked, in 2021. Comparative data, to prior years, is not visible on the website; nevertheless N26 has mentioned that existing inequalities have become more pronounced during the pandemic.

World Economic Forum's (2021) gender gap report has highlighted the following points in relation to the impact of COVID-19. Gender gaps are assessed over four dimensions: economic participation and opportunity, education, health and survival and political empowerment. One hundred and fifty-six countries are covered, and the score is measured between 0 and 100. This statement highlights the pandemic gender equality risk, "Preliminary evidence suggests that the health emergency and the related economic downturn have impacted women more severely than men, partially re-opening gaps that had already been closed" (World Economic Forum, 2021, p. 5). Global average distance completed to parity has degressed by 0.6 percentage points. Due to this, the World Economic Forum has estimated that it will now take 135 years to close the gender gap. Gender gap in political empowerment has widened since 2020; it will take 145 years for gender parity to occur in political empowerment. In relation to economic participation and opportunity, 58% of the gap has been closed, and there is slow progress; the proportion of women as skilled professionals is increasing, as well as wage equality (slowly); counteracting this is the persistent lack of women in leadership (only 27% of women are in leadership positions).

Using data from the International Labour Organisation, LinkedIn and Ipsos, the World Economic Forum (2021), in relation to the pandemic impact, has highlighted that during the pandemic 5% of women (compared to 3.9% of men) have lost their jobs. There is a marked decline of women being hired in leadership roles, representing 1–2 years of reversal in progress. Industries with more severe regression in relation to women in leadership include consumer sector, non-profits and media and communication. There is also evidence of greater anxiety and stress during the pandemic due to job insecurity, more hours involved in unpaid and paid work and reduced options of care facilities. There is an increasing gendered impact of automation and digitisation during the pandemic, on jobs. There has been a slight decline of women in cloud computing jobs, and there is substantial gap in other areas such as engineering and technology disruptive fields. These factors combined have a scarring impact on future economic opportunities of women, as reduced re-employment prospects and continued decrease in income (World Economic Forum, 2021).

The United Nations (2020) has also identified the pandemic as "…deepening pre-existing inequalities, exposing vulnerabilities in social, political and economic systems which are in turn amplifying the impacts of the Pandemic" (p.2). The United Nations (2020) has identified that compounding economic impacts are being felt by women and girls who are now earning less, saving less and holding insecure jobs or living close to poverty conditions. The issue of underpayments for formal economy care jobs, with pre-dominantly women, including nursing and teaching, has been highlighted. Job layoffs have been more prominent in sectors that women are over-represented in including retail, hospitality and tourism. The pandemic has created greater risks for women in the informal sector, where most of global women's employment occurs. Informal work involves use of public space and social interactions; access to them has been severely impacted by pandemic-related restrictions (United Nations, 2020). The risk of women falling into vulnerable situations including extreme poverty due to the pandemic has been highlighted.

Gates and Malpass (2021), as with United Nations (2020), have stressed the pronounced risk of COVID pandemic for women working (which majority of global women are) in the informal sector, having no safety net including paid sick leave or unemployment insurance. They have identified the underlying reasons that exacerbate pandemic impacts including that "Economically marginalised women are often invisible to their governments…they are less likely to have formal identification, own a mobile phone or appear in a social registry". Limited access to technology by a large number of women during the pandemic has been identified as a key limiting factor for relevant risk mitigation. Other risk factors faced by women include health risks, safety risks, market risks and very slim profit margins (Bill and Melinda Gates Foundation, 2021). Closure of businesses in cities due to the pandemic has forced migrant workers back to rural areas in numerous parts of the world. There has been increasing pressure from workers who, before the pandemic, worked in the formal sector, after losing their job, and would be inclined to undertake informal work. This has the potential to cause overcrowding and pushing of other women further down the economic ladder (Bill and Melinda Gates Foundation, 2021).

The International Monetary Fund (IMF), UNDP and UN-Women (2021) have highlighted the pandemic threat to gender equality. Accordingly, the statement made is “The COVID-19 crisis threatens decades of progress on gender equality”. Failure to take immediate action has the potential to cause long-term scarring and long-term harm to gender equality. According to IMF, UNDP and UN-Women (2021), majority of health and social workers are women; thus women are more exposed to the risk of infection. Women also work in sectors most exposed to the threat of job losses.

3.4 Recommendations for Pandemic Caused Gendered Economic Risk Mitigation

Now that gendered economic risks of the pandemic have been established, recommendations covered in literature to mitigate the impacts of these risks are now addressed.

According to Bill and Melinda Gates Foundation (2021), with a focus on vulnerable women in economically developing countries, it is recommended that economic linkages be rebuilt as well as demand for products and services offered by women-owned businesses. There also needs to be rural employment schemes for returned migrants (from urban areas), specifically focused on women. Any initiatives commenced by women entrepreneurs need to be supported by governments, for example, through public procurement programs. Public procurement quotas for female entrepreneurships need to be established and implemented.

Čihák and Sahay (2018) have recommended the promotion of women to leadership positions in financial institutions. They have provided a business case for relevant initiatives and have provided four reasons for better financial institutional performance with gender equality in bank and supervisory boards. These reasons include women being better risk managers, discriminatory practices encouraging better qualified (than men) women being hired in senior and leadership roles and women promoting diversity of thought, resulting in better decision-making and institutions which attract and select women in senior/leadership roles, also undertaking overall improvements in work-place culture and governance.

Gates and Malpass (2021) have identified three areas for attention by governments. These include digitisation of government identification systems, payment platforms and other relevant services, in collaboration with the private sector. These measures, as the authors have identified, would result in identifying women (especially ones who have worked in the informal sector) in need and would allow transfer of cash fast and securely. Economic opportunities can be shared equitably by generating sex disaggregated data and by providing greater access to the Internet, mobile phones and digital skills to women (Gates & Malpass, 2021). Gates and Malpass (2021) have proposed that governments need to remove barriers to women’s inclusion in the economy, specifically as entrepreneurs. In order for this to occur, governments need to provide easier access to lines of credits and other types of finance to women. They need to boost e-commerce platforms for women entrepreneurs and facilitate overcoming of biases against women-owned businesses in incubators. Public transport needs to be made safe for women employees, and appropriate family and childcare measures need to be provided, to allow women to be more involved in the workforce (Gates & Malpass, 2021). Equal access to remote learning through devices for girls needs to be ensured.

The International Monetary Fund (IMF), UNDP and UN-Women (2021) have identified six key action areas to address widening gender gaps due to the pandemic:

1. Supporting women's incomes through social protective measures including paid leave, cash transfers to unemployed women and informal workers and implementing robust, gender-responsive social protective measures.
2. Supporting women's employment during the pandemic by enhancing availability and affordability of care services, expanding access to paid parental leave. Also, by implementing flexible work arrangements and addressing tax system elements which disadvantage women.
3. Supporting pre-dominantly women worker sectors by providing economic support packages and tax measures, financial support for women entrepreneurs and tax deferrals for these sectors. Also promoting descent work for women through training programs and investments.
4. Undertaking detailed gender-specific assessments of the pandemic and generating sex-disaggregated data and statistics to identify gendered impacts.
5. Creating a coherent strategy, gender budget and adequate allocation of resources.
6. Designing effective policies and assessing gender impacts, also to uncover unintended bias. Also, integrate gender dimensions in performance audits.

The McKinsey Global Institute (2015) has identified six interventions to address gender equality gap during the pandemic. These are the following:

Financial incentives and support: Financial mechanisms including cash transfers which target girls. Tax incentives can play a role in encouraging females in the household to participate in the workforce. Private sector can also offer financial incentives such as school scholarships.

Technology and infrastructure: This encompasses development of supporting infrastructure and greater participation of women in IT. Example provided includes that of India's IT businesses with ensuring safe transport for women employees. Digital products, apps specifically for female entrepreneurs and mobile-based emergency services can help reduce barriers to knowledge and opportunities. Infrastructure such as energy and water and affordable childcare centres can reduce time spent on unpaid work.

Creation of economic opportunity: Private sector needs to play a more active role in promoting diversity and reducing barriers in positions of responsibility and leadership. Recruitment can be unbiased and broad range of leadership styles can be valued more. Skills building programs need to be synchronised with job placements and employment opportunities targeting women.

Capability building: Urgent initiatives include high-quality education in STEM, access to broad range of skills and critical education on financial and digital literacy.

Advocacy: The underlying intention is to shape attitudes and social norms toward gender equality via promotion of role models, support, national awareness efforts and social media campaigns. Such programs need to occur in rural areas as well.

Laws and policies: This involves protection of women's rights and enforcement of anti-discriminatory labour market policies.

Provided below is a framework (based on literature covered) of pandemic (disaster) gendered economic threats and threat mitigation actions.

COVID-19 pandemic threat (to gender equality) classification factors and mitigation actions (derived from literature).

Pandemic threats	Enhanced gender pay gap Low paid jobs (with pre-dominantly women) at increased risk of redundancies Informal sector (with pre-dominantly women) severely impacted by pandemic control measures including lockdowns Enhanced vulnerabilities due to reduced access to essential and legal services by women Enhanced impact (access to education and finances) of lesser access to technology by women and girls Increased (and more) unpaid work for women (compared to men) Increased risk of gendered violence (with increased negative impact on financial position and performance of women) Pandemic and technology combined negative impacts on women's participation in formal work force Reduced number of women in senior and leadership positions, on average, during the pandemic
Mitigation actions	Rebuild economic linkages with a focus on vulnerable women Create rural employment schemes with a focus on women Provide support to women entrepreneurs in public procurement programs Promote more women to senior level positions, also in financial institutions Digitise identification systems and payment platforms; provide access to technology for women and girls Provide easier access to financial capital for women Make conscious effort (by governments and private sector) against unconscious and deliberate bias against women Make infrastructure more supportive for women and their safety Provide financial support for women through social protective measures Support women's employment and flexible work arrangements Undertake gender-specific assessments and generate gender disaggregated data Create gender budgets and commit financial resources to gender equality initiatives Design urgent effective policies using detailed gender impact assessment data Enhance capacity building for women Advocate for gender equality

4 Conclusions

This chapter has provided a focus on the gendered impacts of the COVID-19 pandemic (disaster). A literature review was undertaken for this purpose. It is strongly recommended that governments undertake detailed risk assessments of the widening gender inequality (gender equality gap) as a result of the pandemic. Governments need to undertake disaggregated gender data collection (including relating to the informal sectors of the economy) and implement in-depth analyses of impacts. Governments need to make a conscious effort to target mitigation measures urgently and effectively.

The private sector also needs to play a role in mitigating the risk of widening gender inequality. Policies (workplace) and wider, national level policies need to specifically target the gender inequality risks created by the pandemic. Women's access to essential and legal services needs to be ensured, in spite of dramatic rise in resource allocation to tackle the pandemic.

The pandemic poses as a major threat to gender equality unless focused mitigation strategies are adopted and implemented. Women and girls need to be prioritised even more during the pandemic than prior to the pandemic. In spite of the pandemic posing as a threat, it can also be used to promote better results and impacts for gender equality. It is up to governments to make gender equality a greater priority, more so in the current environment than ever before.

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Chapter 5
Economic Growth and Hazard Risk Reduction

Oluwabunmi O. Adejumo

Abstract Risk and risk dynamics associated with economic activities have been largely relevant in explaining the susceptibility of economies to hazardous and disastrous conditions. This chapter discusses the interplay of the environment and economic activities that predisposes economies to hazardous conditions, as well as viable and plausible options to mitigate or check the fallouts of this nexus.

Keywords Environment · Development · Economic activities · Sustainability · Growth · Hazard · Disaster

1 Introduction

Hazards and disasters are usually used interchangeably as they relate to human lives or sustenance. However, a closer valuation of the two issues reveals that hazards are more of a potential phenomenon that poses threat to humans, life and the environment as a whole, while disaster is contextualized as a negative disruption that results in unmanageable loss of life, economic wealth and environmental quality (Cioccio & Michael, 2007). And mitigation, resilience and adaptation to the unpredictability of disasters depend a lot on a number of factors ranging from economic conditions to social and governance systems (Toya & Skidmore, 2007; Kim & Marcouiller, 2016). Kim and Marcouiller (2016) observe that the countries with strong economic resilience and economic conditions prior disaster face lower losses after disaster. As a result, given that disasters are unpredictable, strong economic conditions can largely check the vulnerability of economies to impending damages. Kim and Marcouiller (2016) further note that in addition to prevailing economic conditions, existing social structures and social capital advance the resilience and local adaptation in cases of disasters.

O. O. Adejumo (✉)
Institute for Entrepreneurship and Development Studies, Obafemi Awolowo University, Ile-Ife, Nigeria
e-mail: adejumobum@oauife.edu.ng

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According to Strömberg (2007), components categorized as hazardous conditions are embedded in human activities within the environment which include socio-economic activities such as manufacturing and construction works, population growth and technological discoveries to mention a few. It is expected that economic activities yield income for economic agents, and an increase in production or income over a period of time is termed economic growth. Restating that an economy is withstanding shocks from possible disasters, economic growth is an inevitable phenomenon. However, as laudable as economic growth appears, economic activities of resource extraction, processing and utilization that lead to economic growth have their hazardous bearing on the environment which spurs disasters (Wisner et al., 2012), thus questioning the extent and relevance of growth in an economy. Little wonder, environmental economists have begun to advocate for economic growth that is less material intensive (Panayotou, 2016).

Given the interrelated nature of economic activities and hazards, Taohidul Islam and Chik (2011) observe that hazards and natural disasters strike developed and developing countries alike, and it usually results in huge destruction and human misery. A cursory look at global statistics revealed that between 2000 and 2019, there has an average of 300 disasters[1] yearly. Except for 2008 where less than 300 disasters occurred, in 2019 alone, a total of 409 natural disasters occurred with the Asian Pacific region experiencing the highest natural disasters given their size and vulnerability. Similarly, Africa has extensively witnessed flood records of about 1.7 thousand natural disasters from 1970 to 2019. According to *Statista*, Africa shares 60% of the total natural disaster's cases within the period. Hence, the difference in the magnitude of effects has been largely attributed to the abilities of economies to check hazardous conditions from resulting in disasters (Dynes, 1999). The earthquake that occurred in Portugal, Lisbon precisely, where about 60,000 lives were lost in 1755, was rebuilt to withstand future disasters within a year owing to the wealth recorded by Portugal then; also, the economic, political, and institutional restructuring accounted for a national rebounce (Dynes, 1999). Strömberg (2007) argued that it is not sufficient to possess wealth from resources as noticeable in developing economies; rather, the ability to transform wealthy or growth-experiencing economies to plan, innovate and mitigate disastrous conditions is the difference we see in the extent to which hazards impact on national economies, which incidentally is also a reflection of the level of development of a nation.

Disasters are related to the management of nature and its resources. Therefore, the extent to which people wield, utilize and mitigate hazardous conditions will not only enhance sustainable livelihoods but also reduce the imminence of disasters. From an economic perspective, which is the crux of this chapter, there have been debates on the economic growth-environmental hazard trade-offs or possible payoffs – which basically involves the wherewithal to reinvest natural resources used up in other forms of capital to generate more productive, more sustainable ventures – generally referred to as *weak sustainability* (Adejumo & Adejumo, 2014; Adejumo,

[1] See https://www.statista.com/statistics/510959/number-of-natural-disasters-events-globally/

2019; Massa-Sánchez et al., 2020). The quest for economic growth via resource exploitation introduces hazards that could result in disasters if unchecked. For instance, exploitation of natural resources like mining for oil, gold, copper, etc. for further production or exportation is usually at a cost to the environment and the economy where such occurs.

Weil (2009) referred to the experience of Spain after Europe's discovery of the new world. Through the trade of gold with America, Spain exported gold to other countries within Europe in exchange for manufactured products and incidentally became very rich. Spain sold gold to most European economies, and these economies developed via innovations and investment in physical and human capital; Spain later suffered from economic sustainability when the resource flow from America ceased. This phenomenon which is referred to as Dutch diseases is a skewed or detrimental relationship between resources utilization and growth sustainability and is a form of economic hazard that could result in disaster especially in economies where resource utilization has not been re-harnessed into other forms of productive capital (like human, social and physical capital) or translated into economic wealth for mitigating environmental challenges and ensuring sustainability. Another instance, Nigeria, which is an oil-rich state, earns most of its foreign income and foreign capital courtesy from the mining of oil. However, despite the economic wealth that results from this resource, the pervading poverty of Nigerians is still an issue and to crown it is the destruction of the environment via mining activities. Incidentally, the displaced agricultural activities that have given way to mining are indicating hazards for environmental and economic sustainability.

Meanwhile, the challenge for sustainable development lies in the utilization of all forms of resources and still mitigating or avoiding hazards or potential disasters. Also, another issue is the ability for economies to translate environmental disruption to optimal and sustainable economic wealth such that instead of experiencing an environment-economic trade-off, pay-offs would occur. In other words, the extent to which economies transform economic growth to sustainable growth as far as environmental and economic sustainability is concerned is contextualized as *green growth* which is far-reaching for sustainable development and more appreciated by ecologist and environmental economist.

The rest of the chapter is sectionalized to include a conceptual clarification and a brief overview of literature of the growth-hazard relations. This is followed by a discussion on the drivers of and adaptive options for the growth-hazard relations and the conclusion of the chapter.

2 Conceptual Clarification

Chang et al. (2012), by distinguishing between vulnerability and hazard, expanded on the thoughts of risk dynamics as it relates to natural occurrences. Risk in itself relates to the interplay between hazard and vulnerability, while risk dynamics is a function of the changes that occur via hazard or vulnerability (Eslamian et al., 2021). As shown in Fig. 5.1, hazard constitutes likelihood events such as

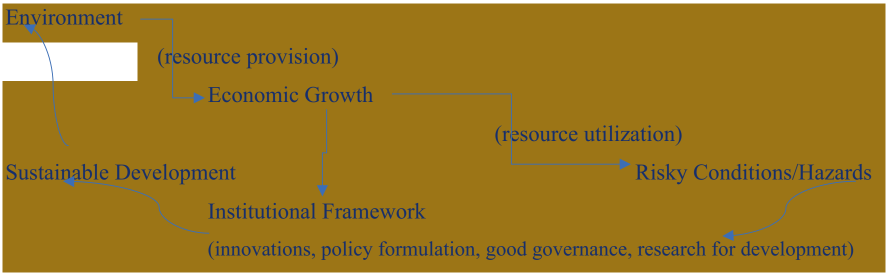
Source: Chang et al. (2012)

Fig. 5.1 Hazard risk and risk dynamics. (Source: Chang et al. (2012))

earthquakes, storms and tsunamis; and vulnerability is passed as the propensity for an event that augments or predisposes to risky or hazardous possibilities such as population growth, demographic changes, social changes, economic growth, urbanization, expansion of built areas, infrastructures and construction activities (Chang et al., 2012). In other words, while explaining natural and environmental phenomenon to apply to disaster and risk dynamics, economic growth is categorized as a condition of vulnerability such that the management of or changes that occur to growth can be an indication of propensity to experience losses especially when it is related to a particular hazard.

In the parlance of economic sustainability, an assessment of being prone to risk, plausibility of disasters or hazard-related conditions are contingent on the degree of susceptibility of an economy (i.e. level of income or income per capita) through relations with climate conditions or the environment as well as institutional framework.

Weil (2009) expanded on the implications of the environment for economic growth by drawing inference on the nexus between human working conditions vis-à-vis climate conditions. Specifically, Weil compared workers' productivity vis-à-vis the climate in temperate and tropical regions and noted that those in temperate zones are more productive. Following the tenets of human physiology, people in warm climates cannot work hard because they will overheat. Also, noting that the substantial part of the energy released by working muscles takes the form of heat, as a result, the heat must be dissipated by the coolness of the weather if workers are to survive, be productive and contribute meaningfully to economic growth. Hence, as shown in Fig. 5.2, to minimize risky conditions and hazards, activities that birth economic growth should be structured with feedback mechanisms that are targeted



Source: Author's readings

Fig. 5.2 Resource utilization and growth – role of institutions. (Source: Author's readings)

at stabilizing (through institutional frameworks) the environment for more productivity and sustainability.

3 Theoretical and Empirical Debate

Several studies have argued from varying perspectives the nexus between development and hazard-related issues. The Rostow's stages of economic growth are an important historical model which captures the pattern of growth that has led economic vulnerability. The five stages include the *traditional society* which engages more in agriculture and has no scientific inclination; the *preconditions for take-off* that involve an outward looking economy; the *take-off* tilts towards industrialization; the drive to maturity involves high standards of living and more use of technology; and the *age of high mass consumption* that involves mass production and consumption (Todaro & Smith, 2012). The existing components of economic growth are reflective of the age of high mass production and consumption. Most production processes involve heavy construction like underground drills, use of fossils and emission of greenhouse gases which are not just hazardous but disaster-prone as well. But, the global challenge of climate change and clamour for green growth has begun to challenge the pattern of economic growth (Ekins, 2002).

From a demographic perspective, rising population or population growth has been classified as a hazardous condition, while overpopulation is a cause of disaster. The case cited by Hamilton (1988) in the flood plain of Ganges and Brahmaputra river in Bangladesh showed that in addition to the high rates of deforestation, overpopulation of the delta region which is typical of non-absorbing surfaces and increase in infrastructure is a major cause impeding rapid run-off and eventual flooding. Taohidul Islam and Chik (2011) also added that Bangladesh suffers frequently from disasters like floods, cyclone storms, tidal surges, river bank erosion, and earthquakes. Meanwhile, from an institutional perspective, Ahrens and Rudolph (2006) argued that governance failures are largely accountable for increases in disasters due to lack of plan and functional structures to mitigate plausible usual or unusual hazards that occur via socio-economic activities. Also, social structures, income inequality, ethnic fractionalization, and religious heritage have been identified as critical determinants of hazards (Toya & Skidmore, 2014).

The effects of natural disaster or unfavourable climate conditions are thought to be more pronounced in developing and smaller economies which are usually reflected via large output declines (Noy, 2009). This is because developing economies are characterized by corrupt and less accountable governance systems, failed institutions, and strained financial systems. Therefore, Toya and Skidmore (2007) argued that as economies develop, economic losses reduce and that as countries earn higher income, higher educational attainment, greater openness, more complete financial systems and smaller government involvement, fewer losses from disasters occur. Similarly, Noy (2009) added that countries with a higher literacy rate, better institutions, higher per capita income, higher degree of openness to trade and higher levels of government spending are better able to withstand the initial disaster shock and reduce negative spillovers into the macro-economy.

Another dimension to the disaster-growth nexus is the time dimension of the effects on such disasters. Chang et al. (2012) argued that disasters such as earthquakes, storms and floods occur sparsely and their probabilistic distribution could shift over decades or centuries due to climate change, technological developments or environmental modifications from human socio-economic activities; however, changes in vulnerability such as economic growth are seen to occur more quickly. And as result, it is expected that the effects of vulnerabilities are short-lived and can be easily mitigated, while hazards are expected to have more far-reaching effects. Empirical studies have shown conflicting evidences on the subject matter. For instance, Noy (2009) noted that natural disasters have significant and adverse impact on the macro-economy in the short run which could result in slowdowns in production. In contrast, Crespo Cuaresma, Hlouskova and Obersteiner (2008) via a cross-country and panel data analysis found evidence of a positive correlation between the frequency of natural disasters and the long-run economic growth. Therefore, in view of environmental threats, these evidences in literatures enable to draw inferences on factors associated with vulnerabilities vis-à-vis the pursuit of economic growth.

4 Economic Growth-Hazard-Disaster Nexus in Developing Economies

Given the variations in environment and resource utilization, the preceding section expands on the mechanisms that could shape the relationship between economic growth and disaster-related occurrences. One would expect that natural disasters should lead to a reduction in economic activities and growth; however, studies have shown otherwise. For instance, Loayza et al. (2012) note that disasters can lead to economic recession but not necessarily; besides, the impacts of disasters differ among disaster types and different sectors. Also, Loayza et al. (2012) observe that moderate disasters (like moderate floods) steer growth in positive directions, while

Fomby, Ikeda and Loayza (2013) note that severe disasters have greater impacts on growth than moderate disasters; Fomby et al. (2013) observe that natural disasters are not alike with regard to growth response. They further note that some disasters have positive effects on economic growth; and the duration of growth response to disaster depends on the type of natural disaster and the sector of economic activity – whether agricultural or non-agricultural sector.

Therefore, an issue of interest is what accounts for the relationship between economic growth and disaster-related occurrences? And what measures can check the vulnerability of economic growth in the presence of hazards or looming disaster?

4.1 Technological Advancement

According to Skidmore and Toya (2002), a plausible explanation for the relationship that exists between disasters and growth is the ability to introduce and utilize better technologies into the economy where disaster has been faced. The use of more sophisticated technology coupled with physical and human capital will cause growth to rise. This is consistent with the Schumpeter concept of 'creative destruction' where newer technologies otherwise known as innovations are utilized to displace existing order or old methods of production. This context of creative destruction has been employed in explaining how economies evolve and surmount the limitations posed by nature and still achieve economic growth especially in the long run. However, where there are no resources or technical know-how to replace the fallouts from natural disasters, economic growth will be challenged.

Thus, where there are positive shocks in production techniques, productivity is enhanced, growth rate is sustained, and the rippling effects from hazards or potential disasters are to a large extent doused (Okuyama et al., 2004). This is typical of the findings of Skidmore and Toya (2002) where a positive relationship is identified between the frequency of climatic disasters and productivity growth for a cross section of 89 developed and developing countries. Therefore, just like Skidmore and Toya (2002), Crespo Cuaresma et al. (2008) submitted that 'disasters provide opportunities to update the capital stock and adopt new technologies', while Skidmore and Toya (2002) noted that a plausible association between total factor productivity (TFP) growth and climatic disasters may just be picking up the substitution of physical for human capital in disaster-prone countries.

4.2 Diffusion and Absorption of New Technologies

Recapitalization and utilization efforts are two different issues especially among developing economies. While disasters could birth the process of recapitalization and purchase of foreign technology, the ability to assimilate and domesticate such technologies within local economies will to a large extent determine growth effects. Crespo Cuaresma et al. (2008) noted that catastrophic risk has negative effect on the volume of knowledge spillovers between industrialized and developing countries and that one major process by which knowledge spillovers or technology absorptions are actualized is through the presence of multinational enterprises (MNEs) in host economies (Damijan et al., 2003; Crespo & Fontoura, 2007). Therefore, to mitigate hazards, adaptability and suitability of technology must be ascertained if expected growth via technological development or diffusion will yield any gain environmentally or resource redistribution that will foster sustainability.

4.3 Natural Resource Utilization

Activities leading to economic growth that engineer hazards could explain the positive co-movement of the hazard-growth nexus in the long run. For instance, in Nigeria, the main source of external income, which is crude oil, is from an environmentally destructive activity. The activities of oil mining in the Niger-Delta region of the Nigerian state have left in its wake an upturn of the traditional agricultural economic activity. It is such that the natural fishing and farming operations of the local farmers have been upturned by mining which destroys top soil layers, as well as oil spillage which destroys water bodies (Aigbedion & Iyayi, 2007). These not only constitute health hazards through aggravating erosion, sinkholes and the contamination of soil, groundwater, and surface water by the chemicals emitted from mining processes but foster disasters such as landslide, subsidence, flooding and tremor. However, following the principles of weak sustainability, economic gains can be redistributed for greater gains and mitigate the effects of resource exploitation and utilization (Dietz & Neumayer, 2007).

4.4 Population Growth

Population growth has been categorized as a naturally hazardous phenomenon. Meanwhile overpopulation can transcend a natural hazardous condition into a disaster if unchecked, as well as increase the potential for loss in disaster event. Strömberg (2007) found highly significant positive coefficients between population growth and disaster-related occurrences in China and India. With a population that grew by 1.2 billion in India and China and 1.8 billion in other sampled countries between 1960 and 2000, Strömberg (2007) noted that an increase of population of ten million is associated with an average increase in the number of disasters by 0.9 in other countries and 0.3 in China and India. Despite this population-disaster nexus, Strömberg (2007) argued that locational advantage if consolidated on can be a cause and an aversion of hazards. For instance, Dynes (1999) argued that if the people of a particular location are lightly lodged or well-spread, the propensity to damage can be averted and should disasters occur, the aftermath or effects can be minimized.

4.5 Overconcentration of Economic Activities/ Rapid Urbanization

Urbanization in itself is a reflection of development, but the ability to reorganize economic activities in urban centres is critical to actualizing resilience. Apart from people seeking for better access to better livelihoods with supportive infrastructures present in the urban areas, people with modern high income-generating economic activities find it worthwhile to reside in urban centres (Bloom et al., 2008). This attraction to the urban centres could evolve a natural hazardous condition; however, studies have argued that urbanization is not the challenge but inadequate planning. For instance, Rumbach (2011) argued that the extent of planning (such as consolidating on informal economies or suburbs to sustain urban centres) is what determines the extent of vulnerability or resilience of Kolkata an urban area in India. Also, Odiase, Wilkinson and Neef (2020) examined the resilience of the Nigerian community to natural hazards in Auckland and equally noted, in addition to planning and reorganizing economic activities, other areas – social, communication, disaster competency and physical resources – for government intervention to enhance the resilience of entrants in vulnerable urban regions.

5 Sustainable Adaptive Options for Growth-Hazard Relations for Developing Economies

Following the discourse on the growth-hazard nexus is the need to chart a course for advancing and sustaining economies in the face of hazardous or potential disastrous possibilities. Therefore, in addition to some views gathered from evidence-based studies, inferences for plausible course of actions for confronting and mitigating hazards are itemized in turns.

5.1 Financial Plan and Mainstreaming

The ability to make provisions for exigencies, for instance, via national budgets, facilitates rapid responses and reduces the effects of hazard-related issues. For instance, Noy (2009) noted that countries with more foreign exchange reserves and higher levels of domestic credit, but with less-open capital accounts, appear more robust and better able to endure natural disasters, with less adverse spillover into domestic production.

5.2 Flexible Institutional Structure

Ahrens and Rudolph (2006) argued that if a country's governance structure enables the implementation and enforcement of public policies conducive to a country's economic and social development, can sustainable livelihoods be achieved and susceptibility to disasters be reduced? Accountability, participation, predictability and transparency are identified as the key features of a governance structure that fosters development and supports risk reduction.

Beyond ensuring the establishment of institutions to check hazards, it is imperative to ensure these structures are not bedeviled by bureaucracies especially in hazardous situations of looming disasters. This issue bothers on an improved structure to mobilize human, physical and financial resources for mitigations of risk and even reconstruction where disasters occur. It is one thing to plan; it is another thing to actualize timely, need-based and appropriate implementations when disasters occur. For instance, a flexible institutional structure that brings about ease in securing approval for funds should be engineered. Also, just like Rumbach (2011) argued, a fusion of formal and informal systems through a flexible governance planning structure can co-locate and co-evolve disaster resilient systems.

5.3 Reinvestment and Diversification

Catching in on the principles of weak sustainability discussed earlier in this chapter, reinvesting funds generated via hazardous-prone economic activities for other productive activities can help disaster-prone areas to make up and diversify the economy, thereby reducing overdependence on natural resource-based income, agitations and conflicts, as well as preserve the ecosystem.

5.4 Knowledge Spillover/Human Capital Development

Crespo Cuaresma et al. (2008) argued from the Schumpeterian notion of creative destruction that disasters present opportunities to appraise the stock of current and adopt new technologies. However, in mitigating the challenges that arise from disasters, asymmetry in technical know-how could determine the extent of knowledge spillovers between developed and developing economies. Crespo Cuaresma et al. (2008) added that only countries with relatively high levels of development benefit from capital upgrading through trade after a natural catastrophe.

5.5 *Social Capital*

Social capital involves a network of usually homogenous groups confronting and consolidating issues for onward development. Toya and Skidmore (2014) showed a panel data evidence of another important determinant of trust to the frequency of natural disasters. They noted that frequent naturally occurring events such as storms require (and provide opportunity for) societies to work closely together to meet their challenges. While natural disasters can have devastating human and economic impacts, a potential spillover benefit of reducing disaster exposure may be a more tightly knit society.

5.6 *Evolving Urbanization-Resilient Approach*

Taking into consideration the peculiarities of different urban systems, it is pertinent to evolve mechanisms that synthesize economic activities with population growth in urban societies. For instance, studies have shown that mechanisms such as need-based planning, utilizing improved building codes and restricting occupancy in disaster-prone areas are relevant in sustaining urbanization (Chang et al., 2012; Rumbach, 2011). Chang et al. (2012) conducted a case study of population growth vis-à-vis seismic hazard and transportation system for the metropolitan area of Vancouver, Canada; and it was seen that reduction in the rate of casualty can be largely attributed to building code upgrades and changes in new construction. It is such that re-arrangement of residences, infrastructures and workplaces cause risk to reduce and allow for spatial redistribution that can prevent earthquakes and other natural occurrences following careful city planning approach.

5.7 *Resilient-Relevant Infrastructures*

According to the United Nations, resilience is contextualized 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' (UNISDR, 2009). Therefore, in consonance with SDG9 9 which states to 'build resilient infrastructure to promote sustainable industrialization and foster innovation', it has become imperative for governance to go beyond just provision of social amenities but amenities that are hazard-compliant.

Gallego-Lopez and Essex (2016) noted that infrastructural resilience should be designed to cater for sudden shocks that are being disaster resilient and climate change responsive, as well as incorporate the fallouts from economic activities like pollution and deforestation that deplete the natural environment. For instance, in mitigating flood disasters, Ahmad and Simonovic (2000) clamoured for the construction of flood storage reservoir. Some other resilient infrastructure investment relevant for development in developing economies can be undertaken within transport, agriculture (such as irrigation), energy, water, communications and the clean environment.

5.8 Frugal Innovations

According to Bouckaert, Opdeeeck and Zsolnai (2011), the economics of frugality involves low material consumption in the process of executing economic activities. Fukuda and Watanabe (2011) noted that due to low investments, developing economies suffer from an autarky cycle between consumption and GDP, thereby causing a high attitude of consumptions via imports and resource exploitation or utilization. Therefore, Fakube and Wantabe argued that one possible trigger for inducement of investment by growth in these economies can be frugality. Also, Anthon (2010) added that the less of resources that are consumed either at firm or household levels will not just result in reducing the hazards that people are exposed to but also foster sustainable livelihoods. Thus, a frugal approach to mitigating hazard for developing economies could include reducing the insatiable thirst for imported products that leaves in its wake pollution and evolve an indigenous approach to production where local resources are utilized efficiently with little or no waste.

6 Conclusions

The Intergovernmental Panel on Climate Change (IPCC) in its fifth assessment report on climate change adaptation notes that appropriate adaptation is a reflection of adequate information as it pertains to risk-related conditions and vulnerabilities (IPCC, 2014). Though inexhaustive, a review of literature has been able to show dimensions via which economic activities (such as high imports, resource overutilization, inappropriate planning and failed institutions) in developing economies generate hazardous conditions which in some instances trigger disastrous occurrences.

To address some of growth-hazard issues in developing economies, a drift from the regular approach to evolving systems is advocated. Some of the suggestions via empirical studies include flexible institutions, financial mainstreaming of climate change conditions, improved social systems that harnesses social capital, resilient infrastructural investments and a frugal approach to socio-economic activities.

Globally, the associated risk and vulnerability with current economic growth components and pattern can be tagged *resource driven*. While developing economies generate numerous gains from resource extraction, developed economies contribute to economic vulnerabilities through resource overutilization for industrialization. In order to confront the disasters or the dynamics embedded in risk from economic activities, policy efforts should be directed at recognizing thresholds for resource extraction and utilization for global economic growth. Moreover, arguing from the Rostow's stages of economic growth, it appears the world economy is at the stage of *high mass consumption*. Therefore, a more radical policy effort should be directed at attenuating the environmental impacts of mass consumption driving resource extraction and utilization across the global economy. Finally, to mitigate propensity to disasters, global economic growth should pursue growth pattern that reflects global commitment to environmental sustainability.

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Part II
Disaster Relief and Recovery Programs

Chapter 6
Resilience in Disaster Relief and Recovery Programs at the Person-Environment Nexus

Silke Schwarz

Abstract Disaster management refers to a cycle of mitigation, preparedness and response and recovery strategies. The phases merge into one another and are not distinct. The overall goal is sustainable development and an increase of resilience in order to mitigate disaster effects. Resilience in the face of a disaster describes the adaptive capacities of communities and societies. It enables the mobilization of resources in order to adjust to the new environment. Disaster management usually focuses on collectives; the discipline of psychology rather emphasizes the individual level and tends to neglect political and historical contexts. In this chapter, an understanding of resilience as a product of cultural, social, economic, political and psychological factors is developed. The psychological concept of resilience is expanded by communal dimensions of solidarity and social conflict when a disaster hits.

Keywords Resilience · Disaster management · Psychology · Solidarity · Social conflict

1 Introduction

Disaster management includes phases of mitigation, preparedness, response and recovery as a cyclic management. Mitigation efforts minimize effects of a disaster (e.g. by analysing vulnerabilities and by increasing communal and individual resiliencies). Preparedness strategies comprise planning how to respond when a disaster occurs (e.g. by emergency trainings). Disaster response involves efforts to minimize the hazards created by a disaster (e.g. search and rescue) followed by the recovery phase when the community "gets back to normal" (e.g. health and safety education

S. Schwarz (✉)
Berlin, Germany

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and counselling programs). Ideally, disaster response targets at sustainable development with a smooth transition from recovery to on-going development. There is no distinct point at which emergency disaster response changes into recovery and then into long-term sustainable development (Wisner et al., 2002). Rather the incorporation of climate change adaptation and resilience into existing disaster management and development strategies is common practice in global and local action plans (Torabi et al., 2017).

This chapter elaborates on psychological dimensions of the management cycle and elaborates on the concept of vulnerability and resilience from a critical standpoint. Resilience has become ubiquitous, from mental health to national security and unemployment to climate change (Hammond, 2014). The concept originally stems from the natural and physical sciences. It refers to the prevention of disasters and is understood as a capacity of systems to manage and rebound from a disruption. With the identification of global threats such as international terrorism, climate change and economic crisis, attention increasingly focused on the responsive capacities of places and social systems, and the concept of resilience migrated into the social sciences and public policy (Hill et al., 2008; Swanstrom et al., 2009).

In disaster contexts, resilience describes the adaptive capacities of communities and societies after a disturbance (Norris et al., 2009). Resilience can enable change when a stressful event occurs that causes transient dysfunction in the "pre-event" functioning level. Resilience facilitates the mobilization of resources in order to adjust to the new environment. Community resilience activates economic resources, information and social ties in the face of a disaster and ends in a successful adaption. The community is understood as a self-organizing system with the potential to develop and expand from disruption and previous disasters. The United Nations Office for Disaster Risk Reduction (UNDRR) (2017) defined 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.

Disaster management applies concepts such as capacities and coping capacities in contrast to vulnerability. They describe positive factors that increase the ability to cope with disasters. Whereas disaster management usually focuses on collectives, the discipline of psychology rather builds on the individual level. Both use similar concepts and terms such as resilience or capacities contrasted to vulnerability. In this article, the individualistic orientation of psychological concepts such as resilience is analysed in disaster contexts and combined with communal dimensions in disaster management.

2 Psychological Perspectives on Disaster Relief and Recovery Programs

2.1 Psychological Resilience in Disaster Contexts

In disaster theories, vulnerability increases the susceptibility to the impacts of hazards (UNDRR, 2017). In psychological theories, vulnerability describes a disposition for mental disorders. According to the diathesis-stress model (Wittchen & Hoyer, 2011), everyone has a personal threshold of vulnerability, and when it is exceeded, the coping process results in mental disorders. As a consequence, normal life is interrupted either gradually by a slowly increasing mental burden or abruptly by a pathological breakdown. Exposure to enormous stress is comparable to exposure to a hazard in cases of disaster. In both contexts vulnerability is a mediating concept.

In the fields of psychiatry and clinical psychology, the person him- or herself is responsible for decompensation (Herzlich & Pierret, 1987). The individual manages stressful conditions inappropriately, leads a lifestyle inappropriate to his or her own vulnerability and as a result becomes ill. With a vulnerability for mental disorders, the affected person is expected to practice adequate disease management. This can be compared to a community located in a disaster-prone area that is held responsible to engage in adequate community-based disaster risk management.

In clinical psychology, the management of vulnerability refers to two different aspects: Some authors consider certain aspects of vulnerability as static, as either genetically predetermined or acquired through the individual's interactions with his or her environment. Vulnerability turns into an individual trait that needs to be targeted with compensatory measures (see Levit-Binnun & Golland, 2012). Another position which is conceptually closer to a process-based, contextual understanding of vulnerability in disaster literature (e.g. Wisner et al., 2002) highlights the dynamic interplay (see Muris et al., 2011). In developmental psychopathology, a variety of protection and vulnerability factors contribute to psychological health or illness. Individual biological and psychological factors, experiences, choices, timing and personal developmental history interact in a complex way and can lead to either increased psychopathology or resilience in challenging situations (Cicchetti, 2010).

Historically, the discipline of psychology focused on strain and adversity and analysed how negative life events negatively affected the individual's ability to function mentally, physically and socially. The introduction of the posttraumatic stress disorder (PTSD) diagnosis to the Diagnostic and Statistical Manual of Mental Disorders by the American Psychiatric Association dominated the psychological research and practice for a long time. Since the 1990s, there has been a gradual expansion in the perspective which focuses on the diversity of human responses to extreme stress (see Bonanno et al., 2010).

During the course of life, human beings typically encounter a variety of difficulties and challenges, ranging from daily hassles to major life events and disaster. Major life events usually do not result in psychological and social collapse. Only a small percentage of exposed individuals develop severe manifestations of problems

(Bonanno et al., 2010). "People may experience distress and disease and yet remain committed and absorbed in their life tasks as parents, partners, workers, citizens, and friends" (Hobfoll, 2011, p. 128). Typically there is a considerable amount of diversity in the longitudinal trajectories of responses to stress (see Norris et al., 2009). Richardson (2002) and Richardson et al. (1990), for example, developed a model, in which a person usually is in balance physically as well as mentally, that is in a state of bio-psycho-spiritual homeostasis, or a comfort zone. A person experiencing disruption, stressors, adversities or life events will adjust and begin the reintegration process. The process can result in four outcomes: resilient reintegration, homeostatic reintegration, reintegration with loss and dysfunctional reintegration. Resilient reintegration describes when an individual attains additional protective factors and a new, higher level of homeostasis. In a homeostatic reintegration, a person remains in his or her comfort zone; no development occurs. The process can also result in a reintegration with loss, protective factors are lost, and a lower level of homeostasis is achieved. When a person uses destructive behaviours such as substance abuse in order to compensate for the losses, dysfunctional reintegration occurs.

The wide variety of trajectories after stressful events, most of which are positive in nature (Bonanno, 2004), resulted in an increasing focus on concepts such as resilience, resources, skills and competence in the field of psychological functioning. Resilience consists of various factors that promote personal assets and protect individuals from the negative appraisal of stressors (Fletcher & Sarkar, 2013). Psychological resilience is "[t]he ability of adults in otherwise normal circumstances who are exposed to an isolated and potentially highly disruptive event […] to maintain relatively stable, healthy levels of psychological and physical functioning, as well as the capacity for generative experiences and positive emotions" (Bonanno, 2004, pp. 20–21). The American Psychological Association considers resilience as the process of adapting well in the face of adversity, trauma, tragedy, threats or significant sources of stress such as family and relationship problems, serious health problems or workplace and financial stressors. Overall, psychological resilience is associated with diverse protective factors such as hardiness (Bonanno, 2004), extraversion (Campbell-Sills et al., 2006), self-efficacy (Gu & Day, 2007), self-esteem (Kidd & Shahar, 2008), positive emotions (Tugade & Fredrickson, 2004), positive affect (Zautra et al., 2005) and spirituality (Bogar & Hulse-Killacky, 2006).

Resilience refers to the achievement of positively connoted states of being, such as health, well-being or fitness. This capacity-focused concept of resilience represents a major rethinking in favour of the positive strengths and virtues within the field of psychology, embodied by the development of a positive psychology (see Lopez & Snyder, 2009). Positive psychology counteracts the victimizing, passive construction of the person beyond the scope of disorders and processes that end in psychopathology. It emphasizes ways in which psychological health, well-being, fitness and happiness (Diener et al., 2010) are encouraged, created and sustained in everyday life.

This shift in focus however also results in problems similar to those in disaster discourse: the individual is responsible to apply self-technologies to process risks and optimize resilience. The person needs to exercise prevention, actively engage in problem-solving and achieve well-being and fitness. The emphasis on individual responsibility and agency is rooted in a North American worldview (Young, 2006; McHugh & Treisman, 2007; Watters, 2010). As with the international framework of disaster management, this conceptual orientation and practice has been exported throughout the world (Watters, 2010; Zaumseil & von Vacano, 2014). It demonstrates the Western neoliberal and goal-based view on human nature which understands human beings' basic motivation as moving towards goals while avoiding threats. It links with Western ideas of self-regulation, conscious control over agency and rational calculation. It highlights the value of an autonomous, independent self that aims at individual enhancements and the conquest of new domains (Morling & Fiske, 1999; Carver & Connor-Smith, 2010).

Psychological concepts usually focus on the individual level and neglect the historical and political contexts people live in. Aspects of power, access to and control over resources that influence health are not evident such as education as well as economic assets such as work, credit, etc. A person's resilience also depends on the social group and communal ties he or she lives in when a disaster occurs. The next section embeds psychological resilience in social contexts.

2.2 Communal Resilience in Disaster Contexts

Disaster can intensify solidarity as well as conflict (Tierney, 2007), and both social dynamics have become central themes in disaster research. With the sudden arrival of external aid, the availability of material resources and the urgent need to distribute them, questions of justice and fair aid distribution arise. Conflict and feelings of envy and jealousy can burden a community in the aftermath of a disaster (Schwarz, 2013a). On the other hand, disasters open windows of opportunity for competing actors to expedite their respective agendas. Settled political power relations can become shifting, potentially leading to conflict as well (Schwarz, 2013b): "Disasters are not neutral. [...] Recovery interventions are also not neutral: they can increase, reinforce or reduce existing inequalities" (ALNAP, 2008, p. 8).

In disaster psychology, the concept of social support increasingly influenced practice and research. Specific properties of a disaster, such as severity of exposure and displacement as a result of the disaster, seem to be relevant to the social support dynamics in coping efforts. Disaster survivors may experience either social support or a lack thereof (Kaniasty & Norris, 1993; Kaniasty, 2012). The quantity and types of relationships with others, that is, social embeddedness, the actual receipt of help as well as the perceived support, that is, the belief that help would be available if needed, are relevant to the social support process. Kaniasty (2012) developed a social support deterioration model that links social support and social conflict with well-being, distress and trauma. The model generates general predictions about social dynamics in the aftermath of a disaster. Mutual aid and support are usually provided at first; solidarity is strengthened. This phase is followed by a decrease in social support. Findings of a study after the 2013 Lushan earthquake in China suggest that what appears to be critical in the process of supporting disaster survivors is the quality, not necessarily the quantity, of support provided (Shang et al., 2019). According to the social support deterioration model, the actual received support, while also contributing, does not completely determine the perception of adequacy (Kaniasty & Norris, 1993; Kaniasty, 2012). A convenient social construction of post-disaster social support impacts health and well-being positively and prevents social bitterness and conflicts, leading to increased distress and pathology.

What continues to be problematic with this model is its emphasis on subjective impressions of adequate support (perceived support) that is not always dependent on actual, communal and material circumstances. A model developed by Hobfoll (2001, 2011), Hobfoll and Buchwald (2004) and Hobfoll et al. (2011) emphasize the importance of social and gender-related inequalities rooted in the power dynamics within a given society and their effect on an individual's access to and control over resources and opportunities to develop resources. Sociocultural and material boundaries of human agency become evident. The concept of caravan passageways (Hobfoll, 2011) describes that people with power, status and privilege live in conditions where they can rather easily accumulate further resources. Caravan passageways regulate the access to cultural capital, material goods and social support. During coping processes, social structures of discrimination and privilege are reproduced. Those who lack status and power continue to experience social discrimination almost independently of their own behaviour. Sociological theories of social conflicts and their resolution (Deutsch, 2000; Maiese, 2003; Kurtz & Ritter, 2011; Wagner-Pacifici & Hall, 2012) as well as social capital approaches (Grootaert & Basterlaer, 2002; Dudwick et al., 2006) capture these dimensions of power and conflict.

Community-based approaches to disaster risk management aim to secure and increase social capital (Putnam, 1995) and enhance community resilience. Norris et al. (2008) understand community resilience as a "set of networked adaptive capacities" (p. 135). Communal resilience can be increased by the promotion of economic development. This entails a diversity of economic resources and equitable distribution of income and resources against a backdrop of interdependencies at the macroeconomic level. Communal resilience can also be strengthened by increasing social capital, that is, network structures and linkages as well as social support, which mainly refer to helping behaviours within family and friendship networks. Social capital includes a sense of community, place attachment and citizen participation. Community competence is defined as a networked collective agency and implies participation, collective efficacy and empowerment. Like any understanding of community resilience, the ideal type model reflects certain value-based ideas about good community functioning. According to Nelson and Prilleltensky (2005), the following core values are relevant: self-determination, caring, compassion and health as well as respect for diversity, participation and collaboration, support for community structure, social justice and accountability. These values reflect a Western, secular orientation and claim universal validity. However, values and orientations are not homogenous, closed or static, but diverse and contradictory, and there are dynamic relationships between local understandings (see Beatty, 1999; Ricklefs, 2008; Berninghausen et al., 2009; Schlehe, 2010). Zaumseil et al. (2013) exemplified a contextualized approach in an Indonesian earthquake district. They highlight local virtues and values as well as a transcendental or spiritual interconnectedness with the cosmos and nature.

"Communities exist in an ecological balance with their surrounding environment. They require a moral economy regulated by ideas about coexistence. For indigenous peoples, this has been traditionally conveyed through stories that are built around culturally informed notions of personhood that link the individual to the community (both past and present) and to the land and environment" (Kirmayer et al., 2011, p. 89).

According to Kirmayer et al. (2011), communities strengthen resilience through political activism and empowerment. If active engagement is successful, this not only brings along material gains but enhances the collective as well as individual self-esteem, which in turn is associated with better communal as well as person-centred mental health and resilience (Chandler & Lalonde, 2008). Enhancing a community's resilience to natural hazards is to improve its capacity to anticipate threats, to reduce its overall vulnerability and to allow the community to recover from adverse impacts when they occur (see Burton, 2015).

3 Conclusions

In this article, the narrow psychological individualistic and apolitical concept of resilience was expanded by communal dimensions of solidarity and social conflict when a disaster hits and embedded into political and historical contexts. Social structures of discrimination and privilege have a significant influence on individual coping processes and resilience trajectories. Coping with disasters always occurs at the nexus of society and environment, involving individuals with their interpretations and related practices. The person-context relationship is co-constituting, and the sociocultural surrounding represents an integral element of any coping process (see Zaumseil et al., 2013; Hasanzadeh Saray et al., 2022). Developing adequate disaster management strategies at the nexus of individuals and their surroundings that are locally specific and culturally relevant remains a challenge.

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Chapter 7
Improving Resilience Capacity of the Policies and Planning for Temporary Shelters in Crises and Disasters

Nilgün Okay, Ebru Inal, Gül Yücel, and Oya Açıkalın Rashem

Abstract Previous disasters have pointed out the importance of post-disaster planning for shelter conditions. Providing safety and comfort for everyone in disaster areas, good shelter conditions are essential for preventing diseases and disaster resilience. Temporary shelters are established in terms of operational procedures, shelter management, and basic human needs but not based on spatial factors. Spatial factors can cause social vulnerabilities and lead to difficulties. While many countries are putting efforts into action under the Sendai Framework of Disaster Risk Reduction (SFDRR) and the Sustainable Development Goals (SDGs) at a legislative level, the local implementation of actions for each of these goals is not successful. Neither inclusivity, accessibility, gender, nor resilience (for all) is included in the national and local disaster plans. Post-disaster sheltering demands an integrated and inclusive planning approach to building disaster capacity. In this chapter, the thematic analysis of policies on post-disaster sheltering is presented, and the international and national regulations related to inclusivity and accessibility in terms of gender are presented, and recommendations for disaster resilient sheltering are provided.

Keywords Sheltering planning · Inclusivity · Accessibility · Spatial · Gender · Resilience

N. Okay (✉)
Istanbul Technical University, Department of Geological Engineering and Disaster Management Institute, Istanbul, Turkey
e-mail: okayn@itu.edu.tr

E. Inal
Department of Emergency Aid and Disaster Management, Faculty of Health Sciences, Canakkale Onsekiz Mart University, Canakkale, Turkey

G. Yücel
Department of Architecture, Engineering and Architectural Faculty, Istanbul Rumeli University, Istanbul, Turkey

O. A. Rashem
Karamanoglu Mehmetbey University, Sociology Department, Karaman, Turkey

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1 Introduction

During disasters, people may lose their homes, and they might be forced to live in temporary accommodations and shelters for a certain time. Temporary shelter as emergency housing provides immediate living spaces to sleep, obtain health services for disaster-related conditions, and receive psychological support for a few weeks (American Red Cross, 2019; Australian Disaster Resilience Glossary, 2018). Usually, temporary housings are provided in and/or outside disaster areas (Sey & Tapan, 1987) and used for short-time emergencies.

Millions of people have to evacuate their homes every year to seek safety and high quality of care in a shock and disaster (IDMC, 2020). Due to a large number of Syrian refugee arrivals since 2011, temporary accommodations were built in many countries (Fekete et al., 2021). In such a crisis, certain limitations of the infrastructure were accepted in hosting millions of people. The emergency shelter has also played an important role in mitigation during the pandemic crisis. In early 2020, both shelters and open spaces were used as emergency field hospitals and quarantine centers for an effective solution in keeping COVID-19 from spreading (Wei et al., 2020).

In many countries, temporary sheltering is in the form of tents or other pre-fabric units (Figs. 7.1 and 7.2). The Red Crescent is the main body responsible for establishing temporary shelter areas in Turkey. After a disaster, it determines the shelter locations and supplies the necessary amount of tents to provide residence to the homeless. Although pre-fabricated houses had been constructed offering better living conditions than the tents, people continued living in the tents because the new housing areas were located very far away from city centers. Unless they are used for short-time emergencies as intended, the conditions of daily life in temporary shelterings can get worse (Acıkalin, 2017; Yücel, 2018). Kako et al. (2020) emphasized that if the care is not available for all people, even for a short period, there is an increased acute complication, leading to worse conditions. People can face high health risk in the long-term sheltering; they can be exposed to epidemic diseases and affected by environmental health conditions (Inal & Vaizoglu, 2017; Miyagawa et al., 2020). Recently, during the Elazig earthquake in early 2020, people were exposed to severe cold weather conditions, rather than urgent food and emergency needs in the villages.

Previous disasters have exposed that the global challenges, hazards (climate change, conflicts, natural hazards, pandemics), and their impacts are not only physical but also social (Drolet et al., 2015). All are affected by the sudden loss of security and privacy and the interruption of daily activities, and social networks, in the aftermath of a disaster. However, due to the domestic workload socially attributed to women, they tend to be the group deeply affected by temporary shelter conditions. The various forms of gender-based violence are a hidden social challenge during post-disaster sheltering (Yoshihama et al., 2019). Moreover, impacts on

Fig. 7.1 Tents and tent cities are used for short-time emergencies. In early 2020 during the series of earthquakes in Elazig, thousands of people experienced sheltering problems in severe cold weather and pandemic conditions. (https://www.aa.com.tr/en/pg/photo-gallery/tents-built-for-earthquake-victims-in-elazig/0)

vulnerable people including the elderly, people with illness, disabled people, pregnant women, and infants are a particularly serious concern. These vulnerabilities increase when easy access to water, sanitation, and health services are not provided (Okay & Ilkkaracan, 2018; Acikalın et al., 2019). Little attention is paid to women's needs in emergency relief provision in terms of safety, privacy, personal hygiene, and sanitation. These social and cultural needs are rarely considered in the design and planning for safe areas and temporary shelters. Therefore, the issues of shelter through the gender lens are probed This chapter aims to focus on the accessibility and exclusivity of women in temporary shelters, examine the global and national policies, and contribute to promoting actions to ensure that sheltering facilities are strengthened and developed sustainable resilience. The findings and recommendations are added to help policymakers and disaster management specialists to improve response planning and to develop inclusive and accessible shelter planning for resilience-based temporary shelters.

Fig. 7.2 After the earthquake people moved to a "container city," composed of prefabricated housings in the Elazig region. (https://www.aa.com.tr/en/pg/photo-gallery/container-city-for-earthquake-survivors-in-elazig/0)

2 Inclusivity and Accessibility in Temporary Sheltering Planning

The temporary sheltering planning fills the most challenging and strategic gap between the response and reconstruction stages of disaster management. Ideally, planning for the design and construction of temporary shelter is essential to determine a strategy before the disaster occurs (Abulnour, 2015). The governments need to establish planned shelters with sufficient living conditions and environmental and healthcare support including accommodation, drinking water and food safety, sanitation (toilet/showers), first aid, and public health services. Shelter facilities are providing schools, sports canteens, and other living conditions during a long stay depending on the recovery time.

The temporary sheltering planning is important to assess the public health status and risks including potential incidents, to improve the living environment (sanitary installations, the emergency restoration of water supply, waste disposal systems) and environmental health and deliver appropriate care to all evacuees (Inal & Vaizoglu, 2017; Wu et al., 2019; Miyagawa et al., 2020). Inal and Vaizoglu (2017) stated that environmental factors have a major impact on health in terms of epidemic diseases, and necessary and urgent arrangements should be planned settlement of shelter camping sites and the infrastructure system before the disaster.

The inadequacy of temporary shelter planning causes problems after the disaster. A series of prominent disasters with the increasing losses highlighted that a more concerted effort should be focused on reducing disaster impacts through hazard mitigation and enhancing resilience (Kwok et al., 2016; Cutter, 2016). Traditional planning approaches cause vulnerabilities and lead to further social problems. Resilience refers to a process of capacity building (e.g., disaster planning), as a post-disaster outcome (collectively cope with, adapt, or respond to shocks and disturbances resulting from physical, social, political, economic, and environmental changes). Therefore, both inclusivity and accessibility in shelter planning are critical factors for the comprehensive approach (Saja et al., 2018).

2.1 Inclusivity

Although the priority is to meet peoples' needs in temporary sheltering, it is also important to ensure normal daily life during the crisis period. Temporary shelters are established in terms of operational procedures, shelter management, and basic human needs. Little attention is paid to women's needs in emergency relief provision in terms of privacy, personal hygiene, and sanitation.

Women are vulnerable not simply because they have less access to male-dominated evacuation shelters but because it enforces women's dependence upon men for warning and preparedness information. As Enarson (2012) states, "gender-blind" reconstruction plannings lead to an increase in women's as well as the community's vulnerability, the widening of gender disparities, and the unsustainable development in affected communities (Yonder et al., 2005; Okay & Ilkkaracan, 2018). Gender issues are often ignored by conventional approaches in planning, and the problems cited at many shelters are due to a lack of gender sensitivity (Ranghieri & Mikio, 2014; Aryanti & Muhlis, 2020). Inclusive approaches are helped to address gender issues in disaster management plans and shelter design policies (Ritchie, 2018; Soden et al., 2014; Baharmand et al., 2016). Therefore, inclusive shelter planning helps to manage operations, builds disaster capacity and resilience, and provides the sustainability of life in good shelter conditions for all people, particularly women.

2.2 Spatial Factors and Accessibility

Post-disaster studies on vulnerability highlight the close relationship between the physical and social aspects of temporary shelters (Takahashi, 2011; Kako et al., 2020). The difficult physical and physiological conditions of temporary sheltering increase social vulnerabilities (Limoncu & Bayülgen, 2005; Tuna et al., 2012). Disaster planning lacking a reflection of spatial factors leads to further difficulties and problems in shelter management. From this point of view, it is evident that considering spatial factors in terms of social space is the strategic needs and conditions for women.

Spatial rearrangement of traditional conceptions is critical for the design of shelter units particularly for women who undertake the responsibilities of home and family care. Moreover, the perspective of social space is important in disaster management to improve sheltering capacity for everyone.

Concerning the domestic labor practices of women, such as cooking, washing, dishwashing, and caring for the children and the elderly inside homes, spatial needs and practices of use reveal the importance of flexibility in standard solutions for shelter units. The design of temporary shelter is an important issue in terms of improving disaster conditions and the recovery of people (Unal & Akın, 2017). Improvable space construction, with its flexibility in use, can positively affect comfort conditions in temporary shelter units with accessibility requirements (Brodie et al., 2006; Potangaroa, 2015; Hong, 2017; Yücel, 2018; Acikalın et al., 2019). Accessibility in temporary shelters requires the use of universal design standards. During response and recovery, temporary sheltering is a challenge with significant maintenance needs and especially spatial accessibility standards.

Sphere (2018) states that easily accessible by everyone, the size of the living area and the construction of the shelter unit can positively affect comfort conditions. Although accessibility in temporary sheltering points to the spatial use of individuals, it generally requires and describes design criteria that are integrated with inclusive and universal design principles. Universal design refers to the designing of products and environments, to be usable by all, and universal designs are equitable, flexible, and simple to use and require low physical effort (CEUD, 2019). Considering these design principles in areas such as toilets, showers, and the kitchen will contribute highly to the daily experiences of the users of the temporary shelter.

3 Methods

Our method is to examine six national and international policies and to find out the gaps in the planning of shelters. Six policies were the Sendai Framework of Disaster Risk Reduction "SFDRR" (UNISDR, 2015a), Sustainable Development Goals "SDGs" (UN, 2015), Sustainable Cities and Communities – Indicators for Resilient Cities "ISO37120" (ISO, 2019), National Earthquake Strategy and Action Plan "UDSEP" (AFAD, 2012), Turkey National Disaster Response Plan "TAMP" (AFAD, 2013), and Directive on Temporary Housing Centers (2015). We are focused on two concepts inclusiveness and accessibility as indicators of the resilience capacity of temporary shelters. To identify the extent of inclusivity and accessibility in terms of gender was covered by current policies, a thematic analysis was conducted. In the analysis, the frequency of the keywords, "temporary sheltering," "resilience," "accessibility," "inclusivity," "gender," and "women," was searched, and policies were systematically examined.

The keywords searched in each policy are the main issues that reveal disaster-related social vulnerability. Temporary shelter, which is the subject of the study, is one of the basic issues in terms of meeting the need for shelter after a disaster and the continuation of daily life. Accessibility and inclusiveness were examined in the policies within the scope of accessible temporary sheltering. The words "gender" and "women" were also included in searching so that they can be seen as a whole with other parameters. In general, the inclusive and accessible temporary shelter will provide a wider perspective for the user in one respect. The examined features of the legislation are tabulated in Table 7.1 by their quantitative characteristics.

3.1 International Policies

Three major international agreements were signed in 2015 including the Paris Agreement during the Conference of the United Nations Framework Convention on Climate Change (UNFCCC); the Sustainable Development Goals (SDGs); and the Sendai Framework for Disaster Risk Reduction (SFDRR). These agreements cumulate huge efforts on sustainability and resilience. Each agreement differs in structure, legal context, and implementation mechanisms, but they all also have common goals and common pathways, with the separation being political and territorial rather than practical (Kelman, 2015).

One particular goal of the United Nations' 2030 Agenda is to "make cities inclusive, safe, resilient and sustainable." According to the UN International Strategy for Disaster Reduction, resilience is defined as the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, and recover from the effects of a hazard in a timely and efficient manner, which encompass the preservation and restoration of its essential basic structures and functions.

The Sendai Framework of Disaster Risk Reduction (SFDRR) provides seven global targets to reduce disaster risks. SFDRR targets are the following: (1) substantially reduce global disaster mortality; (2) reduce the number of affected people globally; (3) reduce direct disaster economic loss in relation to global gross domestic product (GDP); (4) substantially reduce disaster damage to critical infrastructure including emergency services, healthcare, and education facilities; (5) increase the number of countries with national and local disaster risk reduction strategies; (6) develop international cooperation to provide sustainable information support; and (7) substantially increase people's opportunities to access multi-hazard early warning systems and disaster risk information and assessments by 2030. SFDRR supports a people-centered inclusive approach to disaster risk reduction policy to be implemented through local governments to achieve resilient and sustainable development (UNISDR, 2015b; UNDRR, 2019; Mizutori, 2020).

Sustainable Development Goals (SDGs) for the 2030 Agenda provide a plan of action to reduce social vulnerability at the local level, for climate change adaptation, and to increase resilience. Under the United Nations supervision, the adaptation and implementation of all 17 goals are fundamental for countries to achieve across social, environmental, and economic dimensions, thus depending on strong efforts taken on the implementation of specific SDGs, such as gender equality (SDG 5) and reducing inequalities (SDG 10), providing infrastructure (SDG 9), and sustainable cities (SDG 11), and the way we particularly create inclusive and strong institutions (SDG 16). SDG 13 also promotes actions for raising adaptive capacity to

Table 7.1 Six international and national policies evaluated by the keywords used in the thematic analysis; the frequencies (N) of each keyword is noted in parentheses

Legislation	Temporary shelter	Accessibility	Inclusivity participation	Gender women	Resilience
SFDRR (2015)	Priority 4 safety and needs (N = 2)		Priority 2 risk management N = 1	Priority 4 (N = 2)	Priority 3 (N = 1) Priority 4 (N = 2)
SDGs (2015)		Goal 6 for women (N = 2) Goal 7 for women (N = 1)	Goal 16 inclusive education Goal 16 inclusive economic growth for all Goal 10 inequalities (N = 3) Goal 11 for women (N = 2) Goal 16 inclusive societies	Goal 1 poverty (N = 3) Goal 2 vulnerability (N = 3) Goal 3 health (N = 7) Goal 4 education for women (N = 4), gender (N = 3) Goal 5 equality (N = 18), gender (N = 3) Goal 8 for women (N = 5)	Goal 11
ISO37120 (2019)	Emergency shelter (N = 18)	Transportation and information (N = 6)	Collaboration (N = 3)	Gender (N = 0) Pregnant women (N = 1)	(N = 140)
UDSEP (2012)	Action C.3.1.2 strengthening the emergency infrastructure, the formation of temporary shelter areas (N = 3)		Participation of all shareholders (N = 5)	Action C.2.3.1 Social gender roles (N = 1), Women (N = 2)	For achieving resilience of societies and institutions at all levels (N = 1)
TAMP (2014)	Formation of temporary shelter areas and operational responsibilities (N = 23)				
Directive on Temporary Housing Centers (2015)	Addresses various basic physical standards (site slope rate %2–6)			Women representative in administration and women committees (N = 9)	

climate-related hazards and natural disasters with effective planning and management, strengthening resilience including focusing on women, youth, and local and marginalized communities in all countries.

Sustainable Cities and Communities – Indicators for Resilient Cities (ISO37120) is an international standard that addresses indicators to establish a resilient city, to prepare for and recover from and adapt to disaster shocks and crises. The Standard is focused on resilience which is essential for sustainable development of cities, continuous improvement, and building back better after disasters. Resilient cities need standardized indicators to measure and evaluate their performance over the time. A new series of international standards are developed to provide a number of indicators of relevance to a city's resilience planning and assessment.

3.2 National Policies

Turkey has also experienced many serious earthquake disasters. The great Marmara earthquakes in 1999 resulted in 18,769 deaths. After that earthquake, the government began to realize the importance of urban planning in earthquake disaster mitigation. The National Earthquake Strategy and Action Plan "UDSEP" offers guidance on the reduction of earthquake risks and public preparedness against earthquake hazards, as well as supporting disaster research (AFAD, 2012). The Turkey National Disaster Response Plan "TAMP" is a guide on the roles and responsibilities in disaster and emergency response situations. It aims to determine the basic principles of operations before, during, and after disasters and emergencies (AFAD, 2013). TAMP gives responsibilities to all the parties that are involved (ministries, public institutions, and non-governmental organizations). The Directive on Temporary Housing Centers (AFAD, 2015) is a comprehensive guideline for temporary shelters, with Turkey hosting the world's largest refugee population and refugee camps.

3.3 Findings

Six international goals and national legislations were examined to identify the extent to which policies provide inclusivity and accessibility and address gender issues and disaster resilience in temporary shelters. The quantification of these keywords, as proxy indicators of vulnerabilities, helped us identify some important policy issues for discussion from a women-sensitive disaster risk reduction perspective. International and national policies focus on physical conditions and the determination of the needs of risk groups in post-disaster temporary shelters. It is stated in both international and national legislations that women are more disadvantaged and vulnerable in disasters.

Content analysis indicates that the Framework is concentrated on safety and human needs (Table 7.1). The SFDRR has been a highly recognized guide and advises countries to eliminate vulnerabilities to reduce risks and build societal resilience. Within the SFDRR the requirements for sheltering and the continuation of lives are emphasized. The SFDRR also pays special attention to people disproportionately affected by disasters and ensures that "no one will be left behind." The SFDRR recognizes the role of women in risk reduction and supports all gender-specific capacities in the recovery from all disasters, including climate change (Priority 4). Additionally, the SFDRR emphasizes an inclusive or participatory planning approach for local sustainable disaster risk reduction, preparation, and building resilience (Priority 2, 3, and 4).

Based on a content review, the Sustainable Development Goals (SDGs) for the 2030 Agenda do not directly address the issues related to emergency shelters. However, there are several targets related to disaster risk reduction in sustainable development goals (UNISDR, 2015a). For example, Goal 3 is aimed at accessibility to provide well-being and safety, while Goal 6 is aimed at providing clean water and sanitation and access to adequate and equitable sanitation and hygiene for all. Goal 5 pays special attention to the needs of women and girls in vulnerable situations and to eliminate all forms of violence against women and girls. Promoting women's leadership and gender equality in different sectors (education, health, etc.) is within several goals. Besides, all sustainable development goals are critical in building risk reduction and resilience (Table 7.1). The Sustainable Development Goals (SDGs) have focused the attention on interventions that have the potential to provide co-benefits for disaster risk reduction, climate change adaptation, and health (UNEP, 2018). As a result, shelters are likely to be inadequate to achieve SDGs and manage increasing weather extremes and health burdens associated with climate change in the coming decades (Wu et al., 2019).

Sustainable Cities and Communities – Indicators for Resilient Cities (ISO 37120) supports all global agreements, including the Sendai Framework for Disaster Risk Reduction, the Sustainable Development Goals, and the Paris Climate Change Agreement. In standard, emergency shelters, as critical facilities, are referred to as places of rest, reprieve, and recuperation for people displaced by disasters. They provide services and functions that are essential to a city, especially during and after a disaster. Emergency shelters are essential to a city's capacity for disaster preparedness, response, and resilience (ISO, 2019), and urban shelter planning is an indicator of the resilience of a city (Kako et al., 2020). Although resilience is termed both a core component and an essential indicator of sustainable development and disaster preparedness, alongside recovery from and adaptation to crises, the standard stands weak in terms of inclusivity, accessibility, and gender-based planning (Table 7.1).

In a content review of the National Earthquake Strategy and Action Plan (UDSEP), emergency shelters and their standards (N = 3) are designed based on physical characteristics and spatial needs. Temporary shelters are established with regard to physical vulnerabilities (hazardous areas and engineering resilience of facilities); accessibility is in terms of transportation, health, and logistic services (*Action C.3.1.2*). The capacity to cope with disasters and reduce risks and vulnerabilities is addressed in a function of the risk groups that consist of women, children, the aged, and those with handicaps (*Action C.2.3.1*). In disaster management, women are considered as vulnerable groups that increase the social impacts of disasters (*Action C.2.3.1*).

The Turkey National Disaster Response Plan (TAMP) is adaptable to all types and scales of disasters. Responsibilities in the planning and coordination during the event of a disaster are established to achieve the response, temporary sheltering capacities by efficient management. TAMP addresses issues of basic human needs and operation resources in both temporary and permanent housing. The plan aims to determine the building capacity of public institutions and organizations. Moreover, there have been 22 logistics centers established around the country to transport temporary housing and shelter equipment immediately to the disaster area. However, the planning and building of earthquake shelters have been rather slow, largely because of economic and technological reasons.

The strategies and actions included in the UDSEP and TAMP national plans are not evaluated from the rights-based perspective of the Sendai Disaster Risk Reduction Framework, which is aimed at covering everyone. These strategies rather address issues in design and the maintenance and selection of locations.

The Directive on Establishment, Management, and Operation of Temporary Housing Centers describes the details of sheltering standards with five key areas, water supply and sanitation, nutrition, food aid, shelter, and health services to improve the quality of humanitarian response in situations of disaster and conflict. The standards are specified as "At least one female representative from the representatives of the neighborhood, at least one female personnel in the religious services office, and a sufficient number of female security guards should be present for the services to be provided in temporary accommodation centers."

4 Discussions

When disasters occur, people should be provided services in temporary shelters located in schools, office buildings, tents, or other emergency facilities. Both Syrian refugee and pandemic crises showed that shelters have a very crucial role for the communities; during all types of emergencies and disasters, shelters should be safe and accessible. However, these temporary shelters are built immediately during and after crises, and often not planned before the disasters to provide peoples' needs and requirements. In the disaster management cycle, the role of the emergency shelter is identified and considered within the response stage. Therefore, shelters are generally not planned to provide all needs (including social and cultural) and accommodations which are leading to many difficulties after the disaster. Moreover, the planning of shelters is often not built on humanitarian principles, hazards, vulnerabilities, and social resilience alone but is influenced by crisis responders and political as well as economic considerations. Certain limitations of the infrastructure and services that occurred are generally accepted during the response. Wu et al. (2019) have pointed out that poor living conditions in these shelters can aggravate the vulnerabilities of populations. Therefore, to build planned shelter complexes, the government should not only prepare a hazard-free area for sheltering to prevent the immediate secondary disasters but also reduce their social vulnerabilities and provide better living conditions.

Women found the arrangements in the shelters insensitive to their needs (Pincha, 2008; Ranghieri & Mikio, 2014). For example, these shelters did not provide enough privacy for women and girls and were small and dark; therefore, women lived in constant anxiety and discomfort. Due to unhygienic toilet conditions in the temporary shelter complex, many women and girls suffer from various infections. Moreover, livelihood issues are also important for women's empowerment which is linked to living conditions in the shelter. The shelter doesn't have enough space for meeting places for women for social interactions or to start the business. Lack of privacy in shelters and poverty together escalate domestic violence against women and children, also suicidal tendencies and severe depressions.

During the planning phase, those who assist the local community probably do not consider these specific needs in building emergency shelters. Planning for an emergency shelter typically involves ensuring that the shelter will be well-stocked with necessities, such as food, water, and blankets. There is a gap between drivers of planning and operating shelters for providing an overall human security. There are different realities for how different shelter types are operated under different crisis types or different trajectories of post-disaster shelters (Saunders, 2004; Fekete et al., 2021). The sheltering policy had been generally developed based on previous experience and the cooperative international organizations. It is difficult to modify the pre-established policy and allow the ad hoc local decision-making during consequences.

There has been significant progress on the implementation of the global agendas and building national capacities for disaster risk reduction and response plans. However, legislations are still very limited in terms of temporary sheltering accommodation, inclusivity, accessibility, and resilience. There is no internationally standardized terminology for shelter types and shelter definitions that may differ based on disaster types and also across regions and countries. Despite all efforts of local communities in disaster risk reduction, there are limited documents to achieve local information on services during the emergency and mass care for shelter personnel, non-government organization workers, and local public officials. Topics of shelter facilities have hardly been addressed in international legislations; there are no clear policy or other concrete suggestions which have been developed to address the sheltering planning problem.

The SFDRR stresses that risk assessments should inform plans. However, it is unclear how needs assessments and plans are conceptually related and how they inform each other in practice. These documents do not describe capability in a way that makes it is possible to relate social vulnerability and needs assessments and integrate plans. Although various organizations have produced guidelines for shelter management, most of them lack both clarity and detail (Miyagawa et al., 2020). For example, *The Sphere Handbook* is the global guide that mainly focuses on the response and recovery stage for the maintenance of shelters (Sphere, 2018). The book rather states the humanitarian disaster agenda and provides minimum standards for humanitarian purposes. The shelter as a critical infrastructure has been focused only on technical measures providing basic services for humanitarian situations of affected people. There is no methodology on how to identify infrastructure services and the needs and priorities of people.

Many efforts for sheltering are focused on physical structures with less attention paid to social, cultural, and economic aspects. This concept of resilience should be integrated into the sheltering planning during the risk reduction. The pre-disaster stage allows efficient planning through needs and vulnerability assessment during risk reduction, mass care for the local communities during the response, and sustainable development during the recovery after the disaster. For these reasons, a comprehensive approach in shelter planning and making accessible spatial arrangements for the sheltering area is critical in terms of disaster recovery and resilience (Fig. 7.3).

The design and planning of shelters integrating into disaster risk reduction planning can improve the sustainability and the capacity of urban systems and enhance resilience (Wei et al., 2020). Since legislations are important attributes to build disaster resilience, these gaps need to be addressed in current disaster-related policies for the implementation of actions on these critical concepts. The current planning guidelines should be improved to provide more details from the international level to the local level. Significant experience based on the actual demands and needs of local communities should be adopted to guide the planning and construction of the shelters. Local communities can improve their resilience based on various indicators (participatory planning, exchange and share local information, capacity building the 4Cs – collaboration, communication, cooperation, and coordination) through the mitigation programs (FEMA, 2014; Kwok et al., 2016; Güler et al., 2018). This complexity reinforces the need for community participation in

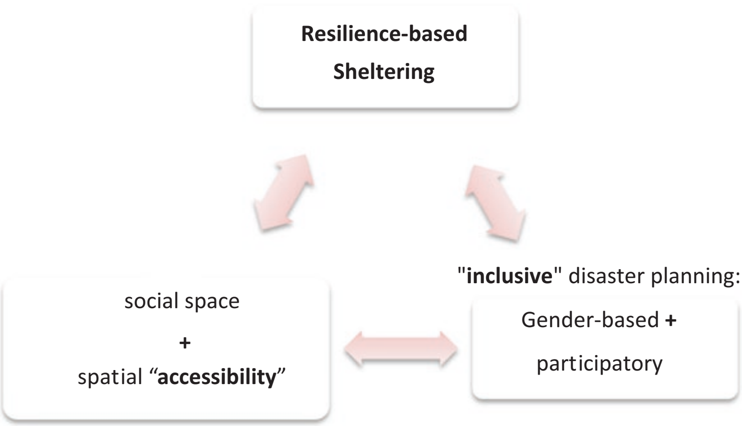

Fig. 7.3 A comprehensive approach based on accessibility and inclusivity for resilience-based sheltering. Inclusive shelter management requests gender-sensitive and participatory planning

planning to meet the range of functional needs and reduce sheltering challenges and further vulnerabilities.

With the holistic approach, there is a need for more guidance for the initiation of plans and actions. Furthermore, the guidelines should be specifically developed for the local public, municipalities, and NGOs. To update guidelines or the process of developing a strategy for sheltering, how to prioritize risk reduction actions is a helpful method, though often missing. Thus, guidelines at the national level guide the process of sheltering management, including vulnerability and needs analysis, by prioritization method. This prioritization conducts a critical assessment before the planning and helps to identify societal and cultural values at risk and the underlying priorities of different groups within the community. Participatory processes were found helpful as well as methods helping to identify different local contexts and realities that challenge the application of standards (Okay & İlkkaracan, 2018). A participatory approach can strengthen post-disaster shelter planning and help to meet peoples' needs, demands, and decisions for recovery processes (Drolet et al., 2015; Güler et al., 2018). The planning with the involvement of women and all will enhance community disaster preparedness, mitigation, and resilience. Therefore, it is urgent to prepare a gender-sensitive shelter planning that applies to all crises with participatory approach (Okay & Ilkkaracan, 2018).

All of the 2015 international agreements support the "all-of-society" (*leave no one behind*) approach which focuses on social resilience as an outcome of capacity building through disaster risk reduction planning process (Cutter, 2016). The SFDRR is the first international agreement to address all needs of individuals for the resilience. Resilience gives an opportunity for local authorities to take proper local measures in mitigation, preparation, and response to severe disasters, both natural (including climate-related extreme crises) and manmade. Resilience broadly defines the social, economic, political, and cultural institutional capacity and ability of the urban systems including people to prepare, respond to shock, bounce back, adapt, and recover from shocks and challenging event disasters (Alexander, 2013; Cutter, 2016; ISO, 2019; Mizutori, 2020). The community have a key role in resilience; for example, women are vital to developing resilience because it provides a base for planning and provides the capacity to make meaning of their migration in dealing with threats, sheltering, and resettlement processes including coping, adjusting, and integration challenges at various levels of the urban systems (Babatunde-Sowole et al., 2016; Drolet et al., 2015; Espina & Canoy, 2021). Therefore, all policies should focus on determining the practical needs of women (Erbaydar et al., 2018; Okay & Ilkkaracan, 2018).

The high rate of gender-based violence during and after the disasters is more than a social issue. Spatial factors can also lead to security problems. Espina and Canoy (2021) recently discussed spatial perspective in disaster shelters. Space can provide surveillance and protection from crimes and violence against women, girls, and children, including vulnerable groups from pregnant women to older frail people and people with some disabilities. Lack of privacy in temporary shelters also contributed to violence against women. The size of conventional temporary shelters generally is uniform for all families leaving large families with extremely restricted space. The shelters are placed closely adjacent to each other, or very limited space is available between them. These observations indicate simply a lack of attention during inefficient and uncoordinated planning and designing of shelter (Unal & Akın, 2017). Architecture plays a vital role in providing an emergency living space that guarantees secure feelings, security, and safety. Aryanti and Muhlis (2020) suggested that a "gender-sensitive emergency space" should allow the affected community members to defend themselves passively.

Additionally, local governments need to establish planned shelters, taking into consideration increasing weather extremes associated with climate change. Well-planned shelters as a disaster risk reduction and mitigation measure should be also integrated into the climate adaptation plan, to promote the goals of urban sustainable development (SDGs) and resilience, to enhance a local adaptive capacity, and to reduce the impacts of extreme disasters (DRR). During disasters, temporary sheltering is a challenge with significant implications for all aspects of people's lives and the local community. As disasters and conflicts continue at their current rates, achieving most of the SDGs will become very difficult. As a good starting point, it is expected that the SDGs and SFDRR together will adapt at urban levels to develop toward disaster vulnerability/risk-informed sustainable development and resilience. Therefore, developing a practical and comprehensive shelter plan combined with evacuation and mass care is crucial and vital to enhancing overall response capacity and to building resilient and sustainable urban systems (Wu et al., 2019). There is a growing need in urgency to plan and design for the "multifunctional" "gender-sensitive spaced" shelters with increasing disaster-affected communities and displaced refugee populations due to natural hazards including climate change, pandemics, and conflicts (Wei et al., 2020). In practice, not all policies turn into implementations, and the detailed field studies to monitor and test policies are recommended. Further research in this area will help with emergency management policy that is inclusive and providing gender needs and priorities in emergency shelter environments.

5 Conclusions

Shelters have frequently been used as temporary living spaces, with people demanding better living conditions with higher standards during the emergency. People using emergency shelters are influenced by the natural, social, and spatial factors that can affect health, safety, and privacy. The government and local municipalities are required to establish planned shelters, provide accommodation, and continue mass care services for a period of time with a safe and clean environment and sufficient living conditions. Well-planned sheltering is considered an effective strategy for reducing vulnerabilities and enhancing resilience to cope up with challenges during a crisis. No matter how good a policy is if it does not turn into a practice, it is no use. To achieve thus, all local administrations and shareholders including local people are required to be involved in planning and operating shelters. For example, previous local experiences can guide to update and improve effective sheltering. An ideal sheltering can be implemented in such a way as to achieve resilience and advancing the SDGs target of linking disaster reduction (SFDRR) and climate change adaptation efforts. The inclusive shelter planning procedures ensure that disaster risk reduction policies must include “leave no one behind.” This is crucial to develop a risk reduction policy that responds to communities’ needs and expectations. An ideal pre-established policy is that participated community-centered considerations and spatial design are crucial for the future of temporary sheltering.

Post-disaster planning focuses on mostly the physical conditions of shelters and operational management during response and recovery, yet all disaster plans tend to be gender blind. The women’s engagement is crucial in DRR, including shelter planning, design, and construction activities. An essential step in ensuring effective planning is to engage women so that their experiences are a valuable input to local strategies for resilience (risk reduction-preparation, sustainable development, and climate change adaptation). To provide better living conditions for everyone and the safety of women and girls, shelter systems (temporary, transitional settlements, and permanent housing complexes) are needed to plan and design with the full participation of the local people, particularly women. Therefore, the planning of shelters requires an inclusive and accessible approach with an even greater emphasis on gender within the pre-disaster processes, where their opinions and points of view are crucial for achieving resilience. For example, within the temporary shelters, there should be a strong partition ensuring a safe space for the personal needs of women and girls. The women’s toilet should be closer to the shelters; there should be a larger number of toilets with adequate water, strong and full-length secured doors, and ventilators; pathways leading to toilets should be lit; spaces should be provided to engage in their home-based occupations, meetings, and gatherings for women. Special attention should be given to shelter designs, location of and access to water points, and bathing and sanitation facilities. Strategies should include lighting and fencing and other safety measures, particularly for the protection of women in shelters.

Although the impact of the recommendations seems to be limited by examining the policy documents, these insights could help to guide to create future policy development and implementation actions that reduce the risk for those most affected.

The following are considerations for shelter planning and design:

– Determine the sheltering standards based on not only social and cultural needs also inclusivity and accessibility for resilience.
– Integrate design and planning of shelters as critical infrastructure into the urban systems.
– Establish emergency shelters combining diverse open spaces as alternatives, for example, gender-sensitive emergency space, community-centered considerations, and spatial design are also crucial solutions for post-disaster shelter and housing programs.

– Guidelines should contain information about the gender needs of communities, their vulnerabilities, information of hazards, and shelter types with critical infrastructure services.
– Participatory methods are helpful to identify different basic, gender, and cultural needs, social vulnerabilities, and other local challenges in the planning.

These steps are important to improve the capacity of living conditions, and actions are needed in providing all accessibility and inclusivity in shelter planning. It is urgent to prepare residence-based gender-sensitive shelter standards to integrate local sheltering plans. Therefore, addressing architectural accessibility in terms of gender in legislation is an important step, and that is directly related to the vital needs and priorities of the sheltered community.

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Chapter 8
Evaluating Risk from Disasters to Improve Resilience: Lessons from Nigeria and South Africa

Yewande M. Orimoloye, Toju Babalola, Adeyemi Olusola, and Israel R. Orimoloye

Abstract Disaster risk is linked not only to the occurrence of severe hazards but also to the vulnerability factors that make disasters more likely when they do. Vulnerability is frequently associated with a set of fragilities, susceptibilities, and difficulties involving the lack of resilience of exposed human settlements in disaster-prone areas. It is also directly tied to social processes and governance deficits in disaster-prone areas. This study aimed at evaluating disaster risk over Nigeria and South Africa to improve resilience in the affected regions and to compare risk to assets in the two countries with the global average. This study reveals that Nigeria recorded losses to assets, economic resilience, and risk to well-being with about 0.12%, 48.3%, and 0.25% compared to the global average of about 0.63%, 61.12%, and 1.07%, respectively. More so, South Africa recorded losses to assets, economic resilience, and risk to well-being with about 0.24%, 55.13%, and 0.43% compared to the global average of about 0.63%, 61.12%, and 1.07%, respectively. Findings from both countries revealed that risks associated with disasters were high compared to the global average. This development requires urgent efforts to reduce risks in the two nations, as climate change continues to magnify natural hazards. Because protection infrastructure alone cannot eliminate risk, a more resilient strategy and

Y. M. Orimoloye
Disaster Management Training and Education Centre for Africa (DiMTEC), University of the Free State, Bloemfontein, South Africa

T. Babalola
Water Resources Management and Agro-Meteorology, Federal University Oye-Ekiti, Oye-Ekiti, Nigeria

A. Olusola
Faculty of Environmental and Urban Change, York University, Toronto, ON, Canada

I. R. Orimoloye (✉)
School of Social Science, The Independent Institute of Education, Johannesburg, South Africa

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inclusion of the outcomes in the planning and decision-making process are needed to critically break the cycle of disaster-induced poverty and vulnerability.

Keywords Asset losses · Disasters · Nigeria · South Africa · Socioeconomic resilience · Well-being

1 Introduction

As a result of rising losses from natural disasters, more proactive risk resilience and management strategies have to be developed (Bănică et al., 2020). As the population grows and settlements expand, more individuals and assets are exposed to danger, yet social and technological advancements do not succeed in diminishing countries', regions', or cities' vulnerabilities (Bănică et al., 2020). Between 1998 and 2017, about 1.3 million people died, and 4.4 billion were injured, displaced, or needed emergency aid due to climate or geophysical disasters (UNISDR and CRED, 2017). Earthquakes and their associated tsunamis accounted for more than half of these fatalities (UNISDR and CRED, 2015). Around 60 million people worldwide were affected by extreme weather events in 2018; thousands of people were killed by earthquakes, tsunamis, and volcanic eruptions, and millions displaced by storms, floods, and droughts.

According to the annual 2020 report released by AON, global direct economic losses and damage caused by natural disasters were estimated to be 268 billion dollars in 2020. Although the loss was significantly less than the losses of 2011 (557 billion dollars) and 2017 (485 billion dollars), it was still significantly more than the average (244 billion dollars) and median (246 billion dollars) loss of the twenty-first century (AON, 2020). Additionally, in the same year 2020, natural disasters claimed the lives of almost 8100 people. Disasters such as cyclones, hurricanes, floods, and other multi-hazard events contributed to these economic losses and fatalities (Nazif et al., 2021),. Furthermore, COVID-19 overtook the globe at the start of 2020, becoming the worst pandemic on the earth since the 1918 influenza epidemic. According to the World Health Organization, the novel coronavirus may have infected more than 10% of the world's population (AON, 2020). Despite advances in science and technology, it is still impossible to fully anticipate and avoid certain disasters (Barzinpour & Esmaeili, 2014).

Apart from the COVID-19 pandemic, disasters caused by climate change dominated the year 2020, for instance, wildfire in the USA and Australia (Haque et al., 2021), tropical cyclone (Islam et al., 2021; Wang et al., 2021), and drought in South Africa (Orimoloye et al., 2021a). The pandemic intensifies the pressures placed on individuals affected by climate disasters, exacerbates their vulnerabilities, and hampers their recovery. With the COVID-19 pandemic, the global framework for sustainable development shifted dramatically. As a result, the world is confronted with the most severe social, economic, and environmental risks (Ashraf, 2021). The devastating consequences of these disasters emphasize the critical importance of minimizing fatalities, injuries, damage to critical infrastructure, and economic loss (Gu, 2019). However, some countries are more prone to specific natural disasters than others due to their geographical locations. For example, China is frequently struck with frequent earthquakes and floods due to its enormous land area, diverse climatic zones, complex geographical environment, and precarious ecological conditions (Han et al., 2016). On the other hand, Indonesia is vulnerable to a wide range of hazards (flooding, droughts, volcano eruptions, tsunamis, earthquakes, epidemics, etc.) because of its geological conditions and geographic location at the confluence of four tectonic plates (Hansun, 2020). In the year 2018 alone, half of the total death in Indonesia were from natural disasters, according to the Centre for Research on the Epidemiology of Disasters (CRED) report.

Africa is one of the most vulnerable regions to natural disasters. The African continent has incredibly diverse climatic conditions ranging from equatorial to desert. Considering the number of individuals affected in the late 30 years, droughts and floods are the most common disaster having the most humanitarian impacts in Africa (Lumbroso et al., 2016). The primary causes of exposure and vulnerability in African countries include fast population growth, urbanization, informal land occupation, and poverty. Like other countries, sub-Saharan Africa, South Africa, and Nigeria are vulnerable to disasters. South Africa, for example, has always been a water-stressed region, with an average annual rainfall of 450 millimeters, far less than the global average of 860 millimeters (Goldblatt, 2011; Turpie & Visser, 2015). It has seen several climate-related disasters over the last few decades, the most recent being the 2014–2016 drought, during which the country received the lowest annual rainfall on record (Davis-Reddy & Hilgart, 2021). Increased variability in temperature and rainfall patterns are predicted to severely hit the country, affecting agriculture which plays a significant role in the nation's economy (Benhin, 2008; Goldblatt, 2011) and livelihoods (Orimoloye et al., 2021).

Flooding is Nigeria's most common natural disaster; it is a prevalent occurrence in many geopolitical zones. For instance, Ibadan in Oyo State and Lagos in Lagos State have recently been affected by flood events where numbers of properties were affected and destroyed due to the events. Because of rising precipitation due to climate change, most of Nigeria's states are progressively experiencing annual flooding during the rainy seasons, for example, Oyo and Lagos States (Echendu, 2020). On the other side of the climate spectrum, various records of droughts in Northern Nigeria have resulted in famines (Abaje et al., 2013; Shiru et al., 2018). Overcultivation, overgrazing, uncontrolled urbanization, rapid population growth, and a high poverty rate exacerbate the natural disaster problem in Nigeria. Disasters such as drought and flood in Nigeria result from insufficient environmental infrastructure, unethical behavior, poor urban planning practices, and increased vulnerability (Oyebode, 2021). Consequently, evaluating risk from disasters to improve resilience in South Africa and Nigeria is crucial considering the number of disasters occurring in both nations. In this light, this study attempts to evaluate disaster risk over Nigeria and South Africa to improve resilience in the affected regions and compare risk to assets in the countries with the global average.

2 Study Area

The world including the African continent has been affected by disaster both human and natural disasters. Droughts, floods, landslides, and storms are common natural disasters, but climate change is increasing the frequency and severity of these weather-related risks in the Africa continent (Orimoloye et al., 2021a). South Africa covers about 1,218,000 square kilometers and has a coastline of nearly 3000 kilometers. South Africa share boundaries with Namibia, Botswana, Mozambique, Swaziland, and Lesotho. South Africa has a low precipitation rate, with an average annual rainfall of 497 mm which contributed to the persistent drought in the region (Orimoloye et al., 2021c). The climate is typically warm and dry, with winter temperatures rarely falling below 0 ° C and summer maxima frequently above 35 ° C (Schulze, 1997).

Nigeria is the world's 32nd largest country, with a total size of 923,768 km^2 (356,669 sq. mi) on the Gulf of Guinea in western Africa. Its borders stretch about 4047 kilometers (2515 miles), and it shares them with Benin (773 kilometers or 480 miles), Niger (1497 kilometers or 930 miles), Chad (87 kilometers or 54 miles), and Cameroon (1690 kilometers or 1050 miles). It has a coastline of at least 853 kilometers (530 mi). The incidence of disaster events such as drought and floods in Nigeria space has a long year of history of the devastation of lives and properties. Extensive flooding is a phenomenon of every rainy session in Lagos, Maiduguri, Aba, Warri, Benin, and Ibadan (Adedeji et al. 2020), and a good record of drought events is in the northern regions (Ekundayo et al. 2021).

3 Data and Methods

The information used in this study was obtained from the Global Facility for Disaster Reduction and Recovery Unbreakable Web Platform (https://unbreakable.gfdrr.org/countrytool). This platform consists of the resilience indicator, which measures socioeconomic resilience in 117 countries including Nigeria and South Africa, and provides insights on what investments and policies drive resilience. It is based on a simple model that calculates asset and well-being losses for multiple hazards: river floods, coastal floods due to storm surge, windstorms, earthquakes, and tsunamis. Socioeconomic resilience is then estimated as the ratio (ranging from 0% to 100%) of expected asset losses to expected well-being losses. A larger socioeconomic resilience means that a country's population can experience larger asset losses while maintaining its well-being. A resilience level of 50% means that $1 in asset losses from a disaster results in a loss of well-being equivalent to a $2 drop-in national income. The tool uses input data from the World Bank (World Development Indicators, ASPIRE, FINDEX) and the UN (Desai et al., 2015). Both nations considered in this study have several times been affected by drought and flood events which make some regions in the two countries vulnerable to disasters. Hence, disasters considered in this study are droughts and floods. The data is from 2015, the latest year the different data sources were all available. As stated in Hallegatte et al. (2016), socioeconomic resilience and risk to well-being are calculated as:

$$\text{socio-economic resilience} = \frac{\text{assest losses}}{\text{welfare losses}} \tag{8.1}$$

$$\text{risk to wellbeing} = \frac{\text{expected assest losses}}{\text{socioeconomic resilience}} = \frac{(\text{Hazard}) \times (\text{Exposure}) \times (\text{Asset Vulnerability})}{\text{socioeconomic resilience}} \tag{8.2}$$

4 Result and Discussions

To achieve the aim of the study, clearly, evaluating disaster risk in Nigeria and South Africa toward improving resilience in the affected regions in comparison with the global average, the result reveals that various policies have influenced the reduction in asset and well-being losses in the two nations.

4.1 Country Losses to Assets, Socioeconomic Resilience, and Well-being

Findings from this study revealed that losses to assets and well-being vary from one country to another especially with various policy priorities. This study shows that Nigeria recorded losses to assets, economic resilience, and risk to well-being with about 0.12%, 48.3%, and 0.24% compared to the global average of about 0.63%, 61.12%, and 1.07%, respectively (Fig. 8.2a). This connotes that losses to disaster events (flood and drought) in Nigeria are far beyond the global average. This necessitates a more reliable action and implementation toward disaster-resilient and mitigation strategy. Risk to asset (% of GDP) is the annual response or repair and replacement costs for assets affected by disaster, while socioeconomic resilience is the ability of the populace to cope with the recovery from disasters. It is calculated by the ratio of asset losses to well-being losses in a particular region. Risk to well-being (% GDP) measures the cumulative impacts of disasters on the resident's well-being, taking into account the lower capacity of poor people to cope with and recover from a shock due to disaster.

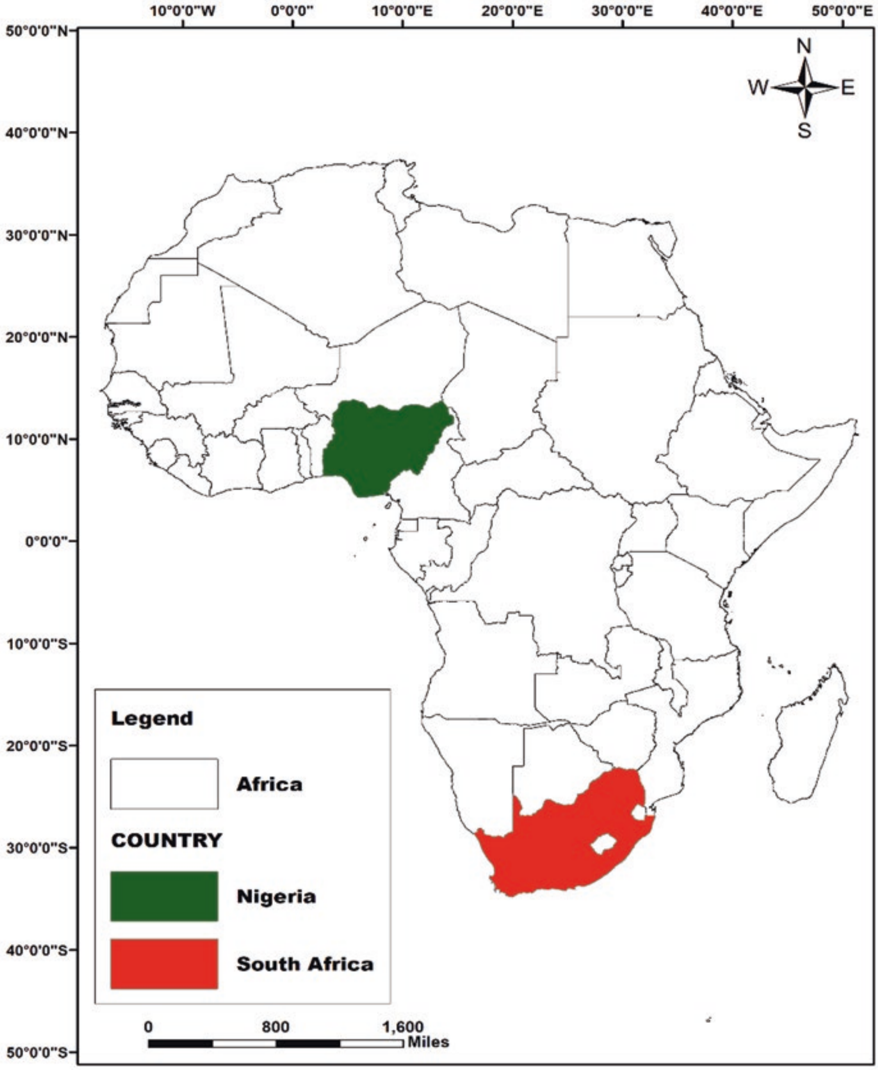

Fig. 8.1 Map showing the study area

More so, South Africa recorded losses to assets, economic resilience, and risk to well-being with about 0.24%, 55.13%, and 0.43% compared to the global average of about 0.63%, 61.12%, and 1.07%, respectively (Fig. 8.1b). This development might have affected various sectors including farmers, local communities, and water-reliant and vulnerability groups. Southern Africa, especially South Africa, has been found to be vulnerable to several natural and human-caused disasters that are becoming increasingly interrelated, according to studies (FAO, 2018; Aryal & Marenya, 2021; Branca et al., 2021). The growing frequency and intensity of

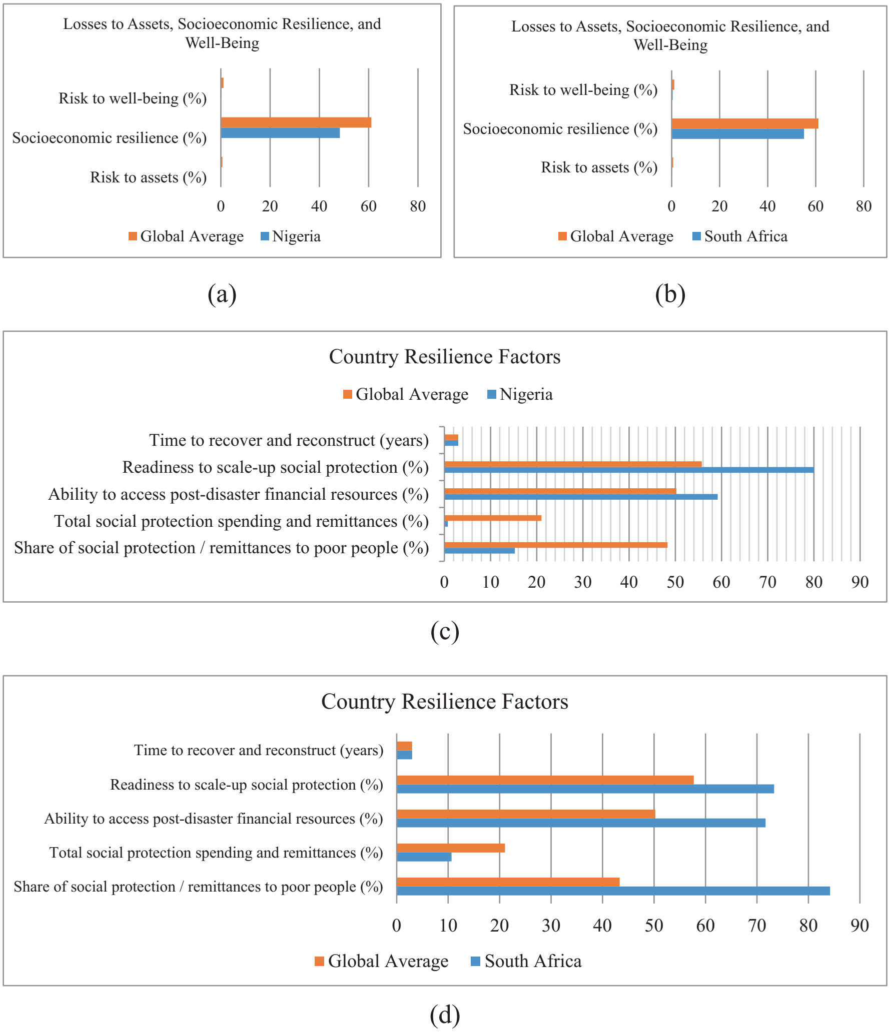

Fig. 8.2 Losses to assets, socioeconomic resilience, and well-being: (**a**) Nigeria, (**b**) South Africa. Country resilience factors: (**c**) Nigeria, (d) South Africa

disasters are further weakening rural households' already low capacity to predict, cope with, and recover from shocks, especially those who rely on agriculture and are particularly vulnerable. Building stronger, more resilient livelihoods are crucial to achieving collective commitments under the United Nations 2030 Agenda for Sustainable Development. The information in Fig. 8.2c and d present country resilience factors for Nigeria and South Africa, respectively; these are the main drivers of well-being and asset losses to disasters (drought and flood). The ability to access post-disaster financial resources (%) in Nigeria is about 59% compared to South Africa with about 71%; both nations are higher than the global average of about

50%. More so, the share of social protection/remittances to poor people (%) for Nigeria is lower than that of South Africa with about 15% and 84%, respectively, compared to the global average of 45% during the same period. Total social protection spending and remittances (%) are also lower in Nigeria compared to South Africa counterpart with about 0.7% and 10.7%, respectively. Overall, South Africa's resilient capacity is more efficient compared to Nigeria's. Studies have shown that lack of proper spatial planning and land use management coupled with lack of resilient capacity with the incapacity of governments to ensure good urban governance exacerbates the cases of disaster in Nigeria (Adedeji et al., 2020; Adefisan et al., 2015). It was also revealed that drought's cumulative impacts in Nigeria have resulted in rising poverty and environmental deterioration, putting the country's capacity to meet the Sustainable Development Goals at risk (Leal Filho et al., 2019).

4.2 Policy Priority in Disaster Risk Reduction Toward Improving Resilience

The information in Table 8.1 reveals how Nigerian policies can influence or reduce asset and well-being losses. Positive and negative values connote cases where the policies decrease or increase losses. For instance, Nigerian policies increase losses by increasing the income of the poor by 10% which influenced the rate of losses while reducing the exposure of the non-poor by 5% of total exposure reducing the rate of well-being losses by about 194 million dollars.

Findings from this analysis revealed that South African policies played vital roles in reducing asset and well-being losses due to disaster events since 2015. More so, a study showed that disaster and natural hazard governance has become a significant policy and legislative focus in South Africa since the early 1990s especially after apartheid (van Niekerk et al., 2018). Information in Table 8.1 reveals various roles these policies have played in reducing asset and well-being losses due to disaster in the country, and these have influenced resilient strategies in combating disaster impacts (Orimoloye et al., 2021b). South Africa has led the way in natural hazard governance in sub-Saharan Africa and most of the developing world and is widely regarded as an international best practice in policy and legislation development. Various natural hazard governance practices in South Africa are commendable. The country's disaster risks, as well as the different natural hazards that drive this risk profile, are given special consideration (van Niekerk et al., 2018; Sutherland, 2019)."

Results further show that the most efficient policies in South Africa in avoiding or reducing well-being losses due to disaster events are accelerated reconstruction and reducing exposure of the non-poor by 5% of total exposure with the worth of about 240 and 160 million dollars, respectively. The least effective is the policy on the increased social transfers to poor people to at least 33% in 2015; this connotes that this policy has nothing to contribute to resilient development. More so, in terms of asset loss avoidance, South Africa avoided asset losses worth about 99 million dollars with a policy on reduction of exposure of the non-poor by 5% of total

Table 8.1 Reducing asset and well-being losses through country policies (Nigeria and South Africa)

Absolute terms	Avoided well-being losses (US$, millions per year)		Avoided asset losses (US$, millions per year)	
US$, millions per year	Nigeria	South Africa	Nigeria	South Africa
Universal access to finance	25	61	0	0
Reduce exposure of the poor by 5% of total exposure	194	79	15	3
Reduce exposure of the non-poor by 5% of total exposure	95	160	65	99
Increase income of the poor 10%	17	10	−6	−1
Post-disaster support package	29	25	0	0
Develop market insurance (non-poor people)	60	103	0	0
Universal access to early warnings	110	141	51	75
Increase social transfers to poor people to at least 33%	129	0	0	0
Accelerate reconstruction (by 33%)	336	240	0	0
Reduce asset vulnerability (by 30%) of poor people (5% population)	61	26	4	1
Reduce asset vulnerability (by 30%) of non-poor people (5% population)	30	49	20	29

exposure followed by universal access to early warning policy with avoided asset losses of about 75 million dollars since 2015 as presented in Table 8.1. Studies have shown that natural disasters affect more than half a million people in South Africa each year, causing an average total economic damage of US$130 million per year (CRED, 2011; van Niekerk et al., 2018). Floods and storm events, droughts, and fires are the most common natural disasters (in order of frequency) in South Africa; this calls for more resilient strategies to combat disaster-related impacts especially drought and floods which are more frequent in the region.

4.3 Developing Socioeconomic Resilience to Natural Disasters

Space, where natural hazards occur, is a complex system. Natural hazards within this space act as shocks within the complex system. As shocks, natural hazards cause instability within the system. This instability could either be in the form of fatalities, casualties, or economic consequences which affect human well-being. Hence, the ability of the system to respond either in a positive or negative way determines its resiliency. Resiliency in simple terms is described as the ability of the system to withstand the existing shock and make a return to its initial state or a "near-state" with minimal damage. However, the capacity of the system to remain resilient has to do with a lot of factors. Furthermore, socioeconomic resilience, hereafter referred to as resilience, is the ability of an economy to minimize the impact of asset losses on well-being and is one part of the ability to resist, absorb, accommodate, and recover in a timely and efficient manner to asset losses (Hallegatte et al., 2016).

As identified by Hallegatte (2014), the behaviour of a system in responding to shocks is bifurcated. That is, there could be a situation of a small shock that necessitates a quick recovery to the initial state, or there could be a more intense shock which a bigger magnitude and recurrent frequency that significantly impairs the system. This type of shock(s) limits the ability of the system to recover and hence inhibits resilience. Systems here referred to as the natural environment, where living and non-living things interact, are largely impaired by the inability of the system to recover from the shock, in this case, a natural disaster. However, in the real-life scenario, a system is attacked by multi-hazards either at the same time or one after another. Therefore, there is the need for the system to be proactively resilient and prepared to resist the impending shocks. As observed in the case of Nigeria and South Africa, the resilience of the two countries differs due to several reasons ranging from factors such as but not limited to polity, governance, economy, climate/location, and population. However, to build a strong and vibrant socioeconomic resilient system, there is the need to go beyond "paying lip" service to disaster risk reduction but creating a conscious and sustainable action plan that can proactively aid a sound-resilient system. Several frameworks are in existence such as the Hyogo gives way to the Sendai Framework. These frameworks are quite efficient in disaster risk reduction and building a resilience system. However, there is the need to develop and couple site/region-specific frameworks that can cater for location differences and system instabilities. This in a way ensures a sustainable design that can adapt to the systemic changes.

To carefully design frameworks that are site/region-specific, there is the need for the government to do the following:

(i) Adequately plan for resilience.
(ii) Provide a careful laid-out design to finance resilience.
(iii) Be ready to partner with relevant stakeholders
(iv) Ensure viable monitoring of results.
(v) Plan for resilience

The Nigerian and South African governments are confronted with challenges that are hydra-headed and complex as a result of the impact of natural hazards. To ensure that they navigate through these complexities and present a strong and sustainable system requires efficient planning that can limit the loss and damage to lives and assets. As mentioned earlier, to adequately plan for resilience is to be ready to integrate disaster risk reduction into planning process at all stages of economic planning. These ensure that across all levels, national, state, provincial, and community, there is a resilient approach to natural hazards (Desai et al., 2015). A plan that adequately cater for those at the community level invariably covers the poor in society. The poor people are most often than not exposed to these shocks more than any other person. In Nigeria, for example, poor people are 50% more likely to be flooded; 130% more likely to be affected by drought; and 80% more likely to be affected by extreme heat. In short, in either Nigeria or South Africa, poor people are losing more, and they receive less support aftershocks and disasters (Hallegatte, 2014).

4.3.1 Finance Resilience

There is the need to consciously put a concerted effort into resilience finance. Governments in Nigeria and South Africa will have to do more in providing funds for resilient programs and projects across all scales. The state of global infrastructure deficit is acute in tropical environments, especially in Africa and Asia (GFDRR, 2015). Hence, it is a known fact that government alone might not be able to act as the sole financier in programs or projects to finance resilience. Hence, there might be the need for relevant stakeholders in the private sector to partner by helping to deliver, maintain, and fund part of these projects or programs. The government can design some sort of financing plots by creating:

(a) Upstream general legal and capacity analysis related to project financing in a specific city and strategic guidance to project teams on potential areas for expanded financing for resilience projects in the city.
(b) Financial and regulatory analysis related to a specific project concept.
(c) Specific transaction advisory and financing services (GFDRR, 2015).

4.3.2 Be Ready to Partner with Relevant Stakeholders

As specified in financing resilience, the government will have to design a solid blueprint to allow relevant stakeholders to be interested in partnering with the government. Since government alone cannot fund these projects or programs, there is the need to attract external partnerships especially with the private and multinational organizations dealing with resilience in all forms. These provide a more robust approach to achieving a lot using different opportunities and key players in addressing various issues within the system as regards resilience.

4.3.3 Ensure Viable Monitoring of Results

For a viable resilient program and design, there is a need for partnership with stakeholders. However, this can only be possible if there is an avenue for monitoring and evaluation of results. Government and various stakeholders should be ready to monitor the results of interventions put in place to build a resilience system either at the national, regional, state, provincial, or community level. These provide feedback for the design and help in understanding the behavior of the system or intervention. Without proper monitoring, there can be a viable resilient design to withstand shocks from natural hazards.

5 Conclusions

The findings from this study show that disasters such as floods and droughts can have a negative impact on development in terms of asset and well-being losses, necessitating the development of people's capacity to prepare for, manage, mitigate, and cope with disaster threats. Both countries' findings found that disaster risks were high when compared to the worldwide average. This development necessitates immediate efforts in both countries to avoid vulnerabilities. As natural hazards become more severe as a result of climate change, and because protection infrastructure alone cannot eliminate risk, a more resilient strategy and the inclusion of outcomes in the planning and decision-making process are required to address the problem of disaster-induced poverty and vulnerability. Strengthening national capacity in the government, public and private sector, and NGOs to mitigate the consequences of disasters such as floods and drought is one of the techniques for promoting long-term disaster resilience. It is important to remember that disaster prevention, mitigation, and planning are preferable to disaster relief and response. In Nigeria and South Africa, effective and timely spatial information on flood and drought monitoring is required, as well as their impact on flood and drought prevention programs. One of the benefits of promoting or improving resilience is that it will help advance solutions and efforts on quantifying risks and potential losses due to disasters in Nigeria and South Africa. Consequently, relevant authorities in these countries should develop policies for various types of disaster risk management. Disaster risk reduction must be mainstreamed into urban and regional planning at all levels of decision-making; governments and key collaborators should address prudent budget allocation, planning, and response mechanisms to manage disasters, resilience activities, response programs, and activities related to flood and drought hazards impacting humans, animals, and the environment. This is anticipated to preserve residents and infrastructure, particularly where development occurs in disaster-prone areas.

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Chapter 9
Perspectives for Collaborative Disaster Risk Reduction: Experience Report from the Brazilian Disaster Knowledge Platform

Leandro Torres Di Gregorio, Alessandra Conde de Freitas, Marcos Barreto de Mendonça, and Manoel Fernando de Souza Domingues Júnior

Abstract The Disaster Knowledge Platform, PCON-Desastres, is an innovative and inclusive Brazilian technological tool that seeks to facilitate the collaborative participation and the integration of efforts between public authorities, teaching/research institutions, community organizations, private companies, other institutions, and individuals who work or are interested in disaster-related issues and is aligned with the guiding principles of the Sendai Framework and the Brazilian National Policy on Protection and Civil Defense. This chapter aims to present an experience report for PCON's building process, the technological aspects, the improvements based on the users' feedbacks, the methodology for collaborative articulation and dissemination, the main outputs, lessons learned, and recommendations. It is expected that this experience report may contribute to facilitating the process of developing, implementing, and/or enhancing other collaborative platforms aiming at disaster risk reduction on a global scale.

Keywords Disaster risk reduction · Risk management · Knowledge management · Collaborative knowledge

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L. T. Di Gregorio (✉) · M. B. de Mendonça
Urban Engineering Graduate Program and Environmental Engineering Graduate Program, Polytechnic School, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
e-mail: leandro.torres@poli.ufrj.br

A. C. de Freitas
Structural Design Graduate Program, Polytechnic School, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

M. F. de Souza Domingues Júnior
Civil Engineering Graduate Program, COPPE, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

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1 Introduction

The harmful effects of a disaster are directly proportional to the hazard magnitude and the exposed system's vulnerability in its various aspects: physical, environmental, economic, political, organizational, institutional, educational, and cultural (Vargas, 2010). According to the United Nations (UN), more than 226 million people are affected by some kind of disaster every year (Castro, 2013). It is important to highlight that the disaster is not the physical phenomenon itself (flood, hurricane, others), but the adverse effects on the affected ecosystem, which are represented by human, material, and environmental damages and their consequent socioeconomic, patrimonial, and environmental losses.

Risk is a parameter that seeks to quantify the potential disaster's damage and losses resulting from the combination of hazard (the space-time probability of a physical process occurrence at a given magnitude) and the exposed system's vulnerability. Therefore, disaster risk management consists of a series of integrated processes and activities whose ultimate goal is disaster reduction through risk reduction and resilience increase. The integrated disaster risk management approach is based on the following groups of macro-processes: prevention, mitigation, preparedness, response, and recovery (Eslamian & Eslamian, 2021).

The field of disaster risk management is complex, highly intersectoral, and interdisciplinary, making it unfeasible to be addressed by a single group or organization, isolatedly. Twigg (2015) highlighted that the scale, frequency, and complexity of disasters, involving physical and social phenomena, can only be addressed by implementing a wide range of knowledge, skills, methods, and resources. Therefore, the design, planning, and execution of risk management actions need to rely on collaborative work among different sectors of society, allowing stakeholders to share ideas, knowledge, and resources. The individuals and institutions, each of them with their knowledge and skills, should carry out actions collectively.

According to Eyerkaufer and Sedlacek (2018), despite being fundamental, the practice of collaboration and integration in risk management actions is a great challenge considering that participation is not effective and, in many times, the most deprived people are not adequately included. Prater and Lindell (2000) emphasized that stakeholders' active involvement, such as residents' associations, non-governmental organizations (NGOs), humanitarian institutions, churches, and others in risk reduction policies, is vital. They also state the difficulty of mobilizing these stakeholders and highlight the need for public policies to ensure effective collaborative work on disaster risk reduction.

The Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR, 2015) is the successor instrument to the Hyogo Framework for Action – HFA – 2005–2015 (UNDRR, 2005) and aims at preventing new disaster risks and reducing existing ones. The Sendai Framework also emphasizes the need for international cooperation and global partnership, which can be fostered by promoting the use and expansion of thematic cooperation platforms such as global systems for sharing information, innovations, and research, as well as by ensuring access to technology and information on disaster risk reduction.

In the direction of the Sendai Framework, the Disaster Knowledge Platform (PCON-Desastres) is a Brazilian tool that seeks to facilitate the integration of efforts between public authorities, teaching/research institutions, community organizations, private companies, other institutions, and individuals who work or are interested in disaster-related issues. This chapter aims to present an experience report for PCON's building process, technological aspects, the improvements based on the users' feedbacks, the methodology for collaborative articulation and dissemination, the main outputs, lessons learned, and recommendations. It is expected that this work may contribute to facilitating the process of developing, implementing, and/or enhancing other collaborative platforms aiming at disaster risk reduction on a global scale.

2 Institutional Framework for Collaborative DRR

2.1 Legal/Documentary Framework

Among the international frameworks with impact on disaster risk reduction, the following stand out: the United Nations Conference on the Human Environment (Stockholm Conference, Sweden, 1972), the United Nations Conference on Environment and Development (Rio-92 or ECO 92), the RIO + 20 Conference, and the International Disaster Risk Reduction Frameworks – Hyogo (2005–2015) and Sendai (2015–2030).

The Sendai Framework implementation is guided by principles among which stands out the one that considers the inclusive participatory aspect when it advocates that (i) "Disaster Risk Reduction (DRR) requires involvement and partnership" (Sendai Framework, 2015, p. 13). Accessible, inclusive, and non-discriminatory participation should be encouraged, with special attention to people disproportionately affected by disasters, especially the poorest. DRR must integrate gender, age, disability, and cultural perspectives into all policies and practices, as well as promote the leadership of women and young people.

In Brazil, after the major disaster in the mountainous region of Rio de Janeiro, the 2012 Federal Law 12,608 (Brasil, 2012) was enacted and instituted the National Policy on Protection and Civil Defense (PNPDEC – Política Nacional de Proteção e Defesa Civil) provided by the National System for Protection and Civil Defense (SINPDEC – Sistema Nacional de Proteção e Defesa Civil) and the National Council for Protection and Civil Defense (CONPDEC – Conselho Nacional de Proteção e Defesa Civil), among other measures. One of the PNPDEC objectives is the development of a national awareness about the risks of disasters, and among its guidelines, the participation of civil society stands out, which is aligned with principles (i) and (ii) of the Sendai Framework, mentioned earlier.

It is vital to value scientific and traditional knowledge; technical, social, cultural, and environmental components; and gender, age, and ethnic issues in society's participation. Therefore, the importance of using and expanding collaborative platforms must be emphasized, making possible, for instance, the sharing of information, innovations, researches, practices, and resources. Guaranteeing access to technology and information and encouraging cooperation between the various stakeholders in DRR actions are also mentioned in the Sendai Framework.

2.2 Examples of Collaborative DRR Initiatives

Liu et al. (2018) present a collaborative and participatory mapping method that involves different stakeholders (e.g., public managers, NGOs, and population) and includes information on hazard, vulnerability, and risk, resources, coping capacity, and up-to-date monitoring of field conditions. These authors presented a pilot project in which the method was applied to a community in Nepal, focusing on the risks related to floods and concluding that the mapping results contributed to increasing local resilience.

Risk management takes place at different spatial scales and, therefore, different governmental levels, resulting in different possibilities for collaborative actions that may exceed the national territory limits. As an example, Tau et al. (2016) presented a collaborative risk and disaster management model applied to countries included in the Southern African Development Community (SADC), which combines theoretical dimensions, policies, and collaborative techniques to enhance governmental risk and disaster management.

Freitas et al. (2016) showed an example of a collaborative network among the population, academia, various civil society institutions, and public managers in a community in the mountainous region of the municipality of Nova Friburgo (Rio de Janeiro State, Brazil) aiming to collaboratively develop landslides and flooding susceptibility and risk maps, territorial zoning plan, monitoring and early warning plan, contingency plan, social control, and community guidelines. According to the authors, the concept of *Knowledge Ecology* (Santos, 2007) was used, through which the importance of heterogeneity and interaction between different types of knowledge is recognized.

Based on the *community ergonomics* approach, a methodology for the development of a collaborative system involving the municipal civil defense, population, NGOs, and technical experts was developed in the municipality of Natal (State of Rio Grande do Norte, Brazil) (Carvalho, 2017). The work was developed in the pilot area of Mãe Luíza district, a region susceptible to mass movements, and allowed the exchange of information in the preparation and response stages, involving knowledge on disaster risk alerts and alarm, spatial orientation, simulated exercises, and instructions through the use of cell phone applications.

Aiming at the involvement and partnership between different stakeholders and based on the necessity of sharing information about disaster risk reduction in Brazil,

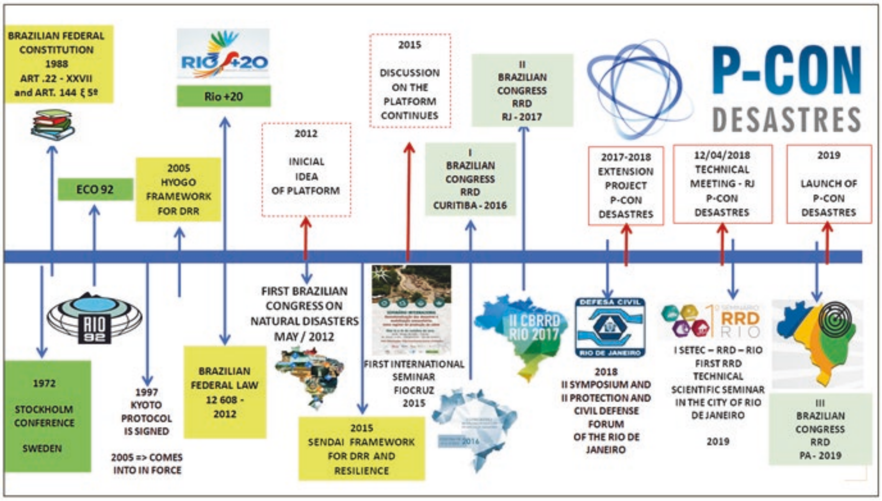

Fig. 9.1 Timeline with DRR frameworks, national (in Brazil) and international main events, and DRR initiatives. (Adapted from FREITAS, 2019, and MORAIS, 2019)

Di Gregorio et al. (2018) created the *Disaster Knowledge Platform* (PCON-Desastres, https://pcon-desastres.poli.ufrj.br/). This tool seeks to facilitate the integration of efforts among public authorities, educational/research institutions, community organizations, private companies, other institutions, and people who work and/or are interested in disaster-related issues. The platform also seeks to involve people disproportionately affected by disasters, such as the poorest and those with special needs, since PCON contents are available free of charge and in a relatively simple way. The creation of PCON-Desastres and the main national (in Brazil) and international frameworks for disaster risk reduction can be found in Fig. 9.1.

3 Collaborative Platforms

Twigg (2015) mentioned that the disaster "community" is formed by those professionally engaged in risk management, including physical scientists, social scientists, engineers, architects, doctors, psychologists, emergency planners and humanitarian workers, diverse humanitarian organizations, government (at all levels), NGOs and other civil society organizations, academia, consultancies, military agencies, and the private sector.

Before the conception of PCON-Desastres in its current version, other collaborative computerized platforms were explored and analyzed: MH Themes, Understanding Risk (World Bank), GRIP (UNDP – United Nations Development Program), Exo Platform, GPSA Knowledge Platform, Operational Support Centers of the Housing and Urban Planning Prosecutions Offices (Brazil), Platform of the Major Risks Institute of Grenoble (France), Disaster Preparedness and Response, CISCO Collaborative Knowledge, and Social Protection Platform (an initiative of the G20 and UNDP), among others. All the analyzed platforms have strengths and weaknesses, but none of them was sufficiently adherent to the requirements previously identified for the different audiences of a collaborative platform for disaster risk reduction. As for the articulation aspect, several initiatives for the constitution of communities of practice and discussion groups are mentioned by UNDRR Prevention Web, 263 of which are public (Table 9.1) and 34 private (UNDRR, 2020).

One of the main limitations was the financial aspect. As the Project did not count with a specific budget, the initial development process was based on volunteers'

Table 9.1 Number of groups of communities of practice and public discussion groups mentioned by UNDRR Prevention Web, organized according to theme and hazard

By theme	By hazard
Advocacy and media (4)	Avalanche (2)
Capacity development (24)	Cyclone (1)
Civil society/NGOs (10)	Drought (4)
Climate change (18)	Earthquake (9)
Community-based DRR (13)	Epidemic and pandemic (1)
Critical infrastructure (1)	Flood (5)
Cultural heritage (1)	Heat wave (1)
Disaster risk management (40)	Landslide (4)
Early warning (5)	Mud flow (1)
Economics of DRR (4)	Storm (2)
Education and school safety (8)	Storm surge (3)
Environment and ecosystems (7)	Tornado (2)
Food security and agriculture (1)	Tsunami (3)
Gender (5)	Volcano (1)
Governance (11)	Wildfire (1)
Health and health facilities (2)	
Inclusion (2)	
Indigenous knowledge (1)	
Information management (11)	
Insurance and risk transfer (3)	
Private sector (3)	
Recovery (9)	
Risk identification and assessment (9)	
Small island developing states (SIDS) (1)	
Social impacts and social resilience (5)	
Space and aerial technology (4)	
Structural safety (5)	
Urban risk and planning (13)	
Water (3)	

UNDRR (2020)

work and personal financial resources from the first three authors. This point made unfeasible the adoption of external paid platforms. From the beginning, it was clear that the platform's development should be based on users' needs and feedback. It means that the tool would require permanent adaptation, which would be difficult to carry on with external platforms. The platform rules' governance was also a concerning point, considering the responsibilities involved and the necessity of a reliable and independent participation process. However, a complete initial user's registration showed to be not practical for the new user's involvement. The language barrier was also a decisive point for creating a Brazilian Platform since the initial target public is from Portuguese language countries (the English version is also in our plans). Further issues will be presented in Sect. 5, especially in the Lessons Learned subsection.

3.1 Basic Technical Details about Platforms

With the evolution of technology, technological platforms' construction also grows, using new concepts and new standards. Thompson (2011) described the web as the new platform, based on criteria that make it more accessible and efficient.

Web-based platforms offer the benefit of centralization, making the ecosystem formed by its stakeholders more dynamic and closer to users' expectations. In broader terms, Marlinspike (2019) argued that more centralized ecosystems bring several social benefits, such as information security, transparency, and equal access.

Like all software-based platforms, a project can develop its web platform for its specific scenario. Alternatively, the projects can buy ready-made platforms (where a third party develops them and offers them as a product) or adapt them. For each strategy, we must use the development method based on the degree of uncertainty, balancing each tradeoff.

For problems that are known and have mapped solutions, buying a platform can bring immediate benefits. The tradeoff is the initial investment and a wide range of features that may not make sense at the beginning of a project.

Problems that are already known but that do not have tested and validated solutions do not benefit from consolidated platforms. A platform that does not solve the problem or needs constant adaptations diverts researchers' focus and makes it difficult to deliver research value. Also, an already established platform may require a high initial investment and continuous investments for its adaptation.

Constantly reformulated problems represent a challenge in building software-based platforms. Pfleeger (2001) approached requirements engineering or surveying customer needs as one of the first of many phases of software development. It is necessary to rethink the software engineering used in platforms of this type when the customer's needs change frequently.

In research projects and collaboration platforms, the need for short development cycles and quick feedback makes it possible to deliver value and obtain better results. At this point, Beck et al. (2001) proposed the Agile Manifesto, where they established principles for the development of software and platforms with a focus on their results to the target audience.

An example using the traditional waterfall approach, researchers initially propose a set of ideas. Soon after, stakeholders map out their technical requirements, and software engineers develop and test them. Only after all this process, which normally takes months, the user's feedback is collected.

In contrast, using Agile, an idea is prioritized based on user feedback. Engineers develop the central part of this idea, and it is tested directly by users. Researchers check, based on the user's metrics, whether development continues or whether another idea should be addressed.

3.2 Using Metrics on Web Platforms

According to Sergey Brin, apud Edwards (2011), the highest cost is the opportunity cost in the software projects that are starting. Thus, prioritizing "what should be done" at each point in the Project is vital for the expected results.

To consolidate and prioritize each idea that appears in a project, the use of metrics balances the cost with the benefit, avoiding the subjectivity of decision-making. On web platforms, mechanisms or tools for evaluating navigation statistics can be used to collect these metrics.

These statistics assessment tools can provide information such as the average time a user has used a resource, how the user arrived at the platform, their navigation flow, or even if the user rejected the content and left the platform. This information is valuable in establishing which idea represents the next opportunity for a project based on a web platform.

In addition to analyzing the data for all users in general, it is necessary to test new features with the public using the scientific method. Siroker (2010) brought the proposal of using A/B tests, where groups try different ways of consuming a web platform. Since the groups use versions of the platform with different functionalities, the metrics help in decision-making and the results' improvements.

3.3 Collaborative Platform Features

Several authors (Wikipedia contributors, 2020) pointed out more than 20 different types of collaboration-oriented software, which were evaluated on a set of characteristics, as shown below:

- Ability to publish content.
- Ability to collaborate with others' content (wiki).

- Ability to manage projects.
- Ability to manage documents.
- Ability to manage communication lists.
- Ability to have discussion forums.
- Ability to publish personal content (blog).
- Ability to search at connect.
- Ability to interact with others (video, chat, e-mail).

Even with this list of features, user engagement is the decisive factor for the success of a collaborative platform. If a platform has no users, there is no collaboration, and it does not achieve its goal. As each audience is different and tends to specialize on a platform, understanding which features are a priority is crucial.

According to Taylor et al. (2016), technical factors such as latency, network usage, and platform loading speed negatively impact the users' experience. These factors can alter the users' perception of the platform, decreasing its efficiency and going against the purpose of the collaboration.

Taking into account systems design decisions, such as horizontal scalability, context separation, caching, and load balancing, technical factors are improved and more resilient. Horizontal scalability provides the service with the ability to expand its service capacity without requiring more robust hardware. Rather than needing computers with more resources, the service expands its capacity with more machines that use fewer resources.

Context separation provides the platform with the ability to have its resources isolated. For example, the platform login does not impact content distribution services. Thus, a spike in logins does not make the platform unavailable to users already logged in. Caching provides the platform with the ability to pre-generate content that is not frequently changed. Besides, all non-personalized content can also be cached. This technique is useful for increasing the platform's capacity without requiring a lot of computational resources. Load balancing provides the platform's ability and components to run on more than one server at the same time. This technique increases its availability, preventing specific or hardware failures from impacting the service.

4 PCON-Desastres Building Process

PCON's building process will be presented in two steps:

- The methodology for the platform's development.
- The methodology for evaluating and spreading the platform, based on users' collaboration.

4.1 *Methodology for the Platform's Development*

4.1.1 General Overview

The initial idea of a knowledge platform for disaster risk reduction dates from 2012 (Fig. 9.2), in a paper presented at the IPCC SREX (Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation) Launch Event (Di Gregorio et al., 2012). In 2015 the idea was taken up and matured throughout 2016, still in a conceptual phase, with the collaboration of other colleagues (the complete Project's history can be found at PCON's webpage, "SOBRE" web menu).

From 2017 on, a new stage started with a new working group, and the Disaster Knowledge Platform Project (PCON-Desastres) was formalized through an extension research project by the Federal University of Rio de Janeiro, developed according to the phases described in Table 9.2.

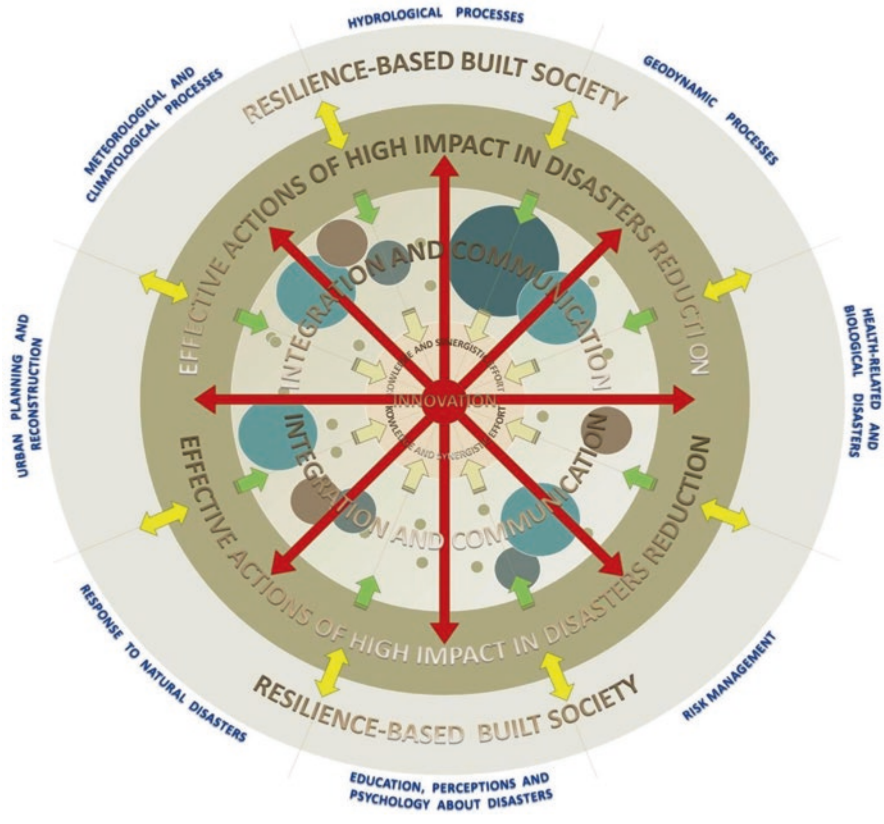

Fig. 9.2 Conceptual model for a knowledge management system in socio-natural disasters. (Di Gregorio et al., 2012)

Table 9.2 Phases of the Disaster Knowledge Platform extension project

Phases	Description
(1) Conceptual revision (2017)	Identification of the main requirements and concepts' improvement on the Disaster Knowledge Platform.
(2) Product design (2017/2018)	Design of PCON-Desastres screens, in a level of detail that allowed the technical development of the tool
(3) Development of the MVP prototype (2018/2019)	Development of the first version of the tool, that is, the minimum viable product
(4) implementation and pilot operation (2019/2020)	Provisional implementation with a restricted user group, to test and evaluate the platform. Different PCON operation modes are also being discussed, tested, and evaluated
(5) Improvement (2020)	Based on the results obtained in the pilot implementation, improvements are being carried out, focusing on short-term feedback from users
(6) Implementation and operation in scale (2021 onward)	With the collaboration of institutions and professionals in the area of disaster risk management, the intention is to carry out an implementation and networking operation on a national scale
(7) Internationalization (2021 onward)	Based on the national experience, it is intended to advance the internationalization for the community of Portuguese-speaking countries and Latin American countries

4.1.2 Technological Overview

To meet the demand for a platform in a simple way, PCON made use of a well-known content management system: WordPress, a platform in the PHP language that uses a relational database. It is a way to get a quick result, without needing a significant investment in features without metrics. However, one of the known problems with WordPress is its need for constant updates due to security vulnerabilities. This point is directly related to the need for continuous investment in a platform based on an adapted tool.

The platform uses the Linux operating system and the Nginx web server as a base to run the CMS. The platform generates metrics through the generation of events on servers and analytics tools like Google Analytics. The platform is periodically audited by information security professionals to ensure that its main functionalities are free from vulnerabilities. Its plugins and systems are updated automatically, to avoid any type of technical debt.

Each new user registered on the platform becomes a CMS user, with more restrictive permissions. In this way, it is possible to offer an authenticated experience to users without developing an elaborate authentication and permissions system.

4.1.3 The Process of Creating Web Menus

At first, the main groups of platform users (target audience or clients) were identified as researchers; civil defense system; public managers (all levels); vulnerable communities (people, groups, companies, and other organizations); the society in general (public opinion); press; NGOs; volunteers; students; and other partners. For each group of users, their main needs and expectations (declared or not) were also identified.

The project meetings were conducted in a free brainstorming format, where group members expressed their ideas as they arose, but within the topics managed by the group facilitator. During the brainstorming, any kind of criticism of the proposed ideas was avoided, but later the content was combined and improved according to the *Design Thinking* method, focused on the development of innovations.

From the general requirements obtained, they designed the main functionalities, which were grouped into four web menus:

- PARTICIPANTS, aimed at registering and displaying the profiles of the platform users.
- ACTIONS, which allow the registration and display of several initiatives carried out by the platform users. The actions in progress can also be viewed through the AGENDA web menu, where a unified calendar of events is presented.
- RESOURCES, which allows the registration and display of materials, human resources, equipment, and other resources that are being OFFERED or DEMANDED by PCON users.
- LIBRARY, which brings diverse contents related to disaster topics, pre-selected by PCON-Desastres curators and preferably organized in the form of thematic lists.

The registered contents can be viewed by the general public (even for not registered users) but can only be posted by users registered on the platform, upon acceptance of a Term of Use and Responsibility and an authorization to make their data available to the general public. The user's IP is also registered at the moment the registrations are made, to prevent contents that are not aligned to the platform's policy.

The registrations made (participants, actions, and resources) are presented in the form of maps, to provide an overview of the spatial distribution of these elements throughout the national territory. Search tools are also available in the tool, to speed up research. PCON's home webpage is presented in Fig. 9.3.

4.1.4 The Process of Creating the PCON Knowledge Tree

The knowledge tree consists of independent sets of identifiers (tags) used to characterize each of the items that will be registered in the platform, that is, the participants, actions, and resources. These identifiers facilitate the search for information on the platform, according to the users' interests.

The tree was planned in three levels, namely, types of disaster (first level), general identifiers (second level), and specific identifiers (third level). The type of disaster is based on the Brazilian Codification of Disasters (Brasil, 2017), which consists

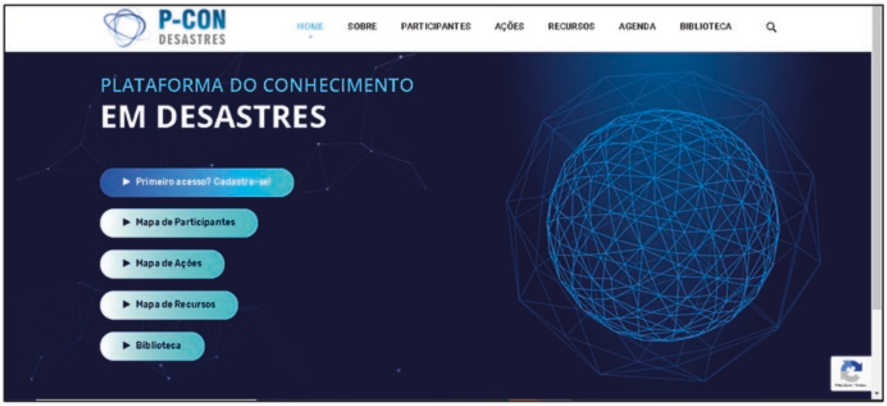

Fig. 9.3 Opening screen of PCON-Desastres. (Di Gregorio et al., 2018)

of the typification of the natural or anthropic phenomenon to which the disaster is related. The following identifiers (general and specific) involve diverse areas of the physical and earth sciences and human and social sciences. The knowledge tree also helps the user to be aware of the broad disciplinary platform scope, and it is possible to select as many identifiers as are considered appropriate for each registered item.

Aiming at the construction of the second- and third-level identifiers, a thematic bibliographic search was initially carried out based on titles and keywords from scientific works on risks and disaster issues, published from 2016 to 2017. A preliminary list of identifiers was prepared and revised according to the perception of the authors of this work, seeking to avoid redundancy.

To introduce and discuss the Disaster Knowledge Platform preliminary version (minimum viable product) to a group of stakeholders, a technical meeting was held in the Federal University of Rio de Janeiro in December 2018 with the participation of different representatives involved in disaster risk management in Brazil, namely, public managers, academics (professors, researchers, and students), community associations, and the private sector (Fig. 9.4). One of the specific objectives of this event was to discuss and validate the knowledge tree initially proposed, and, for this purpose, the participants were divided into groups. After discussion, the groups exposed their opinions, and a new knowledge tree was elaborated. Rejane Lucena, representative of Jaboatão dos Guararapes Civil Defense Superintendence (a municipality located at the State of Pernambuco, Brazil) said: "The discussion of disasters in Brazil had a big boost in the last two years. Regarding disaster issues, we are here to contribute to the national process by presenting our experiences in the Northeast Region" (POLI UFRJ, 2018). Meteorologist Juliana Hermsdorff, the representative of Alerta-Rio (institution responsible for issuing warnings to the population in the city of Rio de Janeiro), declared: "I evaluate it (PCON-Desastres platform) as a very good initiative, especially for bringing together the information of several agencies and people in a single platform" (POLI UFRJ, 2018).

Fig. 9.4 Participants of the PCON platform technical meeting

4.2 Methodology for Evaluating and Spreading the Platform

4.2.1 The Process of Interactive Improvement Based on Users' Feedbacks

As a way of offering new experiences to users, PCON's navigation statistics began to be analyzed. After an initial questionnaire, users' demands were mapped and started to be investigated, taking into account their impact on the platform's use.

In the following, some cases will be illustrated to use the metrics for making the decisions about features on the platform. Each of the two user groups analyzed different variations of each experiment.

Written feedback from users (via an electronic questionnaire) and navigation metrics were analyzed together. In this way, we were able to compare the users' biases with what they did on the platform. For example, in one of the experiments, users asked for more links on publications but only checked the first 5.

To provide a broad spectrum of seasonality, each test of the experiments was performed with a minimum of 6 days. Each experiment could have a natural engagement (users who consume the platform usually) or a suggested commitment (users were invited via e-mail to access the platform). Navigation statistics were collected using the Google Analytics service in its free version.

For the following experiments, we aimed to analyze two or more alternatives that would be appropriate based on the metrics. As we needed to mitigate the effects of batch enrollment, we separated users into groups by alternating their identifiers (users with odd identifiers were located in group 1, and the others in group 2).

During that time, the navigation statistics of users on the platform will be analyzed:

- Bounce rate: “A bounce is a single-page session on your site” (Google, 2020). For PCON, this means that the user opened a unique page and then closed it. That is, the user saw no interest in the platform and, after reading about it, closed the page. Thus, a high bounce rate indicates that we need to make this content more relevant.
- Exit rate: The exit rate counts in all sessions, in how many of them the user left the platform on the page in question.

4.2.1.1 The First Step to Understanding the User

Changing the approach of an existing platform requires knowledge about its consumer. Research methods for this type of information gathering include interviews, laboratory tests, questionnaires by phone or computer, and several others. To have a result in a short cycle, we approached users already registered on the platform by e-mail with a link to a survey form. The form had five questions about frequency of use of the platform, relevant features, general suggestions, and interest in broadcasting the platform. The first form was available for two cycles (12 days).

Survey Result
Among the registered users, 23.5% responded to the form, with 96% of responses received within the 6-day cycle. 51% showed occasional interest in the platform, with periodic use by 15% of users. This 66% of users would be called as the engaged users.

In the suggestions, 35% were related to the active dissemination of content, and 15% related to more significant interaction between them.

Based on these results, it was arrived that the first collection of experiments would be related to the platform’s content. After discussing a set of ideas, the decision was to create a Library web menu (“Biblioteca”) with selected content on the knowledge tree’s topics.

While analyzing the feedback from the first survey, it is discerned that one of the most accessed pages on the platform had a high bounce rate. Analyzing the numbers, it has been seen that the “About” page had an 88.89% bounce rate and a 59.38% exit rate.

The “About” page of the Project explains the history of the Project and its idealization. After the opening paragraphs, an infographic illustrates how the platform works and offers links to other resources. It was decided to divide the page “About” in two, one about the project and the other with its history.

After dividing the “About” page, the exit rate went to 0% in the next three cycles, and the rejection rate was 0% since the first cycle.

4.2.1.2 Experiment A: List of Contents About Disasters

The initial form's results showed that users were interested in the content, something that the platform had not previously provided. Thus, the team of researchers prepared a list with ten bibliographic references on disaster issues. From this, we generated two lists, one with only the names of the papers and another with the papers and a summary.

For each list, in each variation of the experiment, a form is provided where users could offer their opinions about the content. The timeline for each change with the first list was the following:

- First cycle: List on the platform without disclosure.
- Second cycle: Dissemination to group A (users with even registration numbers) without summaries.
- Third cycle: Dissemination to group B (users with odd registration numbers) with summaries.

In the second and third cycles, an e-mail would be sent informing them that new content was available on the platform through a web menu. In the e-mail, we did not directly link the platform content because we wanted to measure whether users would be able to reach new content through the top menu. In the body of the e-mail, there was only a link to the platform's home page.

Experiment A Result

By placing the list on the platform without disclosure, we were interested in assessing whether organic traffic and search engines could take users to new content. In the first cycle, we measured that 7.20% of visits on the platform saw new material and that users stayed an average of 63 s on the page. Users accessed none of the references.

In the second cycle (group A), we found that access related to content was 15.19% of visits on the platform, while 29.73% of accesses were related to login and registration activities. In this cycle, we also had no access to reference materials. Users stayed about 2:36 min on the page with the content.

In the third cycle (group B), we found that access related to content was only 8.31% of visits on the platform, while 28.09% of accesses were related to login and registration activities. In this cycle, we had access to the first three contents of the list. Additionally, in the feedback form (answered by 15% of users who accessed the material), users would like to get a list with more references. Users stayed about 06:29 min on the page with the content.

Upon analyzing the data, it is concluded that many users attempted to log in to the platform or request a new password registration. It is believed that users thought that to access the latest content, they should be registered or logged on the platform.

A more in-depth analysis revealed that users were spending an average of 6:52 min on the registration page at the last cycle of the experiment. Analyzing the data from the previous 30 days, it is concluded that the platform's registration page required more than 4 min. During registration, many users gave up the process and left the platform.

4.2.1.3 Experiment B: Actions at the Home Page

A change was made to the home page on the platform to include a button for direct access to the Library. We also removed the login button and made the page smaller and more focused on accessing content.

To measure the impact of this change on the home page, a new content was registered in the Library web menu. This experiment intended to assess whether users would be able to access the material more quickly with the Library link at the home page. The timeline for the tests with the second list related to the home page was the following:

- First cycle: List on the platform without disclosure.
- Second cycle: Dissemination to all users with summaries.

Experiment B Result

In the first cycle (without notification to users), 11.73% of the platform's activities were related to the Library's content, while 13.57% were activities related to login and registration. There was no access to the references indicated in the lists.

In the second cycle (users notified by e-mail), 19.36% of the platform's activities were related to the Library's contents, while 21.37% of the events were related to registration and login. In this cycle, users accessed the first two items on the list.

After modifying the home page with the inclusion of the button for direct access to the Library, it can be concluded that the number of activities to access the content has grown close to the number of activities related to registration and login. It is found that the bounce rate dropped from 34.33% to 16.95% between experiments A and B.

4.2.2 Methodology for Collaborative Articulation and Dissemination

In the PCON-Desastres platform, the concept of collaborative articulation was applied. This can be understood as the establishment of the relationship between different stakeholders who, through the development of specific activities, contribute, according to their possibilities and interests, to achieve something, with a view to a determined purpose. In the specific case of the PCON-Desastres platform, the purpose, or goal, is the integration of efforts between the stakeholders interested in DRR.

When people attempt to collaboratively solve a significant problem/challenge (such as reducing the risk of disasters, increasing resilience, promoting sustainable development, or adapting to climate change) and to establish a dialogue in which actions/solutions can be shared, proposed, expanded, modified, or opposed, the knowledge co-construction process occurs. The process of "knowledge co-construction" was described by Wells (2001), who considers it an essential part of the process of learning and transformation.

PCON-Desastres enables various stakeholders, interested in participating collaboratively according to their possibilities and interests, to register and consult the information about participants, actions, resources, and the library, which in turn is related to the topic of disasters. In this process, the participants are responsible for the quality of what is produced together, as highlighted by Parrilla (1996, apud DAMIANI, 2008). In this case, the product is the set of information available on the platform. In the integration of efforts and collaboration for the knowledge co-construction process, participants also have the opportunity to establish inclusive relationships that tend not to hierarchize, aiming to achieve goals of collective interest, with the promotion of mutual learning and the exchange of good practices, information, and various resources.

In this sense, it is possible to observe that PCON-Desastres and its collaborative articulation strategies are in alignment with the Sendai Framework, which considers necessary to promote access to innovative and inclusive technological tools for DRR, as well as to the knowledge and information sharing through the collaborative participation of the various stakeholders involved.

Through the collaborative articulation facilitated by PCON-Desastres, it may be easier and faster to achieve more successfully what is desired (e.g., establishing interactions, learning, obtaining resources). Through the use of the different potentialities of registered PCON-Desastres participants and users, the knowledge built by each one and the results achieved may be increased by the interaction between them. In other words, based on the enrichment brought by the dynamic interaction of various specific pieces of knowledge and various cognitive processes in collaborative activities, it is possible, according to Roldão (2007), to achieve the intended results in a better way.

For a well-succeeded collaborative articulation, an important step is to increase the use of PCON-Desastres by the stakeholders. In other words, diffusion must be promoted. This can be understood as the action or set of actions that make it possible to make something/someone (in this case the platform and its contents), known to the public.

Among the PCON-Desastre dissemination actions carried out, there can be mentioned:

(a) Initial mobilization of stakeholders interested in the topic of disasters to participate in a technical meeting to discuss the keywords contained in the platform's knowledge tree, as described in Sect. 4.4.
(b) PCON-Desastres pilot launch in December 2019, with e-mail communication to the participants of the technical meeting held in December 2018.
(c) Dissemination to the general public, through messages broadcast on social networks and three participations in TV/radio programs.
(d) E-mail communication disclosing the platform to organized groups; higher education, research, and extension institutions; and companies, previously selected

by the curators of PCON-Desastres, who work or are interested in the topic of disasters.

(e) E-mail communication disclosing the platform to higher education institutions in low-developed countries that use the Portuguese language, aiming at facilitating joint efforts against COVID crises.
(f) Dissemination of PCON-Desastres in events such as seminars, congresses, and courses, such as SETEC RRD RIO (2019).
(g) Conducting research activities with users of PCON-Desastres.

The releases carried out through social media had a better effect on the number of website hits, but e-mail messages to technical audiences proved to be more effective for purposes of conversion into users. However, the registration of new users and the natural diffusion proved to be lower than expected, revealing dependence on dissemination campaigns and the need to deepen the articulation for network diffusion, with the participation of multiplier users. It is important to emphasize that in the survey conducted with PCON users, 92.3% of the respondents reported an interest in contributing more actively to the dissemination of PCON-Desastres, 65.4% through dissemination on social networks, and 57.7% through mobilization and support to local groups of stakeholders. In the users' suggestions, mentions were very present to improve articulation, interaction among users, and dissemination of the tool through various channels.

Among the actions foreseen for diffusion, it can be mentioned that these are the creation of a virtual environment in other languages (such as English, to carry out PCON-Desastre diffusion actions in countries that use the other languages than Portuguese), the conception of a remote open learning training course to new users, and the creation of short audiovisuals to help in the use of diverse PCON tools.

5 PCON-Desastres Main Outputs

5.1 PARTICIPANTS Web Menu

The PARTICIPANTS web menu allows the different actors who work and/or are interested in disasters to create their profiles and be found by the general public for future interaction. This registration can be done directly through PCON's home page and is divided into two parts:

- INSTITUTIONAL REGISTRATION. Institutions or organized groups (public sector, private, others) that want to join the platform must register from this form.
- PERSONAL REGISTRATION. Individuals wishing to join the platform must register from this form.

The profiles of registered individuals and institutions are available for the public and contain professional data and information on the field of work and interest, both characterized by the knowledge tree identifiers. The registrations can be changed

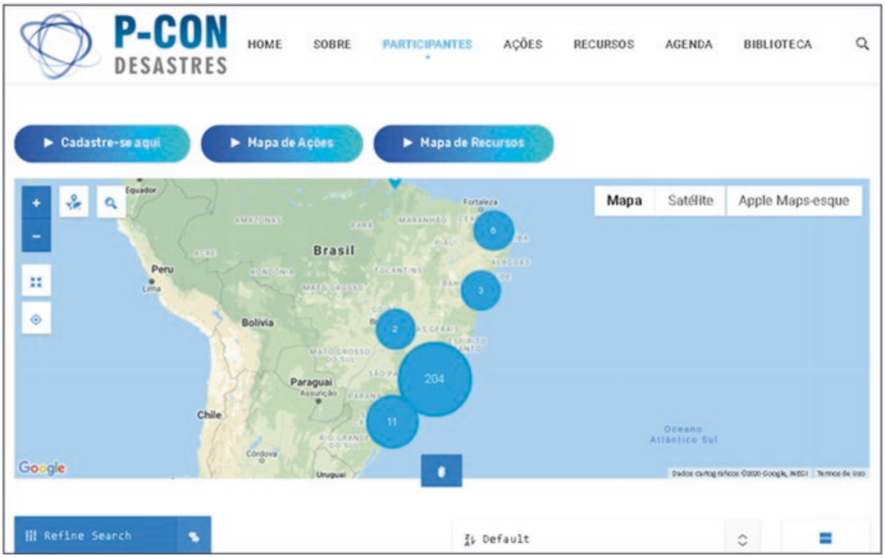

Fig. 9.5 Participants' map. (Di Gregorio et al., 2018)

through the USER's PANEL, where users have complete access and autonomy regarding their previously registered contents.

The participants' map gathers the main information about people and institutions working with disaster-related issues and enables them to locate and consult them directly on the map (Fig. 9.5). Users can also apply interactive filters.

In the survey conducted with PCON users, 94.2% of the respondents considered the functionalities of this section to be relevant, among which 63.5% considered them as VERY RELEVANT. A total of 92.3% considered the display of registered items in maps to be relevant, among which 44.2% considered this resource VERY RELEVANT. Twenty-five percent mentioned that they had heard about PCON through social networks, 25% by e-mail, and none of them through Google searches. Of the respondents 100% reported that referrals from colleagues were determinant to meet PCON.

5.2 ACTIONS Web Menu

The ACTIONS web menu allows registering actions related to emergency response, reconstruction, recovery, disaster preparedness, prevention and mitigation, projects, technical studies, engineering works, field visits, media communications, courses, lectures, congresses and the like, defenses or presentations of academic work, workshops, technical meetings, community activities, and other actions taken by the different stakeholders who work with disasters (Di Gregorio et al., 2018).

In addition to being an opportunity to publicize the work of each participant (PCON users), this tool aims to encourage the exchange of experience between the actors and also provide an overview of the set of actions for disaster risk reduction (DRR). It is divided into two parts: ACTIONS REGISTRATION and ACTIONS MAP.

The ACTIONS REGISTRATION is made by those responsible for the actions, seeking to classify them according to the tree of knowledge terms. The registered profiles are available to the public and contain general information about the actions (title, description, target audience, image, place of performance, team, others), as well as contact details. The participant who registered the action can change the registration anytime through an editing feature contained in the USER's PANEL.

The ACTIONS MAP displays the main information about projects, practices, courses, and other actions registered in matters related to disasters. The user can make queries directly on the map or through interactive filters. When registering, the address must be recognized by Google Maps for the action to be displayed on the map. This functionality allows users to view and consult (passing the cursor over the indication on the map) the actions registered in a given region of interest (Figs. 9.6 and 9.7).

An interesting aspect is that, by registering the period of a given action in PCON-Desastres, it is also possible to consult the action in the collective schedule available on the platform (AGENDA web menu).

In the survey conducted with PCON users, 96.2% of the respondents considered the functionalities of this menu to be relevant, among which 75% considered VERY RELEVANT. The same percentage was repeated regarding the availability of actions in the form of a collective schedule for the community of those interested in disasters. A total of 92.3% considered it relevant that the registered items are presented in the form of maps, among which 44.2% considered this resource VERY RELEVANT. Despite the interest in this functionality, the registered actions in the

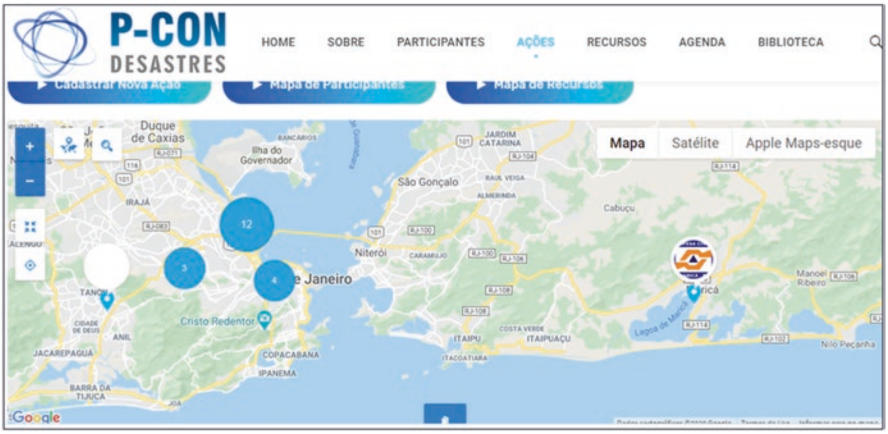

Fig. 9.6 PCON-Desastres actions map. (Di Gregorio et al., 2018)

Fig. 9.7 Actions registered at PCON-Desastres. (Di Gregorio et al., 2018)

platform are still scarce, pointing to the need for further clarification on the potential use of this menu, as well as the dissemination of the platform to the public.

5.3 RESOURCES Web Menu

The RESOURCES web menu allows the registering of materials, human resources, equipment, and other resources that are being OFFERED or DEMANDED by PCON-Desastre users (Fig. 9.8), aiming at facilitating the exchange of resources between users.

This innovative tool acts as a kind of "disaster resources catalog" and allows, in the case of emergencies, those responsible for disaster management to request various resources (e.g., essential items), as well as volunteers to make their work available to act in critical situations. The tool also allows registering missing people and animals, aiming at contributing to the process of finding missing persons in disaster situations (Di Gregorio et al., 2018).

The resources that are no longer being demanded/offered must be deleted from the platform by those who registered them, to avoid mistakes and waste of time by those involved.

The RESOURCES web menu is divided into two parts: RESOURCES REGISTRATION and RESOURCES MAP, presented below:

Fig. 9.8 Volunteer services, equipment, and donations registered at PCON-Desastres. (Di Gregorio et al., 2018)

- RESOURCES REGISTRATION. Those responsible must register here the OFFERED or DEMANDED resources (missing persons, missing animals, machines/equipment, software, services, volunteer work, physical facilities, vehicles, furniture, building materials, items of first necessity, others), providing the maximum details. You can also change the registrations made through the USER's PANEL, located in the upper right corner of the screen.
- RESOURCES MAP. The resources map brings important information about materials, human resources, equipment, and other resources that are being demanded or offered by PCON-Desastres users. The user can make queries directly on the map or through interactive filters.

In the survey conducted with PCON users, 92.3% considered the functionalities of this menu relevant, among which 46.2% considered VERY RELEVANT. In terms of the possibility of registering and searching for missing persons/animals, 80.8% considered this option relevant, and only 23.1% considered it VERY RELEVANT. A total of 92.3% considered it relevant that the registered items be presented in the form of maps, among which 44.2% considered this VERY RELEVANT resource. The results point out that it is necessary to further clarify to users the potential of using the RESOURCES menu and that the functionality of searching for missing persons/animals should be better assessed.

5.4 LIBRARY Web Menu

The LIBRARY web menu presents several contents related to disaster topics. The themes are pre-selected by the PCON-Desastres curators and organized preferably in the form of thematic lists. The LIBRARY menu presents brief descriptions of suggested/indicated references as well as the electronic address to access them (Di Gregorio et al., 2018).

In general, whenever a new list of contents in the Library web menu is drawn up, PCON-Desastre curators send an e-mail to the platform's participants, informing them of the new list made available.

As an example of contents available in the LIBRARY web menu, one can cite the collection on issues considered basic in the area of disasters, entitled (available at https://www.pcon-desastres.poli.ufrj.br/top-10-o-basico-sobre-desastres/), and the collection related to mass movements (available at https://www.pcon-desastres.poli.ufrj.br/top-10-movimentos-de-massa/). Each list has ten items considered relevant to the covered topic.

It is important to highlight that regarding the items suggested/made available in the thematic lists, copyright issues were considered according to the 1998 Federal Law 9610 (Brasil, 1998). For this reason, it was decided to make available only the web links for contents externally hosted, instead of the direct content sharing.

In the LIBRARY web menu, it is also possible for users to express their opinion about the platform by filling out the available questionnaire. There is also the possibility of suggesting themes for the elaboration of new lists on this web menu.

In the survey conducted with PCON users about the registered content lists in the LIBRARY web menu, 75% of the respondents considered the contents VERY RELEVANT, while 25% considered them moderately relevant. Among the respondents 100% thought that a brief description of the contents is useful to the user. Regarding the number of items in the lists (currently with 10 items per list), 75% of the respondents pointed out that the ideal number of items would be 15, while for 25% the adequate number of items per list would only be 5. Despite these results that point to high interest, it was verified by the access statistics that the lists were very little accessed in the weeks following disclosure, indicating that the user's interest in this feature probably refers to medium-long-term behavior.

5.5 Knowledge Tree

Based on the previous research and the results of the technical meeting described in Sect. 4.4, the knowledge tree was revised and is currently composed of 27 types of disasters, 19 general identifiers, and 30 specific identifiers (Table 9.3). In case the PCON administrators deem necessary, new items may be added, such as the recent inclusion of the tag "COVID-19," in March 2020.

Table 9.3 Identifier sets of the knowledge tree

Types of disasters	General identifiers	Specific identifiers
Change in quality/contamination of water/soil/air	Administration and public finances	Emergency and/or temporary shelters
Sea advance	Supervision and control	Medical and psychological assistance
Building collapse	Environmental management	Social assistance and humanitarian logistics
Infrastructure collapse (bridges/tunnels/supply networks/others)	Risk management	Training and capacity building
COVID-19 (coronavirus)	Knowledge management	Resilient cities
Power supply crisis	Standard	Risk communication
Desertification	Standards/legislation and protocols	Damages and other impacts
Deforestation (deforestation)	Public policies and governance	Imbalance/impacts on flora/fauna
Volcanic activity	Disaster preparedness and response	Education
Flash flood	Prevention and mitigation	Equipment/instruments/materials and other technologies
Epidemic and other public health emergencies	Reconstruction and recovery	Environmental impact study/report (EIA/RIMA)
Erosion (coastal/fluvial and continental)	Resilience	Extreme events
Radiation	Risk	Geoprocessing
Water shortage	Remote sensing	Emergency management
Wildfire (forest and urban)	Computerized systems	Waste management
Biological infestation/plague	Susceptibility and hazard	Inventory/history of disasters
Flooding	Sustainability	Reports and expertise
Release/spill/contamination of dangerous product	Land use and occupation	Mapping and cartography
Mass movement (landslides/flow/others)	Vulnerability	Physical phenomena/mechanisms associated with disasters
Dam failure		Modeling (numerical/physical/other)
Drought/dry season		Monitoring/weather warnings and disaster alerts.
Extreme temperature (cold or heat)		Climate change.
Storms (heavy rain/hail/lightning)		Nutrition and food safety
Earthquake		Historical and/or cultural heritage
Tsunami		Urban planning and urbanization
Tornado		Contingency plan
Coastal winds/wave action and/or cold fronts		Evacuation/escape plan
		Risk reduction/prevention plan.
		Projects and engineering works.
		Insurance

5.6 Lessons Learned

The lessons learned include aspects related to the importance of (i) adapting and improving PCON to make it increasingly functional, safe, and attractive to users; (ii) communicating well and spreading PCON widely; (iii) mobilizing and motivating users to articulate and collaborate; and (iv) having a PCON team capable of carrying out activities related to the previous items and being aware of other issues that may be relevant (e.g., financial security and copyright). Part of the lessons learned will be described below.

The disaster knowledge platform, PCON-Desastres, is easy to use, a free and inclusive tool that addresses an important and attractive topic for many stakeholders, organized groups, and public and private institutions, and is aligned with the guiding principles of the Sendai Framework and the Brazilian PNPDEC. However, although it has the potential to integrate and connect the various stakeholders to stimulate collaborative articulations on the platform and outside of it for the DRR, it was realized that the theme DISASTERS, although attractive, may not be enough to mobilize the various actors and encourage them to participate collaboratively, since mobilizing and communicating are not simple tasks. In this sense, it was observed that the actions for PCON dissemination, which include communication and mobilization, through clear and participatory strategies are very relevant and represent a current and future challenge for PCON.

Another aspect observed is that, although PCON-Desastres is a simple tool to be used, users do not necessarily have the available time or the will to use/explore the different functionalities available at the platform. These tools can be very useful, such as the possibility of consulting content through thematic maps, schedule, and interactive filters, as well as the possibility of using the links of registered items (participants, actions, resources, and library) as a bibliographic reference in citations of technical texts or shares in social networks.

In this way, mechanisms were also devised to enable users to be motivated to know the potential of PCON-Desastres and increase the frequency of its use. This has been done through modifications, in the platform interface itself, based on queries and tests carried out with users, making it more attractive and friendly. It is important to highlight that a good part of these activities is carried out by the volunteer PCON team. But PCON still requires additional improvements, including those that make it more friendly and functional for use in other mobiles, such as cell phones and tablets. There are also necessary modifications that make certain resources run faster, such as the consultation through thematic maps, which can be slow depending on the equipment and Internet connection available. In actions to disseminate PCON, the divulgation of successful interaction cases, the inclusion of other languages on the platform, and the adoption of audio description tools for people with low vision are also desirable, as well as the production and dissemination of audiovisuals that make it possible to explain the main PCON functionalities.

It is also important to highlight the need to consider the current legislation in Brazil on copyright concerning the contents made available on PCON, according to the 1998 Federal Law 9610 (Brasil, 1998), in the strategy adopted for the LIBRARY web menu and other web menus.

Finally, it is worth emphasizing the importance and needs for financial resources for the dissemination of PCON, bearing in mind the social significance of the continuity and expansion of the platform's offer to the entire society.

6 Conclusions

The practice of collaboration and integration in disaster risk management is a great challenge.

The Disaster Knowledge Platform is a Brazilian initiative developed to contribute to the integration between the various stakeholders that work on disaster risk management issues. This web tool allows the registration and search of participants (people and institutions), the dissemination of actions and research works developed, the announcement of resources offered or demanded among the stakeholders of the disaster community, as well as the dissemination of content related to the theme.

The construction and implementation processes of PCON-Desastres are developed in a participatory and multidisciplinary way, seeking alignment with the Sendai Framework and with the users' feedbacks. Comments from users and the people who attended the technical scientific events in which the platform was presented corroborate with the expectation that the tool has a high potential to contribute to improving the interactions between the various stakeholders and their collaborative work.

PCON-Desastres platform is focused on the interaction between people and/or institutions without limit of spatial scale. However, special applicability to risk management at the municipal or community level must be highlighted. In this case, specific incentives for the use of the tool at the local level would contribute greatly to overcome the obstacle to integration and collaboration of the various stakeholders, including groups commonly excluded or marginalized.

Despite the user-friendly nature of the tool, training and educational work are important to enhance the Project, not only by increasing the number of participants in the platform but mainly by intensifying the practice of collaborative actions. Therefore, partnerships with municipal risk management agencies and community groups are desirable, as well as an approach by formal and non-formal disaster education, which has proven necessary for the development of a culture of risk reduction (Mendonça and Valois, 2017; Marchezini et al., 2019).

Due to the flexible nature of PCON content, recurrent updates are foreseen when it is necessary to adapt to new demands or approaches in this area resulting from scientific advances or practical experiences in risk management.

It is hoped that this experience report may contribute to the strengthening of collaborative actions for disaster risk reduction, especially in developing countries, as well as to inspire the creation of other Disaster Knowledge Platforms, worldwide.

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Part III
Environmental Hazards and Assessment

Chapter 10
Development of an Earthquake-Induced Landslide Hazard Assessment

Saeid Eslamian and Mousa Maleki

Abstract Landslides have attracted researchers' attention because they are one of the threats to human lives. As landslides cause a lot of damage to forests and their growth, agricultural lands, power and gas transmission lines, mines, engineering structures, and buildings, they create big problems from an economic point of view. Accordingly, landslides have been identified by the United Nations as one of the most important natural disasters of the present decade. Therefore, by recognizing the factors, characteristics, and conditions of landslides, it is possible to achieve methods to prevent the risks and damages caused by their spread. The best possible action in this regard is to prepare a landslide hazard zoning map at national, regional, and local scales so that they can be used to identify sensitive areas and prevent many damages before any accident occurs. In this chapter, landslide hazard assessment methods are introduced, including (1) analytical network process (ANP) method, (2) logistic regression (LR) method, and (3) probabilistic hazard assessment (PHA) method.

Keywords Landslide · Hazard assessment · Analytical network process · Logistic regression · Probabilistic hazard assessment

1 Introduction

Landslides lead to some soil damage patterns, which are often among the most destructive. In fact, the impact of landslides has sometimes outweighed the direct damage caused by severe tremors and fault ruptures (Bojadjieva et al., 2018). The

S. Eslamian (✉)
Department of Water Engineering, College of Agriculture, Isfahan University of Technology, Isfahan, Iran

Center of Excellence in Risk Management and Natural Hazards, Isfahan University of Technology, Isfahan, Iran

M. Maleki
Islamic Azad University, Isfahan, Iran

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Fig 10.1 A large landslide temporarily blocked a river following the 1999 Chi-Chi earthquake in Taiwan. (UC Davis – https://research.engineering.ucdavis.edu/gpa/landslides/earthquake-induced-landslides/)

mechanism of deformation and failure seen in a landslide are usually studied by three approaches: physical model experiments (Askarinejad et al., 2018; Song et al., 2018; Lin et al., 2015; Li & Cheng, 2015), monitoring field survey (Doi et al., 2019; Fu et al., 2011; Qi et al., 2011; Tang et al., 2019), and numerical models. A simple form of landslide is shown in Fig. 10.1.

Besides developments in computing technology, numerical simulation has simultaneously become a powerful and effective tool for analyzing the movement processes of landslides. Generally, numerical simulation methods can be divided into two categories: continuum element methods and discrete element methods. Zhang et al. (2015) evaluated the reactivation mechanism of ancient landslides in Southwest China through FEM and distinguished a critical trigger factor of landslide is disturbance caused by engineering construction. To reach stability analysis of a complex soil-rock mixture landslide, based on the microtremor survey method and strength reduction method, Gao et al. (2018) used FEM to simulate the characteristics of failure.

Natural hazards, as recurring and destructive phenomena, have always existed during the life of the planet and have been a serious danger to humans since the creation of mankind. Earthquakes and landslides are the most important natural hazards that have a very significant coexistence and correlation of time and space with each other. Earthquakes are considered as the main cause of many movements of masses of the earth's constituents such as landslides, rock falls, avalanches, and flows. Landslides seriously endanger human life by destroying their environment, resources, and assets. Financial and human losses are associated with the destruction of facilities and increased costs. Human settlements, especially rural habitats, are sometimes exposed to vulnerability due to algebraic settlement in beds with natural hazardous infrastructure such as fault activity and resulting vibrations. Landslides have a huge impact on the economy on a local and global scale, and thousands of people around the world lose their lives every year due to landslides. Spatial relationships between landslide occurrence zone and environmental factors are key elements in landslide sensitivity. Landslide zoning risk zoning includes dividing the land surface into separate areas and ranking these areas based on the actual degree or capability of landslide hazards on slope slopes. Assessing the sensitivity and risk of landslides is the most important step in preparing a landslide map. Therefore, understanding the mechanism and zoning of landslide-prone areas plays an important role in crisis management.

In general, the existing researches related to landslide risk assessment in terms of methodological approach can be classified into three dominant groups: quantitative, qualitative, and artificial intelligence (AI) attitude. Qualitative attitudes are based on the mental judgments of one or a group of experts, while quantitative attitudes are based on strict mathematical rules regardless of any personal bias. Artificial intelligence techniques can use subjective knowledge or pattern matching techniques to solve a set of mathematical equations. Artificial intelligence techniques extensively cover artificial neural network (ANN), expert systems, and other basic knowledge and basic law techniques. According to the aforementioned research, to prepare for a landslide, sensitivity map can be prepared by using models such as logistic regression (LR), hierarchical analysis process (AHP), network analysis process (Analytical Network Process (ANP)), artificial neural network, a variety of statistical bivariate models, Landslides Nominal Risk Factor (LNRF) model, logic model fuzzy, and so on.

Specialists in tectonic geomorphology, especially the branch of hazards, should consider the preliminary risk analysis (PHA) as the first step in system safety analysis and classification of potential process and functional hazards of subsystems and based on risk assessment and documentation of hazards of base systems. New or modified through the analysis and evaluation of a group of general risks under the influence of the system operator and provide suggestions for monitoring risks (Vincoli, 2006).

2 Earthquake-Induced Landslide Hazard Assessment Methods

2.1 Analytical Network Process (ANP) Method

In this method, the risk of landslides affecting the vulnerability of settlements and lands, especially after an earthquake, is assessed and zoned. In general, the purpose of such a study is to zoning of stable and unstable seismic zones (principle of better prevention than treatment) which can have favorable effects in reducing vulnerability resulting from appropriate environmental and urban planning. Therefore, this method uses quantitative analysis of elements affecting the occurrence of slope hazards using network analysis process and comparing it with logistic regression model to quantitatively analyze stable and unstable areas in the earthquake-affected area.

This method is part of descriptive-analytical research with a comparative approach. In order to implement the model and prepare a landslide sensitivity map, collecting and preparing a database of effective factors in the occurrence of landslides are one of the most important stages of research. For this purpose, first, the desired area is determined by considering the form and hazardous processes and emphasizing the area affected by the earthquake. Then using 14 parameters (altitude, climate, precipitation, slope direction, soil, topographic humidity (TWI), geology, slope, slope length (LS), distance from waterway, distance from road, distance from fault, waterway strength SPI), landslide zoning is performed. In the first step, with the help of topographic maps, the area elevation model (DEM) layer with the appropriate pixel size is prepared, having this layer using different operators in the GIS package, layers such as slope, slope direction, and drainage network that will be extracted at a distance from the river used in the model.

Investigation of factors affecting the occurrence of landslides in an area is one of the basic cases for landslide hazard zoning. Zoning using the best factors is more accurate, and the result of zoning will be appropriate and useful. If the factors are correctly identified, it is easier to evaluate and analyze each of them, and they can be affected in terms of impact.

The first step is to identify and delimit the study area, which in line with the overall purpose of analyzing the role of tectonic behavior of the fault zone in creating geomorphic hazards, the area affected by the earthquake with appropriate intensity is selected; since the effective factor in the studied landslides is defined as a predetermined hypothesis of the earthquake factor, in order to verify the hypothesis, it is necessary to compare each identified landslide zone with aerial images before the earthquake. Then, in order to increase the reliability, locals and indigenous people through interviews question and classify the time period of the landslide before and after the earthquake and, in case of conflict, base the judgment on field observations and the existence of parameters such as freshness, slip wounds, lack or lack of vegetation, and so on.

2.2 Logistic Regression (LR) Method

One of the statistical methods is predictive for dependent variables that have zeros and ones with occurrence and nonoccurrence. In this method, the regression relationship of the variables is not linear but in the form of an S-shaped curve or logistics. In this model, estimates and estimates are in the range of zero to one, where numbers close to zero indicate a lower probability of occurrence and numbers close to one indicate a higher probability of occurrence. Landslide location in the combined landslide database using LR method and global-scale landslide susceptibility

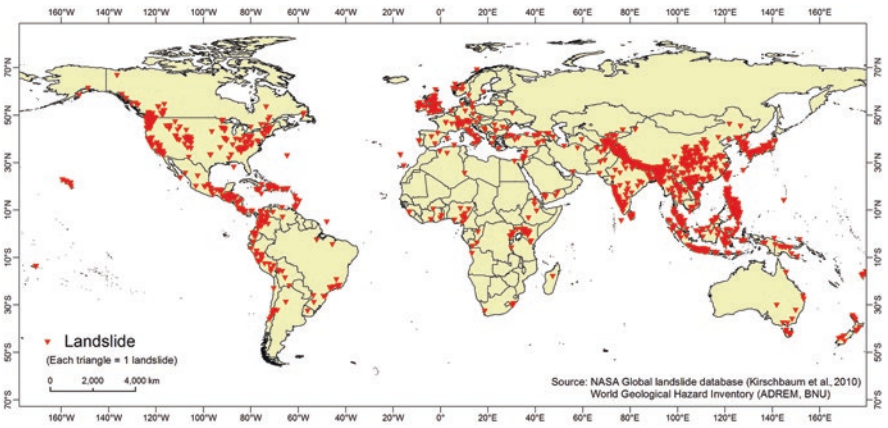

Fig. 10.2 Landslide location in the combined landslide database. (Lin et al., 2017)

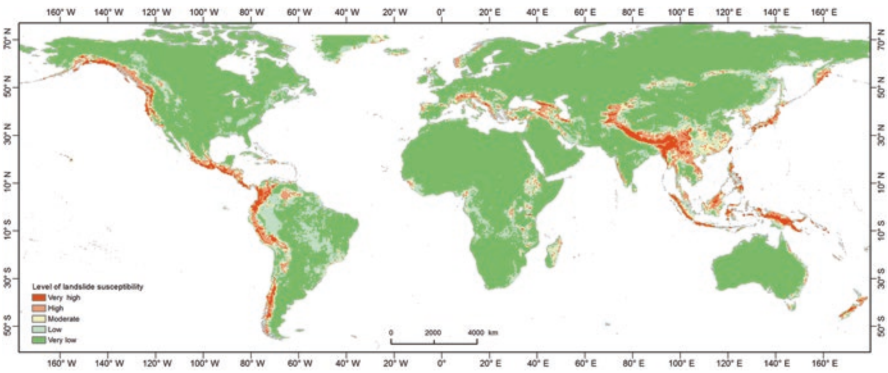

Fig. 10.3 Global-scale landslide susceptibility map. (Lin et al., 2017)

map are shown in Figs. 10.2 and 10.3. In logistic regression, the dependent variable is expressed using Eq. 10.1:

$$Y = \text{Logit}(P) = \ln\left(\frac{p}{1} - p\right) = C_0 + C_1X_1 + C_2X_2 + \ldots = C_nX_n \qquad (10.1)$$

Logit = The logit function is the quantile function associated with the standard logistic distribution.
$\boldsymbol{p}$ = Probability of dependent variable
$\boldsymbol{C_0}$ = Constant value
($\boldsymbol{C_1, C_n}$)=Coefficients that show the partnership of independent factors for variable Y
($\boldsymbol{X_1, X_n}$)=Variables of independents

For logistic regression method, the peripheral software is used to prepare the mapping map of the earthquake; the following steps should be performed:

2.2.1 Investigating the Effective Factors in the Earthquake

In order to investigate the potential of earthquake occurrence of eight gradients, directions for domain, lithology, land use, elevation classes, distance from the fault, distance from the river, distance from the road as factors and factors effective in the occurrence of landslide region. Whose preparation procedures are summarized:

Preparation of the effective factors in the occurrence of landslide region as different layers of information in the GIS environment and the transfer to the permanent software that includes:

1. Provide river layers, fault, and road through topographic map of 1/25000 and create distance maps of the parameters used by the distance function.
2. Create slope maps and directions of DEM (altitude digital model).
3. Preparation of land use map based on unexplored classification landsat satellite image.
4. Preparation of lithology map.
5. Convert landing data of the region using landsat satellite images and also Google Earth to slip zones.
6. Adaptation of information layers with map of the landslide area and calculation of their density per unit area.
7. Perform logistic regression model using Idris software.

Table 10.1 presents the effective factors in landslide susceptibility assessment for both regional and global scales.

2.2.2 Model Evaluation

2.2.2.1 Chi-square Test

Test is a valid and conventional test for logistic regression from the difference between −2ln (L) for the best fit and −2ln (L0) model for the zero hypothesis. If this statistic is 95%, chi-square > 14.1 is zero hypothesis (H0).

2.2.2.2 ROC Test

ROC curve is one of the most useful and efficient methods in providing definition characteristics, probabilistic identification, and prediction of systems that estimate the accuracy of the model quantitatively.

2.3 Probabilistic Seismic Assessment of Landslides

Probabilistic investigations in the area of seismic landslide hazard assessment are often based on an uncertainty evaluation of geological, geotechnical, geomorphological, and seismological parameters. But, realistic situations are very complex,

Table 10.1 A summary of explanatory factors in landslide susceptibility assessment for regional scale and global scale

Factors	Geographic scale of study	
	Regional	Global
Topography	Slope gradient, slope aspect, elevation, plan curvatures, profile curvatures, slope morphology, standard deviation of slope gradient	Median, minimum, and maximum slope values from DEM, topography index, slope angle, elevation
Geology	Lithology, density of geological boundaries, distance to geological boundaries, weathering depth, tectonic uplift, geological age	Lithology
Hydrology	Proximity to drainage lines, water conditions, drainage density, distance from river, stream power index (SPI)	Drainage density
Soil	Texture, material, soil thickness, topographic wetness Index (TWI), soil type, soil moisture	Material strength, soil wetness, soil moisture, soil type, soil texture
Precipitation	Rainfall, total monthly precipitation, annual precipitation	Precipitation rates from rainfall accumulations in the past, extreme monthly rainfall with 100 years return period
Land cover	Vegetation cover, age, diameter and density of timber for vegetation, land use/cover, road construction	Land use and land cover
Ground motion	Peak ground acceleration, earthquake, and seismic shaking	Peak ground acceleration and peak ground velocity

Lin et al. (2017)

and thus uncertainties of some parameters such as critical displacement and water content are hard to describe with accurate mathematical models. In this research, a probabilistic procedure based on the probabilistic seismic hazard analysis method and the Newmark's displacement model is presented (Wang et al., 2020). Practical laboratory based models and field works of earthquake-induced landslides have shown that, for a unique slope, adequate information about ground motion, geometrical features of the slope, and the physical and mechanical properties of the class of soil, Newmark's cumulative displacement model can fairly predict the slope displacement (Newmark, 1965; Wilson & Keefer, 1983; Rathje & Bray, 2000; Pradel et al., 2005; Wartman et al., 2005; Jibson, 2011). Nevertheless, at spatial scales, uncertainties about the recurrence interval of earthquakes mean that it is hard to obtain the accurate predictions of displacement associated with potential future earthquake-induced landslides. Hence, hazards associated with potential earthquake-induced landslides can be described as probabilities, following a two-step approach: (1) probabilistic seismic hazard analysis methods (Cornell, 1968) are used to obtain the ground motion distribution parameters at any arbitrary site in the research area; (2) these results are combined with Newmark's model to analyze the probabilities of earthquake-induced landslides under different ground motion conditions.

2.3.1 Probabilistic Hazard Assessment (PHA) Method

The method of probabilistic seismic hazard analysis suggested by Cornell (1968) introduces earthquakes as random events. Potential temporal earthquakes and ground motion parameters are considered random variables or cycles; spatial patterns of earthquake propagation are modeled by an attenuation relationship. Connected with this viewpoint, probabilistic seismic hazard assessment analyses are improved by further considering the temporal and spatial heterogeneity of earthquakes (Gao, 1986; Gao, 1988; Wu et al., 2011). Plus, seismic ground motions are also significantly influenced by variables such as focal mechanism and local site conditions. With the help of empirical models considering the effects of these variables, such as attenuation relationships and topographic effects models for seismic ground motions, it gives an improved way of estimating ground motion parameters for seismic landslide.

2.3.2 Probable Earthquake-Induced Landslide Hazard Assessment

Fundamental methods and concepts of probable earthquake-induced landslide hazard are mentioned below. First of all, the critical acceleration (a_c) of the sliding block is determined using pseudo-static methods. Critical acceleration of a specific slope refers to the minimum earthquake-induced acceleration at which the downward sliding force of a block equals the frictional force (i.e., the limit equilibrium state under seismic loading). It could be indirectly derived by comparing the stress state of the block under static and seismic dynamic conditions and using the infinite slope method to calculate the safety factor Fs (Wilson & Keefer, 1983; Jibson et al., 2000):

$$a_c = \left(F_s - 1\right) g \sin\theta \qquad (10.2)$$

$$F_s = \frac{c}{\gamma t \sin\theta} + \frac{\tan\phi}{\tan\theta} - \frac{m y_w \tan\phi}{\gamma \tan\theta} \qquad (10.3)$$

where Fs is the static safety factor; c, φ, γ are the cohesion force (MPa), angle of internal friction (°), and unit weight (kN·m-3) of soil and rocks, respectively; θ is the slope gradient (°); t is the thickness of the potential sliding block (m); γw is the unit weight of water (kN·m-3); and m is the proportion of the slab thickness that is saturated. While the critical acceleration is exceeded, the difference between earthquake acceleration and a_c is integrated twice to compute the cumulative displacement of the block with respect to time (Jibson, 1993). With regard to the statistical evaluation of large data packages of ground motion measurement records, the cumulative displacement Dn of the block can be considered as a random variable that follows a lognormal distribution with a standard deviation σ (Ambraseys & Menu, 1988; Jibson, 2007; Saygili & Rathje, 2008; Xu et al., 2012). However, the average value $E(D_n)$ can be described as the empirical function of the critical acceleration ac and the ground motion parameter x:

$$E\left(D_n\right) = f\left(a_c, x\right) \tag{10.4}$$

$$P\left(slide|x\right) = P\left(D_n \geq 5\,cm|x, a_c\right) \tag{10.5}$$

where, Dn is Newmark's cumulative displacement under critical acceleration and ground motion parameter x. Briefly, spatial quantitative evaluation of probable earthquake-induced landslide hazard can be done by combining probabilistic seismic hazard analyses (Wu et al., 2011) and Newmark's cumulative displacement model (Jibson et al., 2000; Jibson, 2007; Godt et al., 2008; Wang et al., 2013). From the viewpoint of empirical probabilities used in earthquake disaster prevention and mitigation, probable seismic landslide hazard assessment is implemented based on regular, mid-frequent, and low-frequent earthquakes, corresponding to Arias Intensity with a probability of exceedance of 63%, 10%, and 2% in a 50-year period (Wang et al., 2020).

3 Conclusions

The studies show that the frequency of landslides increases with proximity to faults and the epicenter of the earthquake and by moving away from the surface of the fault and the surface epicenter of the earthquake; their frequency decreases exponentially. Approximately 20% of the studied landslides have a simple type of activity in which the rupture level is flat, the displaced materials are transient, and the level of rupture depends on the geological structure of the area.

Landslide hazard zoning is one of the most important stages of risk management, especially in geomorphological hazard science, and one of the necessities of land management and natural resource management, and this is even more important in seismic areas because earthquake shocks, along with other causes, increases the potential for sloping movements, creates a kind of synergy, and provides the basis for future instabilities.

Because the ANP method deals systematically with dependencies, that is, it considers all external and internal dependencies between elements and clusters for analysis, but other methods consider these relationships less. Therefore, as the results of previous studies emphasize the preference of logistic regression method, using these methods together and comparing them according to the dependencies of landslide problems to identify landslide-prone areas can be very useful. As mentioned, these methods have had acceptable results in landslide sensitivity analysis.

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Chapter 11
Typha Latifolia as a Tool for Biomonitoring of Hazardous Domestic Effluents

Nedjma Mamine, Fadila Khaldi, and Nedjoud Grara

Abstract Domestic liquid effluents, in the absence of treatment, constitute a risk to human health and represent a significant contribution to the general contamination of the environment, particularly aquatic environments. The most frequently encountered contaminants are detergents, pathogenic microorganisms, metals, organohalogen compounds, and drug residues. This work aims to study the fate evaluated the impact of raw wastewater from the Hannancha commune of the city of Souk Ahras (Northeast Algeria) and their effects on biochemical parameters and biomarkers antioxidant in the halophyte *Typha latifolia*, considered as a purifying organism, bioaccumulator and bioindicator of pollution. The experimental device is composed of four trays with a capacity of 40 L planted with young stems of *Typha latifolia* (with a density of eight plants/m^2). The first, second, and third planted basins are kept for a treatment period of 7 days, 14 days, and 21 days, respectively. However, the fourth planted tray is taken as a control. The systems are fed with raw wastewater from the river of Medjerda. The evolution of chemical pollution translated by the presence of toxic heavy metals such as iron (Fe), copper (Cu), cobalt (Co), aluminum (Al), cadmium (Cd), chromium (Cr), and zinc (Zn) with average contents varies from 0.001 to 0.78 $mg.l^{-1}$. The study of the toxicity of these pollutants on the aquatic plant of the *Typha latifolia* species under the effect of different residence times (7, 4, and 21 days) allowed a significant increase in total sugars, glutathione (GSH), and malondialdehyde (MDA) to be observed in the organ studied (leaf). These results would testify to the initial biological response to the xenobiotics in the environment.

N. Mamine (✉)
Department of Biology, Laboratory of Aquatic and Terrestrial Ecosystems, Faculty of Life and Natural Science, Mohamed-Cherif Messaadia University, Souk Ahras, Algeria

F. Khaldi
Mohamed Cherif Messaadia University of Souk-Ahras, Laboratory of Sciences and Technology of Water and Environment, Souk Ahras, Algeria

N. Grara
Université 8 Mai 1945 Guelma, Faculté des Sciences de la Nature et de la Vie et Sciences de la Terre et de l'Univers, Guelma, Algeria

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1 Introduction

Today, demographic, economic, and urban increases are the source of various sources of environmental pollution, especially in developing countries that are less concerned and less aware of health risks (Fagrouch et al., 2011; Grara et al., 2017; Njuguna et al., 2019; Mamine et al., 2020). All countries have taken various initiatives to establish STPs for the treatment of sewage in urban areas (Rana & Maiti, 2018); however, they are not efficient in removing metals from the sewage (Rai et al., 2015). Among these sources of pollution, the production of domestic wastewater that is often discharged into the aquatic environment without prior treatment and affected by the degradation of water quality (Mamine et al., 2020) deserves special attention because it is seriously altered and seriously threatened by human activities. According to the WHO, 80% of the diseases affecting the world's population are linked to water pollution (WHO, 1989).

Indeed, wastewater domestic is composed of high concentrations of des microorganisms pathogens and biogenic compounds, especially nitrogen (N) and phosphorus (P) and organic matter (OM) (Fagrouch et al., 2011; Grara et al., 2017; Mamine et al., 2020). However, it also contains heavy metals, including those classified as toxic, i.e., mercury (Hg), chromium (Cr), lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu), and zinc (Zn) (Xiong & Wang, 2005; Sharma et al., 2016), which are considered the most hazardous (Liu et al., 2020). Heavy metals present in the wastewater can pose both health risks and environmental, which is associated with its ability to bioaccumulate in the food chain (Das & Maiti, 2007). Ecotoxicology faces the challenge of assessing and predicting the effects of an increasing number of chemical stressors on aquatic species and ecosystems. Herein we review currently applied tools in ecological risk assessment, combining information on exposure with expected biological effects or environmental water quality standards; currently applied effect-based tools are presented based on whether exposure occurs in a controlled laboratory environment or in the field (Connon et al., 2012). All these variables must be integrated and some indexes have been applied to do it. Varieties of methods have been developed for the risk assessment of heavy metals as a sediment enrichment factor, index of the geological accumulation, and pollution load index (Zhai et al., 2015). Chemical toxicity, drought, extreme temperatures, salinity, and oxidative stress are abiotic stresses, and they are a menace to field production and the nature of the environment (Khaldi et al., 2019; Rahali-Osmane et al., 2020). Toxic environmental conditions cause a major hazard in crops and affect plant growth (Banjoko & Eslamian, 2015). Morphological, physiological, biochemical, and molecular changes adversely cause a loss in productivity worldwide (Sharma et al., 2019).

The use of aquatic plant communities for the treatment of several types of effluents has been successfully exploited by domestic effluent (Mamine et al., 2019), dairy industry wastewater (Schwantes et al., 2019), and tannery effluent (Augustynowicz et al., 2020). However, the exposure of purifying plants to these pollutants leads to changes in cell homeostasis through the overproduction of reactive oxygen species (ROS) (Nahar et al., 2017; Khaldi et al., 2019) such as hydrogen peroxide (H_2O_2) and hydroxyl radicals (^{-}OH), which are highly reactive molecules with high oxidizing potential and have the property of attacking and altering the molecular components of the cell (Krayem et al., 2018). In response to these constraints, plants have developed very complex antioxidant defense systems against oxidative stress to prevent or limit cell damage (Yan et al., 2019). The aquatic purifying plants tested are both free or floating such as *Lemna* (Grara et al., 2017) and *Eichhornia* and rooted or halophytic such as *Juncus*, *Phragmites*, and *Typha* (Peng et al., 2018; Khaldi et al., 2019).

The aim of this study is to elucidate the effects of oxidative stress induced by different pollutants found in the raw sewage of the municipality of Hannancha in the city of Souk Ahras, Northeast Algeria, on the helophyte *Typha latifolia* by studying biochemical parameters and nonenzymatic biomarkers.

2 Materials and Methods

2.1 Biological Material

The organs chosen to carry out this study are the leaves of the cattail macrophyte plant of the species: *Typha latifolia* (order, Typhales; family, Typhaceae) (Bergner & Jensen, 1989) is the most common in the region of Souk Ahras, Northeast Algeria. This area from which the samples of *Typha latifolia* were obtained is shown in Fig. 11.1.

2.2 The Study Area and Raw Sewage Sampling

This study is carried out in the extreme east of Algeria in the territory of the city of Souk Ahras, more exactly, the upstream discharge of the Medjerda River or Hannancha discharge (Mamine et al., 2020) (Fig. 11.2). This river ranks among the river of international scope. It crosses the territory of two states: Algeria in the upper part of the current and Tunisia in its middle and lower parts, before flowing into the Mediterranean (Barour et al., 2012). Hannancha is a commune of the city of Souk Ahras, located about 20 km southwest of the city capital. This commune has a unitary sanitation network. Despite the existence of a wastewater treatment plant since 2007, this plant does not treat all of the flow discharged by the sewerage network of

Fig. 11.1 *Typha latifolia*. (Personal photo)

the commune of Hannancha, and only 60% of these flows are treated (NSO, 2016). Discharges are treated; the remaining 40% are discharged directly through an urban secondary canal into the waters of the upstream river of Medjerda (NSO, 2016). This area is known for its subhumid climate and as the important agricultural activities. In addition, it contains a wide variety of crops, including cereals, vegetables, and arboriculture (Athmani, 2008). Raw wastewater sampling is carried out under strict aseptic conditions to avoid the accidental contamination during handling. It is collected in sterile vials that are carefully labeled, stored in a cooler kept at a low temperature (4 °C), and transported to the laboratory on the same day for analysis (Rodier et al., 2009).

2.3 Plant Culture and Preparation of the Experimental Setup

The components that have served as filters are sand and gravel of variable granulometry: large gravel (10–25 mm) and small gravel (4–9 mm). These substrates are washed to remove any impurities that may interfere with the experiment (Fig. 11.3a).

The experimental device (die) is composed of four systems in series: the four 40 l capacity tanks with a length of 50 cm, a width of 30 cm, and a height of 30 cm, filled from bottom to top to a thickness of 8 cm by a succession of three layers, two composed of gravel of decreasing diameter (4–25 mm), and the third, which is the thickest, is made of sand with a thickness of 18 cm. Each basin has a 10% slope facing downstream (Fig. 11.3b).

These bunds are planted with young stems of *Typha latifolia* (with a density of eight plants/m^2). The first, second, and third planted basins are retained for a

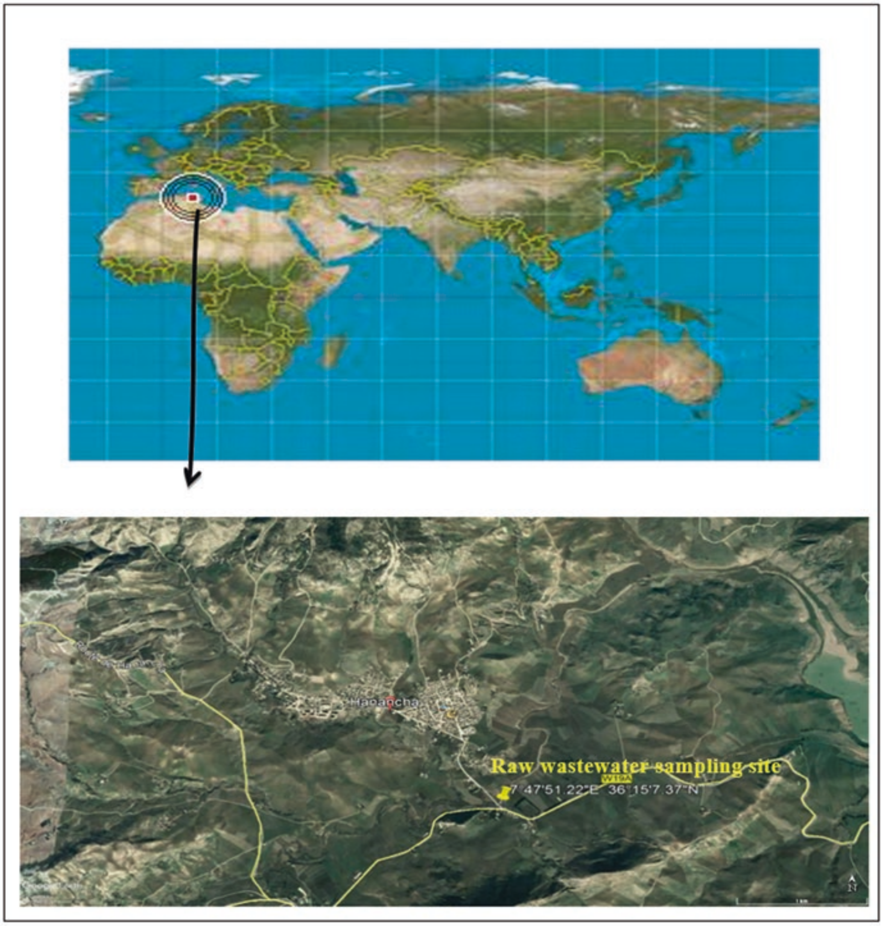

Fig. 11.2 The study area and raw sewage sampling. (https://latitudelongitude.org/dz/souk-ahras)

treatment period of 7 days, 14 days, and 21 days, respectively. However, the fourth planted tray is taken as a control. The systems are fed with raw sewage from the river of Medjerda upstream.

2.4 Methods of Analysis

2.4.1 Determination of Heavy Metal Pollution Indicators

The analyses of heavy metals in wastewater were determined following various analytical methods, as indicated in Table 11.1.

Fig. 11.3 Overview of the experimental setup

Table 11.1 Methods of heavy metal analyses in wastewater

Parametrs	Methods of determination	References
Cobalt (Co)	Spectrometric method	NF T90-112
Zinc (Zn)	Spectrometric method	FD T 90-112
Aluminium (Al)	Spectrometric method	NF EN ISO 12020
Iron (Fe)	Spectrometric method	NF T90-017
Chromium (Cr)	Spectrometric method	NF EN 1233
Copper (Cu)	Spectrometric method	NF EN ISO 15586
Cadmium (Cd)	Spectrometric method	FD T 90-112

2.4.2 Biochemical Procedure

The determination of total sugars is carried out according to the phenol method of Schields and Burnett (1960). Lipid peroxidation is estimated by the evolution of malondialdehyde (MDA) content determined according to the method described by Alia et al. (1995), and the glutathione (GSH) content was measured based on the procedure of Weckberker and Cory (Weckberker & Cory, 1988).

2.4.3 Statistical Tests

The data are presented as a mean of three replicates ± the standard error or standard deviation. The statistical analysis consists of a comparison of the different treatments using the ANOVA test followed by the student's t-test (Dagnelie, 1999). The differences are considered significant at a probability $p \leq 0.05$, highly significant at $p \leq 0.01$, and highly significant at $p \leq 0.001$. The tests are calculated from the statistical application (version 7.1). XLSTAT version 2014.5.03 has been used for this analysis.

3 Results

3.1 Water Quality

The recorded values of the heavy metals in wastewater supply after the analysis shown at the rate of Fe, Cd, Cu, Zn, and Al revealed values meet the quality requirements, for the irrigation water (WHO, 1989) (Table 11.2). Regarding the Cr and Co rates, the high concentrations are noted.

Table 11.2 Chemical characteristics of the raw wastewater feed water.

Heavy metals	Concentrations found (mg/l)	Toxicity thresholds WHO (1989)
Iron (Fe)	0.001	5(mg/l)
Aluminum (Al)	0.05	5(mg/l)
Copper (Cu)	0.12	0.20(mg/l)
Cobalt (Co)	0.32	0.05(mg/l)
Cadmium (Cd)	0.001	0.01(mg/l)
Chrome (Cr)	0.69	0.10(mg/l)
Zinc (Zn)	0.78	2(mg/l)

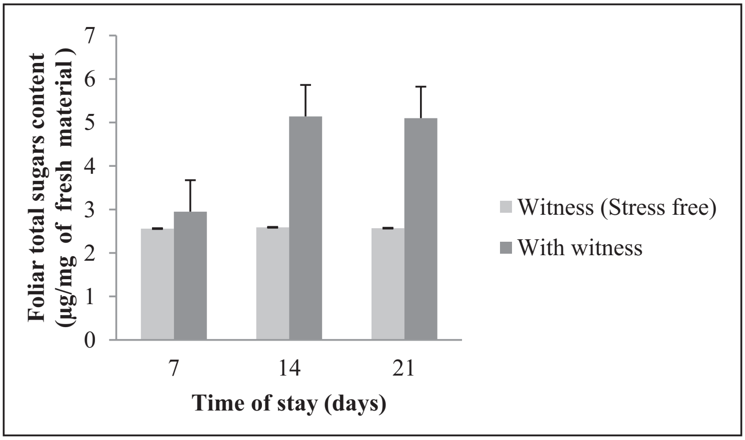

Fig. 11.4 Average total sugar content of *Typha latifolia* leaves

3.2 Biochemical Parameters

3.2.1 Effect of Raw Wastewater on Total Sugars Content

Figure 11.4 illustrates the variations in total sugars in the presence of trace metal elements in the raw sewage at the leaves of *Typha latifolia*. Thus, in the presence of xenobiotics, total sugars in this organ tend to increase in a dose-dependent manner.

This increase is compared to the control (without stress) after 7, 14, and 21 days of exposure to raw sewage. Statistical analysis shows a highly significant difference between total sugars at leaf level in controls and plants treated with raw sewage, with $p \leq 0.001$.

The level of total sugars at the leaf level in the controls increased from 2.55 ± 1.43 to 2.95 ± 0.15, 5.14 ± 0.94, and 5.1 ± 0.5 µg/mg of fresh material for plants retained for 7, 14, and 21 days in the raw wastewater, respectively.

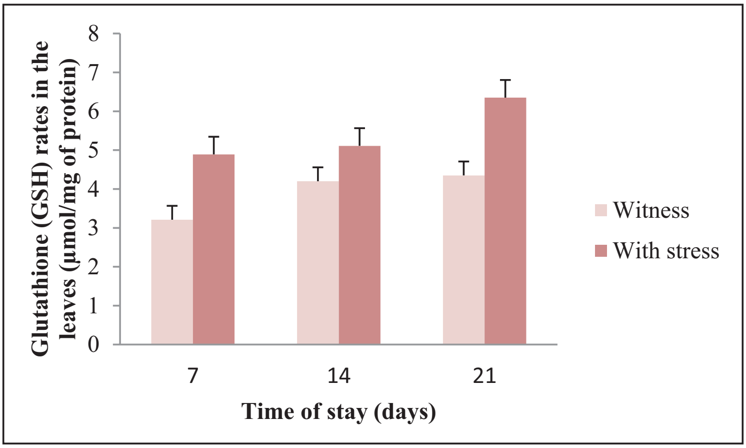

Fig. 11.5 Glutathione (GSH) rates in the leaves of *Typha latifolia*

3.3 Biomarkers Antioxidant Metabolites

3.3.1 Effect of Raw Wastewater on Glutathione (GSH) Rates

Figure 11.5 illustrates the variations in the GSH rates due to metal pollutants in raw wastewater from *Typha latifolia* leaves. When this exposed to xenobiotics, the glutathione (GSH) level increases in a dose-dependent and highly significant way in treated plants, with $p \leq 0.001$.

Indeed, this level increases from 3.92 ± 0.19 µmol/mg of protein in controls to 4.89 ± 1.12, 5.11 ± 1.55, and 6.35 ± 2.42 µmol/mg of protein for plants retained for 7, 14, and 21 days, respectively.

3.3.2 Malondialdehyde (MDA) Rates

Figure 11.6 illustrates the variations in MDA rate**s** at the sheet level in the presence of metal pollutants in the raw wastewater. The results show that in the presence of xenobiotics, there is a positive correlation between the retention time of treated plants and the malondialdehyde (MDA) level.

Statistical analysis reveals highly significant differences for the retained treated plants 7, 14, and 21 in the raw wastewater compared to the controls with $p \leq 0.001$. Indeed, this rate increases from 0.18 ± 0.22 µmol/ mg of protein in the controls to 0.21 ± 0.11, 0.23 ± 0.13, and 0.27 ± 0.16 µmol/mg of protein for the plants retained for 7, 14, and 21 days, respectively.

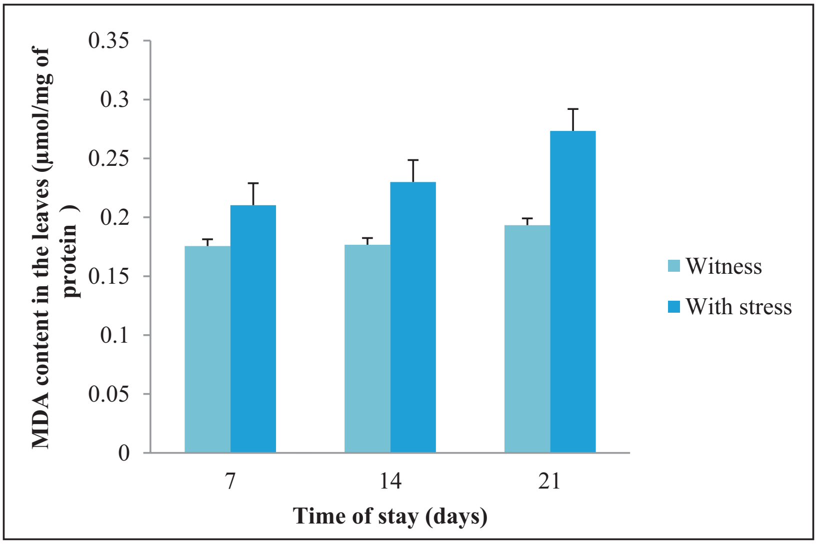

Fig. 11.6 Average MDA content in the leaves of *Typha latifolia*

4 Discussions

The term pollution refers to all the toxic compounds that man releases into the ecosphere and which have a disruptive influence on the environment. However, the development of industrial activities has caused a significant increase in pollution in the air, soil, and water (Semlali et al., 2001). The increase in pollution on the one hand and urban, agricultural, and industrial development on the other hand goes hand in hand with the scarcity of water resources and significant production of wastewater (Miloudi, 2009). Wastewater domestic is discharged precariously and without prior treatment into surface waters (Tfeila et al., 2016). These discharges contain high concentrations of organic micropollutants, nutrients, and metallic trace elements, often in toxic doses, as well as pathogenic microorganisms (bacteria, viruses, parasites, etc.), and thus cause a considerable degradation of the quality of Wadi water (Derwich et al., 2010). Several studies on the influence of untreated wastewater on water quality in the wadis include the impact of an urban effluent from the city of Taourirt on the structure of macroinvertebrate communities in Wadi Za (Eastern Morocco) (Fagrouch et al., 2011), the impact of urban and industrial discharges on water quality in the Meboudja plain (Algeria) (Bougherira et al., 2017), presence of polycyclic aromatic hydrocarbons in surface waters and hospital wastewater (Martins et al., 2018), and state of contamination of wastewater, surface water, and groundwater by pharmaceutical substances (Togola, 2018).

These results can be explained by the metallic pollution of the water of the Medjerda River by the industrial discharges. The WHO (1989) reported the presence of these metals in water, even with low concentrations, induces adverse ecological and health effects. Aquatic macrophytes are relevant ecological indicators of aquatic ecosystem pollution through the use of biomarkers, which are a natural biological tool that can signal the pollution of an environment as well as the bioavailability of toxic substances (Moreira-Santos et al., 2005; Borisova et al., 2016; Korotasz and Bryan, 2018).

The use of helophytes *Typha latifolia*, as a model for the study of the toxicity of pollutants in raw wastewater, finds the first argument, the plant *Typha latifolia*, known for its capacity to accumulate pollutants (Cd, Cr, Cu, Zn, etc.) at high concentrations in its underground and aerial tissues (Ben Salem et al., 2017). However, the investigation showed that an increase highlighted in toaux sugars which may be a response to the oxidative stress caused by the presence of heavy metals and in the presence of xenobiotics in the leaf.

On the other hand, the results showed that we have demonstrated a dose-dependent increase has been demonstrated in the GSH form in the presence of heavy metals. The results are in agreement with those of Ren et al. (2020) who found that low concentrations of cytotoxic cadmium (Cd) increase the GSH concentration in the leaves of the aquatic macrophyte *Typha angustifolia*. They showed that at low doses of the toxicant, the increase in GSH allows the plant cell to develop the defense mechanisms in response to stress. Wang et al. (2017) suggested that the synthesis of GSH in the aquatic macrophytes in the presence of heavy metals is a protective and tolerant mechanism in which the metal binds to the thiol groups of GSH, thus preventing cell damage. A significant increase in malondialdehyde (MDA) content was recorded in the plants subjected to heavy metal toxicity and raw wastewater toxicity. These results indicate that the enzymatic antioxidants are important for heavy metal detoxification in *Typha latifolia* and could explain its tolerance (Bah et al., 2011). Similarly, many studies have shown an increase in malondialdehyde (MDA) content was recorded in plants subjected to heavy metal toxicity (Cr, Cd, Pb, etc.) stress such as *Typha angustifolia* (Bah et al., 2011).

5 Conclusions

In conclusion, the harmful effect of domestic wastewater without any prior treatment leads to potential health risks as it is rich in the toxic chemicals such as heavy metals. The evolution of chemical pollution of irrigation wastewater has shown the presence of hazardous heavy metals such as iron (Fe), copper (Cu), cobalt (Co), aluminum (Al), cadmium (Cd), chromium (Cr), and zinc (Zn) with average concentrations ranging from 0.001 to 0.78 $mg.l^{-1}$. The adaptation of plants to the unfavorable conditions of their environment requires the metabolic changes. These changes should help to minimize the harmful effects of stress and allow the plant to survive. The adaptation of *Typha latifolia* with marked pollution in the sampling basins is translated by a set of modifications: biochemical and nonenzymatic. Biochemically, the results show that the plants of the species *Typha latifolia* to raw sewage stimulate the accumulation of total sugars. The analysis of the nonenzymatic antioxidant system showed that an accumulation and overproduction of MDA and GSH at the leaf level at *Typha latifolia* stressed. The greater the pollution, the greater the synthesis of this non-enzyme is important. The system of vertically draining artificial marshes planted with *Typha latifolia* highlights that this organism is the bioindicator system of pollution that has very good resistance to the urban wastewater. Toxic environmental conditions cause a major hazard in crops and affect the plant growth.

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Chapter 12
Arsenic Control for Hazard Risk Reduction

Roghayeh Khosravi, Ondra Sracek, and Saeid Eslamian

Abstract Arsenic (As) is natural element, which can spread in the environment to a great extent due to human activities. Exposure to As in drinking water and soils has become a global and regional concern. Mining, metal smelting and processing, cultivation of plants, and disposing of wastes from different sources are the main anthropogenic sources of As in the environment. Consumption of arsenic-contaminated water and food are significant exposure pathways for As. Poisoning by As has proven both carcinogenic and noncarcinogenic impacts on human health. New technologies are being developed for As treatment in contaminated water and soil. At this chapter, we discuss geochemical behavior of As in the environment, human health risks of As, and As hazard controls and reduction methods. Several case studies including those performed by authors of this chapter are discussed.

Keywords Arsenic · Hazard · Risk reduction · Contamination · Geochemical behavior · Health risk

R. Khosravi
Department of Water Engineering, College of Agriculture, Isfahan University of Technology, Isfahan, Iran

O. Sracek
Department of Geology, Faculty of Science, Palacky University, Olomouc, Czech Republic

S. Eslamian (✉)
Department of Water Engineering, College of Agriculture, Isfahan University of Technology, Isfahan, Iran

Center of Excellence in Risk Management and Natural Hazards, Isfahan University of Technology, Isfahan, Iran

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1 Introduction

Exposure to arsenic is an issue of global and regional concern. Arsenic (As) is a ubiquitous potentially harmful metalloid found in rocks, soil, water, sediments, and air. Although constitutes less than 1% of rocks, coals, and soils (Alam et al., 2002), arsenic is known human carcinogen by both inhalation and ingestion exposures (Mahimairaja et al., 2005). Arsenic is the 47th most abundant natural element with average crustal abundance of 2.5 ppm. It is more enriched in the upper continental crust, in marine shales and mudstones, hydrothermal ore deposits, coal, and lignite deposits (Bowell et al., 2014).

Arsenic in the environment can have either geogenic or anthropogenic sources. Human activities can spread geogenic As to a great extent (Tarvainen et al., 2020). Weathering of rocks and hydrothermal and volcanic emissions are the geogenic sources of As in the environment (Mahimairaja et al., 2005). Anthropogenic sources of As are agriculture activities including uses of As-based pesticides, herbicides, and fertilizers and industrial activities such as wood and tannery treatment, painting, chemicals, and electroplating industries. Other anthropogenic sources of As are indiscriminate disposal of domestic (sewage) and industrial wastes, mining activities, and metals smelting and processing activities (Missimer et al., 2018; Li et al., 2020a, 2020b; Bowell & Craw, 2014; Mahimairaja et al., 2005). Infiltration of irrigation water and excessive groundwater exploitation are other anthropogenic resources of As contamination in groundwater (Li et al., 2020a, 2020b). Although the anthropogenic origin of As contamination is increasingly becoming important, extensive As contamination of groundwater in regions such as Bangladesh, West Bengal, and Taiwan is of geogenic sources (Mahimairaja et al., 2005; Ravenscroft et al., 2011; Chen et al., 2013). Geogenic As mobilization to groundwater systems is sometimes complicated multistep geochemical mechanisms which control pH-Eh changes (Russell et al., 2021).

Behavior of arsenic and its toxicity depends on several factors, e.g., its source, speciation, and biogeochemical processes (Bowell et al., 2014). Arsenic is found as major component of As-bearing minerals and minor component or adsorbed or disseminated species in structure of different minerals. Pyrite is one of principal As-bearing minerals (As up to 10 wt%) and is found as an authigenic mineral in sediments of different aquatic environments under strongly reducing condition (Nordstrom, 2000). Pyrite oxidizes in aerobic systems to hydrous iron oxides and release sulfate, acidity, and associated trace constituents such as As (Nordstrom & Archer, 2003). Arsenic can occur in the environment in several oxidation states although it mostly occurs either as the arsenite As(III) and arsenate As(V). Arsenite is more toxic, more mobile, and more bioavailable than arsenate (Amend et al., 2014). The pH-Eh conditions in aquatic environments control the prevalent As speciation and sorption or desorption of As (Sracek et al., 2004). Due to redox disequilibrium, both arsenite and arsenate may occur together in water (Bowell et al., 2014). Organic As species are rarely quantitatively determined in soil and surface and groundwater. Reduction-oxidation reactions during metabolism in body of living organisms are causing conversion of arsenite and arsenate and methylation of As(III) to yield methylated arsenic species (Rasheed et al., 2016). The most

Table 12.1 Inorganic and organic arsenic species

Arsenic type	Species	Abbreviation
Inorganic arsenic	Arsenate (arsenic acid)	As^{+5}
	Arsenite (arsenous acid)	As^{+3}
Organic arsenic	Monomethylarsonic acid or methylarsonic acid	MMA^{+5}
	Monomethylarsonous acid or methylarsonous acid	MMA^{+3}
	Dimethylarsinic acid	DMA^{+5}
	Dimethylarsinous acid	DMA^{+3}
	Arsenobetaine	AsB
	Arsenocholine	AsC
	Arsenosugars	–

Rasheed et al. (2016)

prevalent inorganic and organic arsenic compounds found in water, food, soil and hair, urine, and nail of humans as biomarkers are listed in Table 12.1 (Rasheed et al., 2016).

Both organic and inorganic species of As are strongly absorbed across the human gastrointestinal tract (Mahimairaja et al., 2005). There are several medical symptoms of arsenicosis including, e.g., melanosis, leucomelanosis, keratosis, hyperkeratosis, dorsum, non-petting edema, gangrene, and skin and internal cancer (Alam et al., 2002; Shankar et al., 2014; Smedley & Kinniburgh, 2002; Choong et al., 2007; Charlet & Polya, 2006). Arsenic poisoning is reported from more than 70 countries (Ravenscroft et al., 2011).

Potential routes of exposure to arsenic are ingestion of foods and drinking water, dermal exposure, and inhalation of aerosols containing arsenic (Missimer et al., 2018). Among various sources of As in the environment, drinking water probably poses the greatest threat to human health (Smedley & Kinniburgh, 2002). The impact of airborne arsenic may be difficult to detect in not highly contaminated regions due to very low concentrations observed in atmosphere compared to soil (Bowell et al., 2014). However, some studies show that anthropogenic airborne emission has the highest arsenic hazard quotient and cancer risk in the regions where geogenic arsenic exposure is limited because the use of contaminated groundwater is well controlled (Chen et al., 2013) or occur in industrial non-geogenic contaminated region (Tavakoli et al., 2020).

Gold mining and processing are identified as the sources of some of the highest recorded concentrations of As in water (Coudert et al., 2020). Exploitation of low-grade refractory As-bearing sulfide minerals (e.g., arsenopyrite, and arsenian pyrite) led to the production of As-rich effluents through the oxidation of gold ores, via hydrometallurgical routes, and/or release of As from mine tailings due to their exposure to air and water (Coudert et al., 2020; Wang et al., 2019). The weathering of As-rich sulfide residues of gold mining is another source of As contamination in environment.

In this chapter, the following subjects are discussed: (a) how human health risk of arsenic is evaluated in contaminated regions and (b) which methods are used for As remediation of polluted soils and water and for hazard risk reduction in the environment (Eslamian & Eslamian, 2021).

2 Assessment of Human Health Risk of Arsenic

Cancer is the most common cause of death in the world, and environmental pollutants are one of main responsible factors (Karakurt, 2019). Arsenic-contaminated water and food (agriculture products irrigated with polluted water or food prepared and cooked with polluted water) are significant exposure pathway for arsenic (Juhasz et al., 2006; Rasheed et al., 2016). The risk of arsenic exposure for an individual depends on many factors, such as water intake and body weight (Chen et al., 2018; Li et al., 2020a, 2020b; Yang et al., 2018). Contaminant bioavailability referred to as the fraction of administered dose of contaminant that reaches blood from the gastrointestinal tract is an important criterion used in human health risk assessment (Ruby et al., 1999). Arsenic speciation is the main control of arsenic bioavailability. Most of arsenite and arsenate species can be absorbed in the body and transported via the blood stream to the body tissues (De Capitani, 2011). Arsenic bioavailability in rice, the staple food of many people in the world, depends on arsenic speciation, which depends on rice crop, arsenic concentration, and its speciation in irrigation water and in cooking water. Juhasz et al. (2006) determined the speciation of arsenic in greenhouse-grown and supermarket rice and determined arsenic bioavailability in cooked rice using swine in vivo model. Results indicate that in supermarket rice, arsenic was found only in the inorganic form but was in dimethylarsinic form in greenhouse-grown rice. Due to low bioavailability of dimethylarsinic acid, only 33 (±3)% of the total rice-bound arsenic was bioavailable. In contrast, in supermarket-bought rice cooked in water with sodium arsenate, arsenic was found only in the inorganic form, and its bioavailability was much higher, reaching 89 (±9)%.

Assessing As health risk for humans only by comparing the concentration of total As (ignore speciation) with safe limits in drinking water (10 μg L^{-1}) or in ingested food is not reliable and comprehensive approach. Recent study by Ahmad et al. (2020e) showed that even the WHO guideline for drinking water (10 μg L^{-1} As) is not sufficiently protective and does not correspond to the excess lifetime cancer risk of 10^{-6} in the Netherlands (considered as virtually safe dose according to Dutch policy). Based on their calculations, exposure to each additional μg L^{-1} As through drinking water can increase the risk for lung cancer development in the Dutch population by 0.025%.

There is a need to know more about arsenic fate after input to soil through irrigation water in water-soil-plant system especially from the perspective of arsenic speciation and fractionation changes for evaluation of arsenic health risk in soil and crops for human. There are different approaches for bioavailability of soil As. Rahman et al. (2017) evaluated human bioavailability of As in old and recent arsenical pesticide-contaminated soils using an extraction test replicating gastric conditions, an operationally defined bioavailability extraction test with 1.0 M HCl and in vivo bioaccumulation test using earthworms (Fig. 12.1).

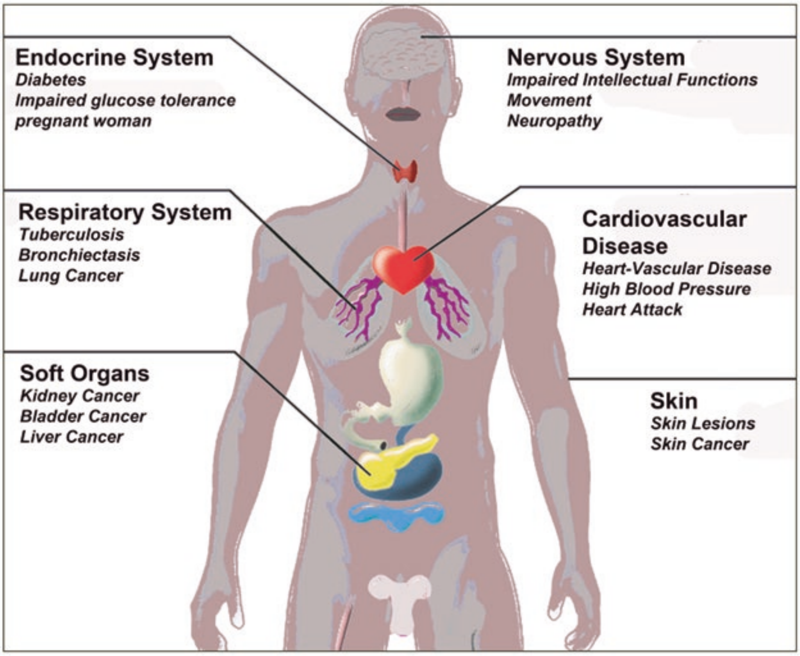

Fig. 12.1 Adverse health effects due to chronic As exposure through drinking water (Ahmad et al., 2020e)

3 Arsenic in Soil and Water Resources

Arsenic above the European Union (EU) recommended maximum acceptable limit for agricultural soil (20 mg/kg) has been associated with mining activities and the metal processing industry (Tarvainen et al., 2020) and contaminated groundwater used for irrigation (Bhattacharya et al., 2012). In addition, As can be enriched significantly in soils from past use of arsenical pesticides (Yokel & Delistraty, 2003). High loading rates of arsenical pesticides, coarse soil texture, low organic matter content, and use of irrigation promote deeper movement of As into soil and even contamination of underlying shallow groundwater (Peryea & Creger, 1994). However, atmospheric pollution and the phosphate fertilizers application are regarded as the main sources of anthropogenic arsenic in agricultural soils (EFSA Panel on Contaminants in the Food Chain (CONTAM), 2009).

Sequential extraction procedure often revealed As fractionation in soil which controls bio-accessibility and bioaccumulation of As. Soluble, exchangeable, and sorbed fraction of total As are considered as bioavailable and bioaccumulative As in soils. Bioavailability and bioaccumulativity of As decreased due to aging of arsenical pesticide-contaminated soils (Quazi et al., 2010; Rahman et al., 2017). Arsenic release from mobile (bioavailable) fractions contributes to its content in immobile fractions such as crystalline Fe(oxide-hydroxide) and residuals. Organic-rich soils often have high As concentrations (Missimer et al., 2018; Li et al., 2020a, 2020b). In anaerobic soils, As is typically found in combination with sulfur. In aerobic soils arsenate is the predominant species, whereas in anaerobic soils, arsenite is the dominant species (Campbell & Nordstrom, 2014). However, in soil and sediments, in metastable As-bearing phases, and under the impact of anaerobic microbial activities, speciation of As does not frequently adjust to pH-Eh condition (Xu et al., 2011; Khosravi et al., 2019).

Data about As concentration, its fractionation, and speciation and physiochemical characteristics of soil such as pH-Eh condition, texture, organic matter contents, and age of contamination can be useful for successful remediation and management. The default Soil Cleanup Target Level (SCTL) that varies greatly by state and country depends on background concentrations and is determined by regulatory agencies according the site-specific risk assessments (Missimer et al., 2018).

While there are anthropogenic sources of arsenic, geological weathering is the primary cause of arsenic release into groundwater (Rasheed et al., 2016). For example, several million people are at risk from drinking As-contaminated water in West Bengal (India), Bangladesh, China, Vietnam, Taiwan, Chile, Argentina, and Mexico (Mahimairaja et al., 2005; Ravenscroft et al., 2011; Bretzler & Johnson 2015). People with hard manual work in tropical regions surpass the average daily water intake by a factor of 2–3, and for them the limit should still be decreased (Chakraborti et al., 2010). People drinking As-contaminated water over prolonged periods often show typical arsenical lesions, which are manifestations of As toxicity (Mahimairaja et al., 2005). In response to health concerns about arsenic in drinking water in the United States, the US Environmental Protect Agency (USEPA) reduced the drinking water standard for arsenic from 50 μg L^{-1} to 10 μg L^{-1} in 2001 which also matches the World Health Organization health-based recommendation (U.S. Environmental Protection Agency (USEPA), 2001).

4 Arsenic Removal from Contaminated Soil and Water

In recent years, there have been extensive efforts to find effective and economical methods for As removal from contaminated soils and water in all over the world. The methods can be divided according to their mechanism to seven major classes including: ion exchange, phytoremediation, adsorption, phytobial remediation, chemical precipitation, electrokinetic technics, and electrocoagulation (Alka et al., 2020b). Each method has its advantages and disadvantages (see Table 12.2). Ion exchange, chemical precipitation, electrocoagulation, and membrane technology have been used for As removal from water, wastewater, and synthetic water. On the other hand, adsorption, phytoremediation, nanophytoremediation, phytobial

Table 12.2 Advantages and disadvantages of methods used for As removal from the soil and water system

Method of removal	Advantages	Disadvantages
Adsorption	Easy operation handling; flexibility; low cost; sludge-free; high removal efficiency	Sorbents have to be replaced after adsorption bed gets and loses the capacity for removal; sorbents have low specific surface area when using metal oxides; suitable for water with low as concentrations
Ion exchange	Total removal; limited toxic Sludge production	Must be rejuvenated frequently to ensure complete removal; costly; each exchanger is specific for different as species; the resin is also responsive to natural anions
Phytoremediation	Eco-friendly and highly economic; occurs by using plants to assimilate arsenic from soil; land restoration	Time-consuming process; climate affects hyperaccumulating plants; microbes produce additional pollutants; pollutants may interact with metabolic processes of plants and hinder their growth
Nanophytoremediation (NP)	Improves phytoremediation efficiency and in situ remediation; transforms pollutants into less toxic forms; cost-effective	–
Phytobial remediation	Eco-friendly and cheap; Enhances phytoremediation Rate; increases plant defense responses to stress; assists in control of phytopathogens and plant growth	–
Chemical precipitation	Simple and effective; specific components removed	It forms residual products and processing cost is high
Electrokinetic processes	Cost-effective in removal of heavy metals	Small portion of soil at one time is treated
Electrocoagulation	A novel and promising arsenic removal strategy; efficient and relatively cheap Operates with local materials	Not effective for extracting trivalent arsenic; producing sludge; strongly affected by coagulant form and dose, solution pH and competing anions
Membrane technology	High efficiency; low energy Consumption; high filtration performance	Costly, large volumes of contaminated water

Adapted from Alka et al. (2020b)

Case Study 1: Arsenic hazard from Domestic Well Water
Arsenic concentration in domestic wells needs to be measured and controlled because they are the major sources of water in some regions of many countries. Any changes in pH-Eh condition in groundwater system can lead to geochemical disequilibrium in aquifers and release of contaminants such as As due to dissolution/precipitation of oxides (hydroxides) or sulfides, which are hosts of different trace elements. This can have negative implications on home water treatment such as reduced contaminant removal efficiency and iron fouling, which can lead to contaminant exposure from domestic well water (Erickson et al., 2021).
For example, according to the study of 250 new domestic wells in Minnesota, North Central United States, well installation changes geochemical conditions in aquifers for more than 12 months. In one well, which had extremely high initial arsenic about 1550 μg L^{-1}, contamination decreased after 15 months to 5.2 μg L^{-1}. Erickson et al. (2021) investigated reasons for increase of As concentration after well installation. They found that well installation procedures introduce oxic drilling fluids and hypochlorite, a strong oxidant used for disinfection, thus inducing geochemical disequilibrium. The oxidation of arsenic-containing sulfides (which lowers pH) combined with low pH dissolution of arsenic-bearing Fe (oxyhydr)oxides caused the very high observed arsenic concentration.

remediation, and electrokinetic processes have been used for both water and soil remediation.

The restrictions for soil and water treatment technologies, local and national authorities' requirements, a country's development stage, and local regulations for arsenic levels determine which method can be used for arsenic treatment (Alka et al., 2020b).

4.1 Ion Exchange

Ions retained electrostatically on the solid phase surface can be exchanged with ions of similar charge in solution. This effective method is used to remove contaminants such as arsenate from contaminated water (or wastewater, Alka et al., 2020). It should be noted that this method extracts only arsenate (not arsenite) from water due to its negative charge in water (unlike dissolved arsenite in water which often is neutral, Jadhav et al., 2015). In this method, different synthetic resins are typically used as exchanger (Lee et al., 2017). Resins are regularly regenerated to displace the exchanged ions after application period. The ion exchange process does not generate large amount of waste and is affordable (Lee et al., 2017). Increase of TDS in water leads to decreasing in efficiency of arsenic removal (Jadhav et al., 2015).

Case Study 2: Use of ArsenX^{np}, a Hybrid Anion Exchanger for arsenic Removal in Remote Villages in the Indian Subcontinent

Highly As-contaminated groundwater used as drinking water is the cause of widespread arsenic poisoning affecting nearly 100 million people living in Bangladesh and West Bengal. Arsenic concentration exceeds the maximum contaminant level of arsenic (50 μg L^{-1}) in drinking water in India. In thousands of villages in Indian subcontinent, arsenic-rich groundwater is the only viable source of drinking water.

Sarkar et al. (2007) investigated the performance of hybrid anion exchangers which are essentially spherical anion exchange resin beads containing dispersed nanoparticles of hydrated ferric oxide (commercially available as ArsenX^{np}) for arsenic removal over a long period. In addition, they investigated the regeneration of the media, elucidated arsenic removal mechanism, and also studied strategies of arsenic remediation in Indian subcontinent.

The sorption columns used in the field for removal of arsenic are either single columns or split columns, which allow entry of atmospheric oxygen to promote the oxidation of dissolved Fe(II) species in arsenic-contaminated well water to insoluble Fe(III) oxides or hydrated ferric oxide particulates (Fig. 12.2). Apart from the usual role played by the sorbents like ArsenX^{np} or

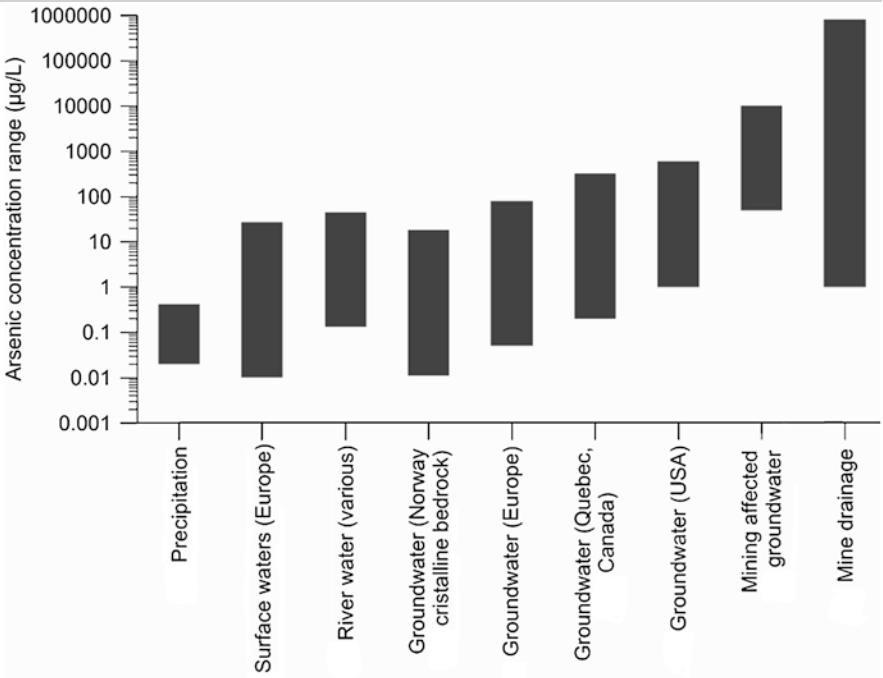

Fig. 12.2 Arsenic concentration ranges in water resources. (Adapted from Coudert et al., 2020)

Case Study 2: *Continued*

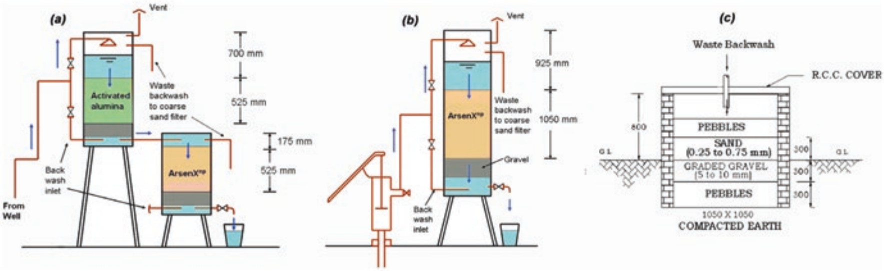

Fig. 12.3 Schematic detail of construction and operation of a (**a**) split-column unit and (**b**) single unit used in the field, (**c**) details of the coarse sand filter for entrapment of waste backwash containing hydrated ferric oxide particles. (Sarkar et al., 2007)

activated alumina, hydrated ferric oxide particulates also improve the treatment process. Each As removal system is attached to a hand pump-driven well and is capable of providing arsenic-safe water for approximately one thousand people in villages. No chemical additives, adjustment of pH, or electricity is required to run these systems. Every system was running for more than 20,000 bed volumes before a breakthrough of 50 μg L^{-1} of arsenic was reached. Upon exhaustion, the media was withdrawn and taken to a central regeneration facility where 2% NaCl and 2% NaOH solutions were used for regeneration. After regeneration, the spent solutions, containing high arsenic concentration, were transformed into solid residuals and were disposed safely to avoid any significant arsenic leaching. Laboratory investigations have confirmed that the regenerated $ArsenX^{np}$ was amenable to reuse in multiple cycles without any significant loss in capacity (Fig. 12.3).

4.2 *Phytoremediation*

Phytoremediation uses hyperaccumulating plants with extensive root system, high tolerance, and rapid growth to remove pollutants, and the technique requires very little nutrient input and is easy to manage (Manoj et al., 2020). This method is further classified as phytoextraction, phytostabilization, phytofiltration, and phytovolatilization, which are based on the metal uptake and transport routes (DalCorso et al., 2019). However, a plant may use more than one strategy simultaneously (Favas et al., 2014) (Fig. 12.4).

The efficiency of As removal by phytoremediation method can be enhanced by using chelators, inoculation by microbes, (Irshad et al. 2020a, 2020b), soil amendments (Irem et al., 2019), and introduction of nanoparticles (Moameri & Khalaki, 2019). For example, inoculation with the strain of *Cupriavidus basilensis* could increase the abundance of aioA-like genes in the rhizosphere and As accumulation in *P. vittata* by up to 171% (Yang et al., 2020). Nanophytoremediation (NP) that combines phytoremediation with nanotechnology for contaminants remediation is

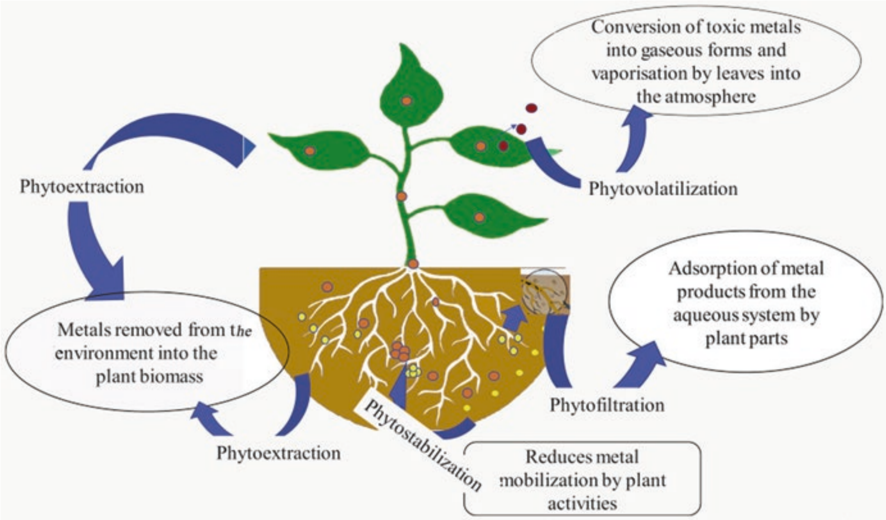

Fig. 12.4 Description of phytoremediation processes occurring in plants. (Modified from Alka et al. (2020))

known as a green and eco-friendly technology. Nanomaterials can eliminate the need for treatment, reduce the cleanup time, and remove and dispose toxic substances from soils and water (Chen et al., 2021). However, few studies exist on the removal of arsenic using nanophytoremediation and underlying mechanisms governing the synergistic removal bioremediation technologies (Alka et al., 2020b).

Case Study 3: As- and Cd-Contaminated Soil Remediation with Multi-Walled Carbon Nanotubes Combine with Hyperaccumulator Solanum Nigrum L.

Nanomaterials have been increasingly applied for the remediation of contaminated soils, but few researches have been reported on the complex interactions of nanomaterials with heavy metals in phytoremediation. Some studies give a strong evidence to promote the phytoremediation for As-contaminated soils by using nanomaterials.

Chen et al. (2021) have conducted a pot experiment to investigate the effects of different doses of multi-walled carbon nanotubes on the plant growth and accumulation of Cd and As in hyperaccumulator plant. Hyperaccumulator of Cd *Solanum nigrum L.* (*S. nigrum*) was cultivated in Cd- and As-contaminated soils amended with carbon nanotubes at 100, 500, and 1000 mg kg^{-1} for 60 days. Root and leaf growth was inhibited by dose of 1000 mg kg^{-1} carbon nanotubes. However, the application of carbon nanotubes in doses of 100 and 500 mg kg^{-1} has increased the shoot length and plant dry biomass by 5.56–25.13% and 5.23–27.97%, respectively. Meanwhile, multi-walled carbon nanotubes at 500 mg kg^{-1} significantly enhanced the accumulation of As by about 32.47% in *S. nigrum* and alleviated Cd- and As-induced toxicity, by motivating plant growth, stimulating antioxidant enzymatic activities, and increasing micronutrient content ($p < 0.05$). The bioconcentration factor of As decreased (15.31–28.08%) under carbon nanotubes application, which played an important role in the alleviation of phytotoxicity. Besides, bioavailable Cd and As were reduced in rhizosphere soils and the most significant reduction 16.29% for Cd and 8.19% for As was found in 500 mg kg^{-1} carbon nanotubes treatment. Generally, these findings demonstrated that suitable concentration of carbon nanotubes can enhance remediation efficiency in As- and Cd-contaminated soils.

4.3 Adsorption

Adsorption is a suitable As removal technique that is highly efficient for arsenite and arsenate remediation (>95%, Alka et al., 2020). Since it has low cost and do not need so skilled personnel to run treatment procedure, it can be used for arsenic removal from drinking water in rural and peri-urban areas in developing countries (Kumar et al., 2019). Adsorbent type, initial concentration of As, speciation and interfering species, exposure period, pH, and temperature influence the efficiency of this technique of As removal (Litter et al., 2010; Sarkar & Paul, 2016). The oxidation process of arsenite by atmospheric oxygen is very slow, and at pre-treatment step of this method, arsenite is converted to arsenate using different oxidants such as ozone (O_3), hypochlorite (HClO), potassium permanganate ($KMnO_4$), and hydrogen peroxide (H_2O_2) (Ahmad et al., 2018; Ahmad et al., 2020a, 2020b, 2020c). Arsenic adsorbents have been successfully applied for arsenic remediation including granular adsorbents, metal oxides coated on sand, iron oxide-based sorbents engineered biochar, zero-valent iron, clinoptilolite-rich zeolitic tuff, iron/olivine composite, activated carbon, agriculture wastes, and activated alumina (Bundschuh & Chatterjee, 2013; Bretzler & Johnson 2015; Alka et al., 2020b). Different adsorbents materials including the composite materials and nanomaterials have been classified by Maity et al. (2020) according to their application in laboratory or in field, type of water (surface water, groundwater, drinking water, and waste water), pH, initial As concentration, and the percent of arsenite and arsenate removal. See this article for further details about different As adsorbents. They concluded that especially Fe nanoparticles and/or composite materials are quite effective for the As treatment process.

Case Study 4: Removal of Arsenic Using Natural Geological Materials at Chaco-Pampean Plain in Argentina (Bundschuh & Chatterjee, 2013)
There are high concentrations of As in groundwater around Santiago del Estero in Chaco-Pampean Plain in NW Argentina. Groundwater is of Na-HCO_3 type and frequently shows high pH values. Redox status is generally oxidizing and As is present as As(V). Local population is poor and there is a need for low- or zero-cost As removal material. Several natural materials have been tested including soils rich in clay from Santiago del Estero region and lateritic soils from Misiones Province in the north of Argentina. Adsorption experiments performed in batch mode showed much higher As removal for lateritic soils from Misiones (up to 99%) compared to soils from Santiago del Estero (40–53%). This was consistent with lower oxalate extractable Al and Fe soils. Potential limiting factor can be the cost of lateritic material transport from Misiones to Santiago del Estero.

Case Study 5: Field Removal from Natural Water by Zero-Valent Iron Assisted by Solar Radiation
The towns of Camarones, Esquiña, and Illapata are in the Atacama Desert in northern Chile. Local residents use water from the Camarones River (TDS ranges between 1 and 2 g L^{-1}) for both human consumption and agricultural activities. The concentration ranges between 1000 and 1300 μg L^{-1}, and is mainly in the form of As (V). High As concentration in river has chronically affected the rural populations living near the river and caused a variety of health problems. In addition, high concentrations have been reported in the soil, plants, and animals in the area. In situ removal method was applied to this highly contaminated water by Cornejo et al. (2008). High removal efficiency (above 99%) was necessary to obtain the World Health Organization (WHO) recommended level of 10 μg L^{-1}. Cornejo et al. (2008) approach was based on the use of steel wool, lemon juice, and solar radiation. They used surface method analysis to optimize the amount of zero-valent iron (steel wool) and the citrate concentration (lemon juice). The optimal conditions when using solar radiation were 1.3 g L^{-1} of steel wool and 0.04 mL (one drop) of lemon juice. Under these conditions, removal percentages were higher than 99.5%, and the final concentration was below 10 μg L^{-1}. The main characteristics of method were highly effective removal, easy to use, and inexpensive implementation.

4.4 Phytobial Remediation

The toxic metals cannot be degraded entirely from the environment, but they can be accumulated by microorganisms, and the uptake of metals by bacteria can take place (Harms et al., 2011). In phytobial method, plants and microbes including algae, bacteria, and fungi are combined to mitigate soil and groundwater As (Roy et al., 2015). It is cost-effective and is widely accepted by society (Sodhi et al., 2019). Under phytoremediation technology, heavy metal hyperaccumulator plants have been extensively employed to extract high concentrations of heavy metals, but slow growth, limited biomass, and stresses caused by heavy metals decreased the efficiency of hyperaccumulators (Asad et al., 2019). Recently, plant growth-promoting bacteria that assists phytoremediation have been applied for both improving plant metal tolerance and promoting plant growth while achieving the goal of large-scale removal of As (Alka et al., 2020a). Plant growth-promoting rhizobacteria produce several metabolites, including growth hormones, siderophores, and organic acids, which aid in solubilization and provide essential nutrients (e.g., Fe and Mg) to the plants (Asad et al., 2019). Although phytobial remediation of As was proved a very successful technology, there are various pathways of As tolerance mechanisms not fully understood (Irshad et al., 2021). Arsenite oxidizing bacteria such as *Alcaligenes faecalis* and arsenate reducing bacteria including of *Sulfurospirillum arsenophillum* and *Sulfurosprillum barnesii* are examples of bacteria involved in bioremediation of arsenic (Sodhi et al., 2019).

The impacts of symbiosis between microorganisms and plants on As remediation and detoxification were recently investigated by Irshad et al. (2020b), Roy et al. (2015), Zeraatkar et al. (2016), Guarino et al. (2020), and Wang et al. (2020).

Case Study 6: Alleviation of Arsenic-Induced Phytotoxicity of Rice Plant Using Groundwater Inhabited by Bacillus and Paenibacillus Strains

Arsenic contamination in agricultural soil is causing several hazardous health effects through percolation in food chain. Rice plants are being affected more than other agricultural crops due to the use of arsenic-contaminated groundwater for irrigation, their higher arsenic uptake, and mobilization tendency (Kalita et al., 2018).

A hydroponic experimental setup has been conducted by Banerjee et al. (2020) for evaluating the effects of two potent arsenic-tolerant bacterial strains including *Bacillus thuringiensis A01* and *Paenibacillus glucanolyticus B05* for possible mitigation of the arsenic-induced phytotoxicity and to maintain overall growth of the rice seedlings. Miniket cultivar-IR-50 widely cultivated in West Bengal was used in this study. Their results show that:

- *Bacillus thuringiensis A01* could reduce arsenic uptake up to 56% (roots) and 85% (shoots) and *Paenibacillus glucanolyticus B05* up to 31% (roots) and 65% (shoots) in a hydroponic environment.

- Germination percentage has been enhanced significantly.
- Expressions of oxidative stress defensive enzymes such as superoxide dismutase, peroxidase, and catalase have been augmented at seedling stages (21 days) toward detoxification of arsenic imposed excess ROS generation.
- There was increment of leaf thiobarbituric acid reactive substances.
- Phenolic and flavonoid mediated free radical scavenging ability of the test plants increased significantly.

This study results revealed that selected bacterial strains could perform efficient bioremediation of arsenic-contaminated rice cultivation.

4.5 Chemical Precipitation

Chemical precipitation is a technique that uses reagents such as ferric salts, sulfides, magnesium salts, and calcium salts for removal of heavy metals like arsenic (Alka et al., 2020b). These reagents help in removing arsenic by converting dissolved arsenic to low-solubility compounds. The most common reagents used in the removal of As especially in As-rich wastewater are ferric arsenate and calcium arsenate (Alka et al., 2020b). Treatment of arsenic-rich acid wastewater produced in the mining and smelting process with iron salt and lime is an economical and effective method (Wang et al., 2019).

Also, ferric-based coprecipitation low-pressure membrane filtration is a promising As removal method. Coprecipitation of arsenate with Fe(III) (oxyhydr)oxides is a widely used As removal method. However, arsenite coprecipitation with Fe(III) (oxyhydr)oxides is less effective in the pH range of most groundwaters because arsenite is uncharged and has a significantly lower affinity for adsorption to Fe(III) (oxyhydr)oxide surfaces (Ahmad et al., 2020c). Laboratory investigations indicated that As coprecipitation with Fe(III) (oxyhydr)oxides rapidly reached equilibrium before membrane filtration, within 1 min. Therefore, As removal efficiency was not improved by increasing water residence time (Ahmad et al., 2020c). The As removal rate increased with increasing the Fe/As ratio in water (Wang et al., 2019). Also, a higher Fe(III) dose was required to reduce As(V) to sub-μg/L levels for feedwater containing high concentration of oxyanions such as phosphate and silicate and low concentration of cations such as calcium (Ahmad et al., 2020c). Even stability of amorphous coprecipitates is usually poor if the Fe/As ratio is lower which can release As after disposing the coprecipitates (Wang et al., 2021).

4.6 Electrokinetic Technics

The electrokinetic technique (EK) is an innovative, in situ, and effective method that guides the movement and transport of free pollutants in soil within electrical field in processes such as electrophoresis, electromigration, water electrolysis, and electro-osmotic flow (Xu et al., 2019). The EK has limitations in removing As because dissolved As is difficult to treat, and using this method increases the risk of mobility of other heavy metals (Alka et al., 2020b). Coupling with other techniques may increase this method efficiency, making it more economically and environmentally friendly. The EK method can be coupled or combined with permeable reaction barrier (PRB, Yuan & Chiang, 2007; Yao et al., 2020; Ji et al., 2020), anaerobic bioleaching (Lee et al., 2009; Kim et al., 2012), application of chemical reagents (Yuan & Chiang, 2008), humus, and humic and fulvic acids (Li et al. 2020a, 2020b; Xu et al., 2021).

4.7 Electrocoagulation

Electrocoagulation (EC) process is a very efficient and economic tool for removing various water pollutants such as turbidity, phosphate, fluoride, and various heavy metals (Nidheesh & Singh, 2017). The EC process is also effective promising technology for removal of arsenic from water (Mohora et al., 2018; Demirbas et al., 2019) and other solutions (Alka et al., 2020b). Electrocoagulation is using various sacrificial metal anodes such as aluminum, iron, magnesium, zinc, etc. for in situ generation of metallic coagulants. Iron and aluminum are more common to use in EC method, and aluminum anodes are less efficient than iron electrodes (Alka et al., 2020b). The electrolytic oxidation of the anode occurs after the application of direct current and the metallic anode dissociates into di- or trivalent metallic ions (Nidheesh & Singh, 2017). The EC is using electrical energy destabilize the colloidal suspensions, leading to the dissolution of different heavy metals and metalloids including As and then their flotation and flocculation (Maitlo et al., 2019).

The EC process is started when a potential is applied through an external power source and the sacrificial electrode undergoes oxidation as given below for mild steel anode (Balasubramanian et al., 2009):

$$Fe_{(\mathrm{s})} \rightarrow Fe^{2+}_{(aq)} + 2\mathrm{e}^- \tag{12.1}$$

and the cathodic reactions can be written as:

$$2\mathrm{H}^+ + 2\mathrm{e}^- = \mathrm{H}_2 \tag{12.2}$$

$$2\mathrm{H}_2\mathrm{O}_{(\mathrm{l})} + 2\mathrm{e}^- \rightarrow \mathrm{H}_{2(\mathrm{g})} + 2OH^-{}_{(aq)} \tag{12.3}$$

Release of OH^- at the cathode continues due to the formation of cationic monomer species attributable to the dissolution of electrolyte that occurs at the sacrificial mild steel anode (Demirbas et al., 2019):

$$Fe^{2+}_{(aq)} + 2OH^-{}_{(aq)} \rightarrow Fe(OH)_{2(s)} \tag{12.4}$$

$$Fe^{2+}_{(aq)} + 2H_2O_{(l)} + O_2 \rightarrow Fe(OH)_{3(s)} + H_{2(g)} \tag{12.5}$$

$$4Fe^{2+}_{(aq)} + 10H_2O_{(l)} + O_2 \rightarrow 4Fe(OH)_{3(s)} + 8H^+_{(aq)} \tag{12.6}$$

Arsenate absorbed/precipitated by forming complex with Fe^{3+} as below:

$$4Fe(OH)_{3(s)} + AsO^{3-}_{4(aq)} \rightarrow \left[Fe(OH)_3 * AsO_4^{3-}\right]_{(s)} \tag{12.7}$$

Performance of the EC method depends on (a) speciation of As, (b) materials used in cathode and anode, (c) anions and cations concentrations in water, and (d) pH (Nidheesh & Singh, 2017). The removal of arsenate is easier than that of arsenite, and arsenate can be completely removed (Nidheesh & Singh, 2017). Then oxidation of arsenite to arsenate occurs during the EC process (Kumar et al., 2004). Testing of As removal efficiency through the EC process with different anode-cathode pairs of iron and aluminum implies that Al-Fe and Fe-Fe systems are more efficient compared to Al-Al system (Gomes et al., 2007). Presence of iron in water has positive impact, but fluoride, phosphate, silicate, boron, and bicarbonate decrease the efficiency (You & Han, 2016; Wan et al., 2011; Silva et al., 2018; Goren & Kobya, 2021). Silicate and phosphate ions affect performance more than boron, bicarbonate, and fluoride (Goren & Kobya, 2021). Generally, sulfate presence in water didn't affect the As removal efficiency by the EC process at low concentration. However, when sulfate concentration increased to 100 mg L^{-1}, As removal efficiency decreased significantly (Wan et al., 2011; You & Han, 2016). Similar to sulfate, the impacts of magnesium and calcium cations in water on efficiency of As removal by EC process are dependent on their concentrations in water (You & Han, 2016; Hu et al., 2014). High pH and high initial arsenic concentration decrease the As removal (Wan et al., 2011). For example, Can et al. (2014) study shows that the highest removal efficiency was observed at initial pH = 4, and You and Han (2016) observed the fastest removal efficiency at pH = 7. Also, the external addition of air (O_2) enhanced the efficiency of electrocoagulation process and improved As removal (Syam Babu et al., 2021). The obtained experimental results showed that the efficiency of arsenic removal increased with increasing current density (Can et al., 2014).

4.8 Membrane Filtration

Membrane technology is addressed as a pressure-driven process, widely known as one of the most efficient technologies, and it has the potential of reducing arsenic concentration by 96% (Alka et al., 2020b). High pressures are required to force the water to pass across a membrane to change water from concentrated to diluted. Driving pressure increases as selectivity increases (Choong et al., 2007). Laboratory investigations by Nguyen et al. (2009a, 2009b) implied that the arsenic separation efficiency increased only by a few percent with increasing applied pressure (from 138 to 552 kPa). Membranes are commonly divided into four categories based on increasing selectivity: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and hyperfiltration or reverse osmosis (RO) (Choong et al., 2007). The MF can be used to remove bacteria and suspended solids (pore sizes of 0.1 to micron) and UF to remove colloids, viruses, and certain proteins (pore size of 0.0003–0.1 microns), and NF relies on physical rejection based on molecular size and charge (pore sizes are in the range of 0.001 to 0.003 microns). The RO uses pore size of about 0.0005 microns and could be used for desalination. Different types of membranes are used in removal of arsenic from water systems (Pramod et al., 2020), such as NF (Gonzalez et al., 2019), UF (Ahmad et al., 2020c), and RO (Schmidt et al., 2016). The NF and RO are the most promising technologies for selective removal of arsenic (Figoli et al., 2020). Cake-layer formation is the predominant membrane fouling mechanism (Ahmad et al., 2020c). The molecular weight cutoff (MWCO), electrokinetic charge, and individual salt rejection characteristics are the important membrane properties governing the separation of arsenic (Nguyen et al. 2009a, 2009b). Removal of arsenic by membrane filtration is highly dependent on As speciation and properties of membranes (Nguyen et al. 2009a, 2009b). Investigations imply that the removal efficiency of MF was low and only 37% of As(III) and 40% of As(V) were removed by MF (PVA membrane, Pure-Envitech, Korea) due to its large pore size (Nguyen et al. 2009a, 2009b). However, the removal efficiency of MF increased dramatically up to 90% for As(V) and 84% for As(III) when an amount of 0.1 g L^{-1} (nZVI) was added into arsenic solution (Nguyen et al. 2009a, 2009b).

The performance of the NF is better for removing of As(V) than As(III) (Nguyen et al. 2009a, 2009b) which results in the dominance of Donnan exclusion over steric exclusion in controlling the As removal capacity of the membrane (Nguyen et al. 2009a, 2009b).

Quality of raw water is important factor, which controls coagulation/MF (C/MF) hybrid method. Zhang et al. (2012) show that increase of dissolved organic carbon and HPO_4^{2-} and HCO_3^- concentrations would moderately decrease As(V) removal by (C/MF). However, ions such as Cl^-, NO^{3-}, F^-, SO_4^{2-}, K^+, Ca^{2+}, and Mg^{2+} have little effect on As(V) removal. However, in As removal by NF membrane, the rejection of monovalent As(V) increased by the presence of Cl^- and decreased by the presence of SO_4^{2-} due to mutual interactions between anions (C. M. Nguyen et al., 2009a, 2009b). Also, pH range is important in control of As(V) and As(III) removal through NF (Nguyen et al., 2009a, 2009b). For example, C. M. Nguyen et al.'s (2009a, 2009b) results show that the removal of As(V) increased with increasing pH over the range from 4 to 10, while As(III) removal significantly increased over the pH range 8–10.

Boussouga et al. (2021) investigated the removal of As(V) by NF and concluded that rejection of As(V) is not affected by increasing salinity but increases with increasing pH. Also, their results show that the presence of humic acid enhances As(V) rejection by 10–20% with the loss of NF due to increase of membrane surface charge.

Assessment of NF and RO membranes for simultaneous removal of arsenic and boron from spent geothermal water implies that tested NF and RO membranes were successful in arsenic removal and RO membranes showed better performance in terms of both arsenic and boron removals (Jarma et al., 2021). Remediation of natural As(V)-contaminated groundwater (As concentration ranging from 59 to 118 ppb) in Calabria, Italy, was treated by NF using two types of membranes commercialized by GE Osmonics, named HL and DK, both made of polyamide thin film and with the same molecular weight cutoff (MWCO). This remediation led to As concentration lower than 10 pbb in groundwater, and the highest water flux was obtained with the HL membrane (Figoli et al., 2020). Arsenic removal from water by UF membrane can be enhanced extremely when coupled with different complementary methods such as photocatalysis (Molinari & Argurio, 2017), adsorption, and sand filtration (Ruiping et al., 2009). In addition, there are several different ways to increase the As removal performance of UF membranes such as micellar-enhanced UF (Iqbal et al., 2007; Yaqub & Lee, 2020) and electro-UF (Hsieh et al., 2008).

5 Switching to Save Water and Soil

Arsenic intake to the environment increased several times due to industries development in recent decades, which led to catastrophic changes in ecosystem. For example, total As concentration increases several times in sediments of freshwater lake in China (Chen et al., 2015). This resulted in >tenfold loss of crustacean zooplankton and > fivefold increase in highly metal-tolerant alga. It is possible to control As intake, but it is difficult due to complexity involved in dealing with contaminated sites, exacerbated by site characteristics, hydrogeological conditions, unknown source term, chemical form, and complex land use (Mahimairaja et al., 2005). Then prevention of As contamination of water resources and soil is always preferred approach compared to As mitigation.

Sometimes geological and geomorphological conditions trigger the release of arsenic to groundwater. Alluvial aquifers with reactive organic matter, low-lying topographic features, and slow groundwater flow caused by low hydraulic gradients provide favorable conditions for arsenic enrichment (Hasan et al., 2007; Bhowmick et al., 2011; Li et al., 2020a, 2020b; Ravenscroft et al., 2011). During the exploration for new groundwater resources of drinking and irrigation water, the geological, geomorphological, geochemical, and hydrogeological conditions in aquifers should be considered to find the best sites for exploitation of fresh and As-free water. In most affected countries such as Bangladesh, shallow groundwater shows higher As concentration than deep groundwater (Ravenscroft et al., 2011). It is due to young reactive organic matter in sediments, excessive irrigation pumping, evaporation, and groundwater level fluctuation which changes the pH-Eh condition and lead to geochemical disequilibrium in aquifers (Ravenscroft et al., 2011; Zabala et al., 2016; Bandara et al., 2018; Das & Banerjee, 2020; Li et al. 2020a, 2020b). It can be recommended to use deep groundwater with low As concentration at least for drinking and use shallow water only for irrigation, but pumping rate in deep wells has to be controlled to avoid the penetration of shallow As-rich groundwater to deep aquifers (von Brömssen et al., 2014).

Several recommendations have been given to prevent of As contamination of soils and groundwater due to cultivation and irrigation: (a) large-scale use of rainwater in irrigation systems in regions where water used for cultivation has high As concentration; (b) cultivation in controlled conditions such as hydroponic systems especially for hyperaccumulator plants such as rice; (c) prevention of using treated or nontreated wastewater from municipal, urban, industrial, and mining resources in cultivation; and (d) limiting application of fertilizers and pesticides. In addition, agricultural activities on As-contaminated soils and with high As concentration in irrigation water should be abandoned.

Important anthropogenic sources of As release to the environment are disposed solid wastes and wastewater. For example, the application of sewage sludge (Tarvainen et al., 2020, Li et al., 2020a, 2020b) and mine drainage (Coudert et al., 2020) are potential sources of arsenic. Generally, As treatment of As-contaminated water, wastewater, and soils should not only maximize As removal but also should allow for the production of residues that are geochemically stable over long term (Coudert et al., 2020). Successful treatment of As-contaminated water, wastewater, and soil treatment should take into consideration appropriate disposal methods for arsenic-bearing wastes (solid or liquid wastes generated by different treatment procedures). Arsenic-bearing wastes should be disposed in environments that limit the potential risks of As release and contamination of water and food sources. Current disposal options for As-bearing wastes include landfilling, stabilization, cow dung mixing, passive aeration, pond disposal, and soil disposal (Clancy et al., 2013). Suitable environments for As-bearing wastes (solid or aquatic) are those with similar conditions under which As was mobilized (Clancy et al., 2013), for example, a passive aeration system for oxidized As-bearing wastes or anaerobic system for reduced As-bearing wastes. Additionally, it is necessary to consider microbially mediated transformations of As and Fe, and wastes should be stored in environments with limited microbial activity.

Case Study 7: The Application of Groundwater Flow Modeling for of Deep Low Aquifer at Matlab, Southeastern (von Brömssen et al., 2014)
The Matlab site in southeastern is heavily contaminated by As at shallow and intermediate depths with As concentrations up to 360 μg/L and As present mostly as As(III). On the other hand, deeper aquifers show much lower As concentrations or are As free. Switching of groundwater pumping to deeper aquifer as viable option was tested by groundwater flow modeling. Parameters for the modeling were obtained using hydraulic head monitoring, pumping tests, and ^{14}C dating. Based on the modeling results, local flow system reaches the depth about 30 m below ground surface. This is a consequence of strong anisotropy of hydraulic conductivity ($K_z/K_{x,y} < 1000$) obtained by calibration of monitoring data. Below this depth, regional flow system with much older groundwater with low As concentration is located. Currently, the risk of cross-contamination by irrigation pumping is low because irrigation pumping wells are installed in relatively shallow depth, but installation of deep irrigation wells could increase the risk in future. It is suggested to develop deeper wells for drinking water purposes, but installing deep irrigation wells is discouraged.

6 Conclusions

Arsenic is a naturally occurring element. However, anthropogenic activities such as mining metal processing and cultivation of crops change geochemical equilibrium and mobilize arsenic. Fast urbanization and industrialization also mobilize arsenic and increase its transfer to the ecosystems. High arsenic concentrations in air, soil, and in surface waters and groundwater have an impact on human health due to inhalation of As-contaminated air and ingestion of As-contaminated drinking water and food. Loss of some species living in ecosystems and decrease of cultivation producibility are the results of increasing of As concentration in aquatic environments and soil. Input of As from drinking water and food depends on many factors such as lifestyle, age, gender, race, and weight. It is necessary to consider and anticipate the changes in As mobility and bioavailability for human, animals, and plants before starting extraction of groundwater and mining, industrial, and agricultural activities or other processes changing pH-Eh conditions and geochemical equilibrium. Disposal of wastes from different sources should be done as safely as possible to reduce the possibility of As release from disposing sites to the environment. Principal methods of arsenic remediation from contaminated water and soil including adsorption, ion exchange, phytoremediation, phytobial remediation, chemical precipitation, electrokinetic processes, electrocoagulation, and membrane technology discussed in this text. We need to find more practical, economical, and eco-friendly remediation methods and technologies with a minimum waste production for As treatment. Global climate change can exacerbate water crisis and As-contaminated soil and water resources problems.

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Part IV
Climate Adaptation Monitoring and Resilience

Chapter 13
A Climate Adaptation Monitoring Tool for Sustainable Marine Planning

Juan Carlos Vargas-Moreno, Enrico Ponte, and Bob Glazer

Abstract This chapter explores an approach to address the challenge of adaptation planning in the management of marine resources under a changing climate. The authors address this challenge by developing an analytical approach to manage both uncertainties associated with the changing climate and anthropogenic changes and providing marine and coastal resource managers with a prospective assessment of the potential impacts associated with climate change on coastal and marine resources. The study presents the case of southern and central west coast of Florida in the United States, a low-lying landscape highly susceptible to various climate change impacts including sea level rise, changes in temperature and other where the authors worked with numerous scientists, managers, and a broad base of stakeholders to create a participatory process for adaptation planning. It has shown that adaptation planning must be approached in a holistic manner which considers resource vulnerabilities, identifies activities that mitigate those vulnerabilities, and includes components that identify when to implement the activities. Taken together, the approach that was outlined presents a comprehensive treatment of climate adaptation planning which addresses both the interests of species conservation and societal values, both of which must be accounted for if effective species conservation is to be achieved.

Keywords Climate adaptation · Monitoring tool · Sustainable marine planning · Florida

J. C. Vargas-Moreno · E. Ponte (✉)
GeoAdaptive LLC, Consultant, Boston, MA, USA
e-mail: eponte@geoadaptive.com

B. Glazer
Florida Fish and Wildlife Conservation Commission, Tallahassee, FL, USA

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1 Introduction

In the last 20 years, biodiversity conservation of marine ecosystems is becoming a global priority as fish stocks continue to decline, eutrophication of coastal areas is ongoing, and extinctions of marine species continue.

This article explores an approach to address the challenge of adaptation planning in the management of marine resources under a changing climate. The authors address this challenge by developing an analytical approach to manage both uncertainties associated with the changing climate and anthropogenic changes and providing marine and coastal resource managers with a prospective assessment of the potential impacts associated with climate change on coastal and marine resources. The study presents the case of southern and central west coast of Florida in the United States, a low-lying landscape highly susceptible to various climate change impacts including sea level rise, changes in temperature, and others where the authors worked with numerous scientists, managers, and a broad base of stakeholders to create a participatory process for adaptation planning.

Specifically, the study represents a prototype effort of a scenario-based approach, which will help managers and scientists identify, map, and evaluate marine species' vulnerabilities to climate change. The scenarios integrate terrestrial sources of impacts together with marine resources with the goal of identifying changes in the future coastal environment of Florida under a variety of stressors and changing conditions and to assess potential impacts to "species of greatest conservation need" (SCGN). Florida defines SGCN as "species that are imperiled or are at risk of becoming imperiled in the future" (Florida Fish and Wildlife Conservation Commission, 2012).

The study was designed to build on the previous studies that piloted the process of marine spatial scenario planning, specifically the "Implementation of a Scenario-based Model of Adaptation Planning for the South Florida Marine Environment" (KeysMAP SWG# 1253; Vargas-Moreno et al., 2013). The previous work approach was based on spatial-resilience adaptation planning – the idea that in a changing world, regional biological management activities are best targeted not at fighting change but at improving the ability of habitats and species to adjust to it. This requires both the ability to characterize the challenges and to assemble appropriate stakeholders to work together to address them.

Based on a broad consultation with experts from the Florida Fish and Wildlife Conservation Commission (FWC), the US National Oceanic and Atmospheric Administration (NOAA), and local stakeholders, the study focused on the fundamental interactions between marine resources, climate change, and management actions – a complex system characterized by dynamic and multidimensional cause-and-effect conditions taking place when natural and management changes occur simultaneously.

The work was centered on the climate change exposure to a suite of estuarine-associated fish species that share similar vulnerabilities to climate change and/or other stressors. Using this "common vulnerabilities" approach, our work went beyond vulnerability assessments to develop potential management response scenarios.

Many previous studies, including previous scenario efforts conducted in the region by the authors,[1] have focused at the scale of individual species. However, the "common vulnerabilities" approach operates at a habitat and management area scale and considers management actions that impact multiple species. While many management organizations continue to assess species-level outcomes, the first part of our process uses species' vulnerability and climate scenario analyses to systematically select species as representatives of an entire suite of species sharing common vulnerabilities. This approach aligns closely with FWC's Integrated Conservation Strategy (Florida Fish and Wildlife Conservation Commission, 2016) in which actions can be tied to several SGCN to maximize the benefits and efficiencies of interventions, rather than have a single set of strategies focused on an individual species or habitat. The concept of marine scenarios was retained from our KeysMAP study, but it is enhanced to consider potential management actions both spatially and temporally.

Marine spatial-planning scenarios are a valuable means to engage visualize with stakeholders the consequences of potential management actions interacting with environmental change. In this context, a scenario-based futures approach is different from conventional marine management. Most fundamentally, it requires not only observational data and statistical or mechanistic models based on them but also simulations that play out against future conditions beyond the range of most historical observations. Such long-term work is subject to compounding uncertainties and is generally not possible to do without making important assumptions. The major contribution of scenario planning is not that it makes uncertainty go away but rather that it manages it by making assumptions clear and providing interim guidance.

The concept of "triggers" is an important addition to traditional scenario planning, which has often been undertaken as a relatively isolated, long-term strategic process. Triggers make explicit the links between scenario projections and contingency planning and add emphasis to the importance of monitoring. Monitoring is indicated where and when projections identify potentially troublesome impacts. Meanwhile, contingency planning is needed for two reasons. First, it allows time for scientific research to be done in advance of management need. Second, it allows managers time to develop and implement policies, particularly those which are slow and complex. Policies involving major federal actions with full public review might take a longer timeframe. By estimating triggers in advance of need, this form of adaptive scenario planning can provide managers, scientists, and stakeholders critical advance notice.

In previous work by the authors, climate exposure was found to be an integrating concept well supported by newly available downscaled climate data, including the identification of potential management actions and a proposed a management strategy for considering them. In this study, the prior approach was extended in terms of

[1] See https://public.myfwc.com/crossdoi/fundedprojects/GrantDetails.aspx?ID=218

species, geographic coverage, and the development of triggers and adaptive management choices and monitoring indicators.

Ultimately, the aim of the study is to provide a systemic risk analysis framework and tool to assist authorities in the process of prioritizing from groups of species at highest risk an identification of adaptation approaches that can be monitored and adjusted in space and time. Perhaps most useful about the process was that it supported systematic thinking, across scales and management jurisdictions. In this sense, the ability to spatially simulate a subset of these scenarios as a tool to integrate both management and environmental changes allowed to capture and reduce numerous uncertainties that otherwise escape the decision process in adaptation planning. The use of scenarios provided a crucial contribution, allowing the research team to assess the likely consequences of the simulated futures on habitats and species equipping the consulted stakeholder to derive an appropriate set of adaptation measures.

The application of the approach presented in this article was limited mainly by a short project development time. This impacted the ability to develop a more systemic and exhausting process to identify stakeholders. As such there are potential knowledge gaps in the participatory process. This limitation is relevant to highlight since stakeholder process required participants to both characterize the challenges and to define monitoring indicators for the adaptation process designed.

Another potential limitation is the potential issues rising from the use of species that share similar vulnerabilities to climate change and/or other stressors. The use of the "common vulnerabilities" approach simplifies the process to design, prioritize, and monitor adaptation measures but limits the applicability of the framework and tool to the multiple specific species programs that populate today many environmental management organizations.

2 Organization of the Study

2.1 Area of Context

The study area was focused on the estuaries of Tampa Bay and Charlotte Harbor which are located on the central west coast of Florida, USA (Fig. 13.1). The Tampa Bay harbor and estuary are a heavily utilized recreation and commercial waterway bordered by the greater Tampa – St. Petersburg – Clearwater, area, one of the largest metropolitan areas in the United States with a population of 4.3 million in 2012 and an average annual growth of 2.5% based on US Census Data (https://www.census.gov/).

The area surrounding Charlotte Harbor estuary does not contain the same levels of urbanization as the Tampa Bay area. It is the second largest estuary in the state and is considered one of the most productive wetland complexes in Florida but faces threats from increasing urbanization and natural resource overuse.

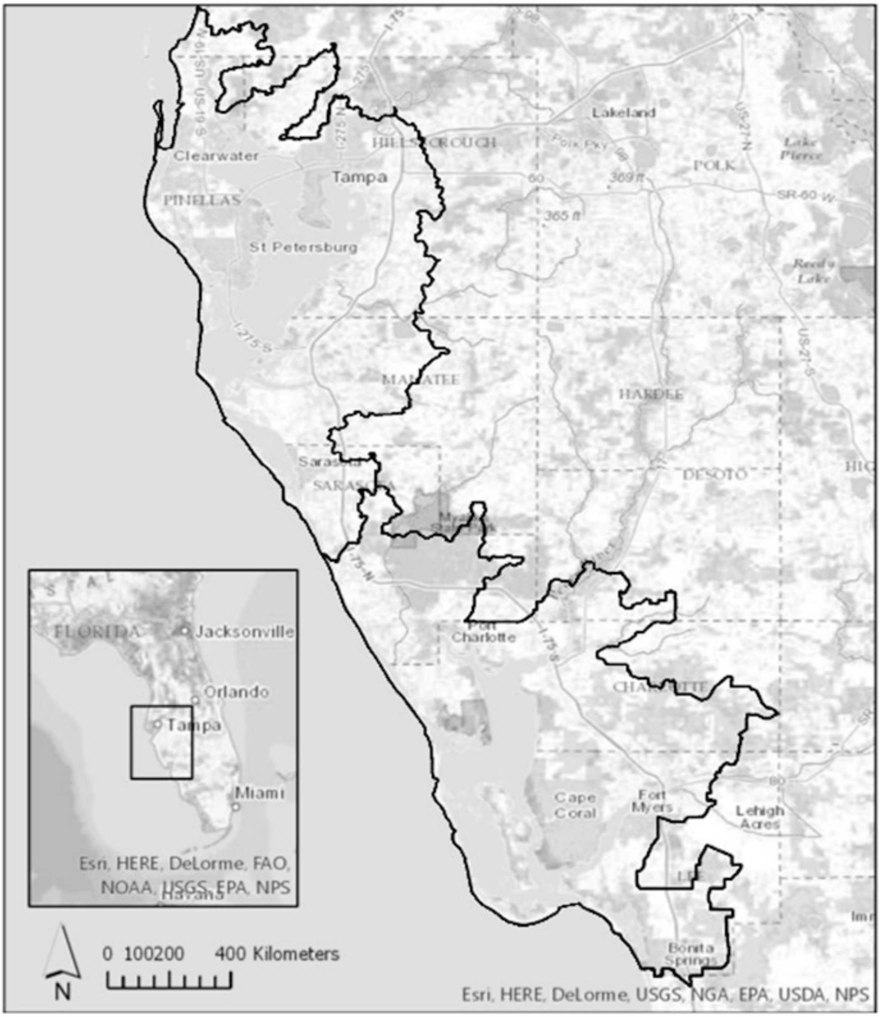

Fig. 13.1 Location of study area and extent of analysis

2.2 Future Land-Use Scenarios

The modeling process that represents potential futures for the state of Florida was produced from spatial representations of climate and land-use changes over time based on a series of drivers that were modified, depending on projections, to generate scenario outputs.

A historical baseline and several marine future scenarios were generated from expert workshops, available spatial data, and simulation modeling. Conceptually, the scenarios track IPCC Representative Concentration Pathway (RCP) Scenarios

4.5 and 8.5 (Pachauri, Rajendra et al., 2014), for climate, and previously define "business-as-usual" statewide scenarios for conservation and development) (see http://peninsularfloridalcc.org/page/climate-change-scenarios). The scenarios also leverage an extension set of data from field observations collected by FWC over the last 30 years in a program known as "Fisheries-Independent Monitoring¨ (FIM). The combination of these data sources and simulation model outputs represents a relative comprehensive and deep look at estuarine and nearshore environments as they have been measured over recent decades and are expected to respond to both climate change and continued coastal development.

The scenario set recognizes three drivers of change in the marine and estuarine environment. These include seawater temperature, salinity, and sea level rise. In the littoral environment, the drivers are salinity, vegetation change, conservation, and urbanization.

Based on these factors, three different scenarios representing two major future land-use directions were developed for the project. Scenario 1: Plan/Trend 2060 RCP 8.5 forecasts the continuation of growth rates and conservation priorities currently occurring in Florida, under a high sea level rise (1.0 m) assumption by year 2060. Scenario 2, Proactive, and Scenario 3, Proactive Plus, are similar in nature to each other but different from Scenario 1. Scenarios 2 and 3 include the assumptions that additional funds and policies would support increased conservation measures across the state and follow University of Florida's Geoplan's Critical Lands and Waters Identification Project (CLIP) conservation prioritizations.[2]

The difference between these two scenarios is the method of conservation acquisition. For all scenarios, climate change forecasts remain the same as Scenario 1 and incorporate sea surface temperature, salinity, and sea level rise as environmental drivers. Because Scenarios 2 and 3 were so similar, for this project, Scenarios 1 and 3 were assessed for the adaptation strategy processes.

Two of the three scenarios, which were developed for use in the species exposure analyses, were chosen for further integration into the adaptation strategy assessment portion of the project. Considering the importance of the different drivers that are altered depending on the scenario chosen, the variables were integrated for Scenario 1 Plan/Trend and Scenario 3 Proactive Plus into the STAPLEE (Social, Technical, Administrative, Political, Legal, Economic, and Environmental) methodology (see Adaptation Prioritization section). These two scenarios recognize six drivers of change: SST (sea surface temperatures), salinity, SLR (sea level rise), changes in salt tolerant coastal vegetative species, conservation areas, and urbanization areas. The scenarios forecast different configurations of potential outcomes by varying the intensity or development of the drivers. The scenarios' potential effect on the prioritization and selection of relevant adaptation strategies was examined by creating a separate STAPLEE chart for each scenario. Ranking of the criteria was performed

[2] CLIP stands for Critical Lands and Waters Identification Project (CLIP) a geospatial identification of critical lands for Conservation in Florida, developed by researchers at the University of Florida, USA. See Version 4.0. Technical Report – September 2016. Jon Oetting, Tom Hoctor, and Michael Volk

for each scenario, considering its assumptions, drivers, and potential outcomes on the environment and species in question.

2.3 Participatory Workshops

Two participatory workshops were held to gain information, direct project efforts, collect opinions from biological and ecological experts in the region, and formulate baseline data. The first workshop, held in April 2015, involved estuarine and coastal marine species and habitat experts to develop suites of species, which both represented the range of habitats in the bays and were sensitive to climate change stressors. The description of species suites indicates both the pros and cons of using species representatives; however, in this case a "common vulnerabilities" approach allows for groups of similar species to be considered in subsequent analyses through the representation of each ecosystem by a single species:

> These suites are designed to represent a "coarse filter" from a conservation planning point of view. They are purposefully chosen to be representative of the common vulnerabilities faced by a much larger set of species using Southwest Florida's coastal waters. While there is always some potential for bias in selecting any form of indicator or umbrella species, in this case the risk was mitigated using an electronically-enhanced Delphi process and an abbreviated form of a well-tested Climate Vulnerability Process previously developed by NOAA.[3]

The results of the first workshop determined a species representative for each of the 12 estuarine and coastal habitat types in question, as well as a representative species for all estuarine and coastal habitat types.

3 Methodology Overview

The identification and stressor-specific prioritization of potential adaptation strategies represents the core of the study and the first phase of work. Strategies were assembled from the result of a participatory workshop with biological and ecological experts and integrated with additional strategies gathered from literature review and case studies from similar geographical areas. The resulting 27 potential adaptation strategies were divided in 3 groups: nonstructural, structural, and combined strategies.

[3] The key previous work developed by the National Oceanic and Atmospheric Administration (NOAA) include the 2010. Adapting to Climate Change: A Planning Guide for State Coastal Managers. NOAA Office of Ocean and Coastal Resource Management. http://coastalmanagement.noaa.gov/climate/adaptation.html

The STAPLEE methodology[4] used by the Federal Emergency Management Agency (FEMA, 2003) was adapted for this project to prioritize the adaptation strategies. This methodology was implemented using specific indicators tailored to the geographic area. The STAPLEE method was completed twice for two different alternative future scenario models to illustrate the differentiation of each scenario's effects on strategy prioritization. The team considered the different impacts on each of the STAPLEE method's criteria according to the description of each scenario (Scenario 1, Plan/Trend, or Scenario 3, Proactive Plus; see Sect. 2.3 for complete descriptions of scenarios).

The results coming from the modified STAPLEE methodology were integrated with a subjective assessment of each strategy's potential to reduce climate vulnerability for the project's focal species. The method uses seven criteria for evaluating a mitigation action (social, technical, administrative, political, legal, economic, and environmental), and each criterion is divided into sub-indicators that are evaluated individually using a scoring procedure. At the end of the process, final rankings of each adaptation strategy for the two different scenarios and for each focal species are presented.

The second phase of the project identified and determined climate change exposure triggers (=trigger points) which initiate adaptation strategies to increase resilience of the species to the identified climate stressors. Specific triggers were identified for three indicators of climate change that affect estuarine species and their habitats: sea surface temperature, salinity, and shoreline change. The shoreline change indicator was divided into three sub-indicators: (1) erosion rate, (2) persistence of saline wetlands, and (3) persistence of mangroves. The trigger values for these three indicators were defined based on literature review, expert opinion, and collected biological information, such as focal species' thermal and saline thresholds. These specific factors will be described in the results section of this study.

The final phase of the project developed two important programs: a suite of monitoring programs that help inform when the triggers are reached and a monitoring tool associated with each indicator and trigger to inform managers which adaptation strategies to initiate upon being triggered. Tracking the tool phase by phase, it is possible to follow the entire process of the project through to the determination of the most appropriate adaptation strategies to be implemented, dependent on the scenario chosen.

The participatory and consultative workshops represented a structural component of the study. As such the authors began its analysis by first hosting a series of workshop discussions on the scenario exposure and adaptation strategies in January 2016. In this workshop, the participants were presented with the results of the exposure assessments developed and were asked to evaluate and rank the degree of

[4] STAPLEE allows emergency managers to apply a consistent analysis to the range of mitigation options they are considering. The term STAPLEE is an acronym that stands for the following evaluation criteria: social technical, administrative, political, legal, economic, and environmental. Each of these terms represents an opportunity or constraint to implement s particular mitigation option.

significance of the potential stressors (sea surface temperature, salinity, and coastal change) on the representative species for each ecosystem. The participants felt that for most of the species, exposure significance was predicted to be minimal to moderate. Only a handful of species, mostly estuarine representatives, received votes for potentially high exposure impacts. The final tally indicated that experts felt three species (two estuarine, one coastal) would be negatively impacted by rising sea surface temperatures; three species (two estuarine, one coastal) would be negatively impacted by rising salinities; and that six species (three estuarine, three coastal) would be negatively impacted by coastal changes.

The second part of the workshop entailed a brainstorming session, asking participants to suggest a comprehensive list of potential adaptation strategies applicable to each stressor for the impacted species and management areas in question. The brainstorming session originally focused on areas of each estuary subdivided by location, but it soon became apparent that the participants felt the suggested strategies should be applicable to all locations throughout the estuaries in either location. It was decided to divide the suggested list of strategies into three categories based on the method of implementation: policy, management-based, or nonstructural strategies (10), physical implementation-based or structural strategies (9), and a third category, which includes strategies that combine both structural and nonstructural elements (6).

Salinity modeling – Environmental data for Charlotte Harbor, Tampa Bay, and Florida Bay including the nearby coastal zones were obtained from the Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute's Fisheries-Independent Monitoring Program. The data were separated into two classes representing the summer (i.e., rainy season: May 15th to October 14th) and the winter season (October 15th to May 14th). Using ArcGIS Pro, the data were further subdivided into two geographic regions representing Tampa Bay and Charlotte Harbor. Kernel Interpolation with barriers (i.e., excluding land) was used to create three classes of salinity: (1) fresh/brackish water: 0 ppt–17 ppt, 2) saline:17–35 ppt, and 3) > 35 ppt. Interpolated salinity values outside a realistic range (i.e., <0 ppt) were removed.

To develop future scenarios representing current (i.e., "normal") conditions, RCP 4.5 and RCP 8.5, rasters were created which were based on the historical salinity data. To accomplish this, a polygon was created using the area where salinity was estimated to have values of 0–17 ppt because it was concluded that this class will see the greatest change under future climate change scenarios. These data points were imported into SPSS (Statistical Package for Social Science) and, based on results from an ANOVA (analysis of variance), split into five bins based on years according to average salinities. The first bin included the 2 most saline years in the dataset, the second bin was comprised of the next 4 high-salinity years, the third bin was made up of 15 years with salinities in the middle range of the distribution, and the last two bins were made up of the 6 years with the lowest salinities, and these were not used in constructing the rasters.

Scenarios were developed from maps created from the bins. The first bin was used to represent RCP 8.5, and the second highest salinity bin was used in making a raster that represents RCP 4.5. The remaining 15 years represented the "normal" state of the estuaries. The 6 years with the lowest salinities were left out of the raster creation.

4 Results

4.1 Adaptation Strategies Identification

4.1.1 Description of the Strategies

Based on relevant literature and team experience, the research team organized the adaptation strategies into three different groups: nonstructural, structural, and combined strategies.

Nonstructural strategies are those that reduce the effects of a hazard using nonphysical solutions such as land-use planning, zoning, early warning systems, simulations, policies, laws, etc. (UNISDR, 2009; FIFMTF, 1992). The nonstructural measures may be proposed by public or private initiatives. There are many stakeholders who can implement such measures including government authorities, NGOs, international organizations, and private sector companies. NOAA's habitat restoration program calls these types of projects "passive restoration, which involves changes to management practices and use of landscapes."

Structural measures for mitigation are those that reduce the effects of a hazard involving a physical intervention such as dams, dykes, levees, elevated buildings, retaining walls, seawalls, etc. (UNISDR, 2009; FIFMTF, 1992). NOAA's habitat restoration program calls these types of projects "active restoration, which involves 'on-the-ground' or 'dirt-moving' activities." Usually, these are traditional engineering strategies that require a significant financial investment but are only designed to address a specific type and intensity of hazard. These types of strategies are typically at odds with conservation and natural systems and can reduce local species' resilience to extreme events, as well as affect overall ecosystem function.

An initial list of adaptation strategies was derived using brainstorming in a workshop within which participants proposed a comprehensive list of potential adaptation strategies applicable to each stressor for the impacted species and management areas in question. A literature review was also conducted with the goal of identifying case studies that addressed similar approaches and provided the case studies provided additional adaptation approaches.

The case studies were also used to provide information to evaluate the strategies including (1) the potential impacts on species and ecosystems, (2) the cost of implementation, (3) popular or political support, and (4) degrees of success. The strategies derived within the workshop were supplemented by the additional strategies from the case study review, and a final list of 27 potential adaptation strategies was created. The list consisted of 12 nonstructural strategies, 9 structural strategies, and 6 combination strategies (Table 13.1). Of the nine structural strategies, four were related to the temperature stressor, further four were related to the salinity stressor, and one was related to the shoreline change stressor. Of the nonstructural adaptation strategies, two addressed temperature, two addressed salinity, and eight addressed the shoreline change. For the mixed structural/nonstructural category, two addressed temperature, one addressed salinity, and three addressed shoreline changes (Table 13.1). Subsequently, the adaptation strategies were subdivided according to the three different triggers. These are addressed in the subsequent section.

4.1.2 Adaptation Strategies Prioritization

Standard advice from business and economics is to invest in activities where the rates of return on investment (ROI) are the highest (Wilson et al., 2007). For this approach to be most effective, an explicit statement of overall objectives is required (Klein et al., 2010). ROI has been applied to the conservation of terrestrial biodiversity (Murdoch et al., 2007), but it has yet to be applied to marine conservation.

A literature review was performed to identify the best methodology for prioritizing adaptation strategies based on ROI. The STAPLEE methodology developed by FEMA (FEMA, 2003) was selected as a prioritization criteria tool because of its holistic approach that addresses many issues of societal importance. This method uses seven criteria for evaluating an adaptation action: social, technical, administrative, political, legal, economic, and environmental. Each criterion is divided into sub-indicators that are scored individually. This methodology is used to examine opportunities (benefits) and constraints (costs) of implementing each action from the perspective of all seven of the STAPLEE criteria. The goal of prioritizing the list of potential strategies is to assist managers in directing the flow of funds and effort to effectively address the stressors identified in the analysis.

The evaluation of each adaptation strategy was informed by the criteria of each STAPLEE category (Table 13.2) and was adapted specifically for this project by including elements from KeysMAP. Questions used to assess each category were also developed to better guide the evaluation. The associated scores were weighted in three different levels: three for easy/yes/low, two for moderate/maybe/medium, and one for unfeasible/no/high (Table 13.3).

4.1.3 Species as a Strategy Prioritization Tool

Ultimately, the objective for prioritizing adaptation strategies for this study was to determine which strategy(ies) have the greatest effectiveness in reducing vulnerability of specific species to climate change stressors. One species was selected by experts as representative from each of six (estuarine) or seven (coastal) habitats representing the full range of environments in the study area (Table 13.4). The selections were based on information available on its life history and habitat associations. The species were selected based on consideration if the species was SGCN, the importance of the species as an FWC managed species, and/or if the species is

Table 13.1 Adaptation strategies identified by category. Stressors addressed by each category are temperature (T), salinity (S), and shoreline change (Sc)

Adaptation strategy	Stressor addressed
Nonstructural strategies	
1. Reduce groundwater withdrawal in the watershed, better groundwater	S
management	Sc
2. Conservation and land-use policies that limit sprawl development	T
3. Design water discharge to focus on historically important areas of the	T
critical life history stages of these fish	Sc
4. Manage for high temperature-sensitive fish	Sc
5. Tax breaks for reducing shoreline hardening; incentivize natural shorelines	Sc
6. Determine relevance of Comprehensive Everglades restoration plan (CERP)	Sc
and initiate applicable measures	Sc
7. Establish slow speed/no wake zones to reduce shoreline erosion	Sc
8. Education of homeowner associations and politicians on benefits of soft	Sc
shoreline engineering alternatives	Sc
9. Prohibit physical coastal structures from being built	
10. Define needed marine migration corridors and integrate those areas into	
conservation through incentives	
11. Public education and outreach to foster a broad awareness of climate	
change issues	
12. Minimizing the impacts of any future development on the highest priority	
areas for biodiversity	
Structural strategies	
1. Increase vegetation cover along shoreline and along tributaries to provide	T
shade and to reduce evapotranspiration	T
2. More shading along ponds, ditches, and canals to moderate temps of storm	T, Sc
water flow within drainage systems into bay	T
3. Reduce shoreline hardening; increase living shorelines	T, Sc
4. Divert cooler deep water to coastal areas	S
5. Hybrid shorelines where natural shorelines are put ocean-side of the	S
hardened shorelines	S
6. Cloud seeding	
7. Private sector storage such as water farming or dispersed water storage,	
followed by better water operations/releases to address salinity increases	
8. Engineer pipelines for water discharge into areas of high salinity	
Structural and nonstructural strategies	
1. Reclaim, reuse, and discharge treated stormwater used in urban activities to	S
increase freshwater flows to estuary	S
2. Creation of a system dynamics model and increased governance capacity, to	T
balance freshwater flows to estuaries during periods of water stress (high	Sc
salinities)	Sc
3. Eliminate unnatural features that minimize water circulation	Sc
4. Beneficial reuse of clean dredge materials (creation of wetlands, islands,	
shoreline stabilization)	
5. Removal of barriers (political, regulatory, urban) to inland migration of	
habitats	
6. Restore purchased properties to reduce flooding hazards rather than just	
removing the structure(s) and maintaining parkland	

Table 13.2 Adaptation of the STAPLEE methodology to the prioritization of climate adaption strategies for Florida

STAPLEE category	Criteria and questions associated with each category
Social	The public must support the overall implementation strategy and specific mitigation actions
Community acceptance	*Is the proposed action socially acceptable to the community?*
Equal impacts on population	*Are there equity issues involved that would mean that one segment of a community is treated unfairly?*
Technical	
Technically feasible	*Is the technology developed enough to implement successfully?*
Secondary impacts	*Will it create more problems than it solves?*
Habitat restoration	*Is it the most useful action with respect to other community(s) goals?*
Administrative	Is there staffing, funding, and maintenance capacity to implement the action?
Staff competency	*Can the community(s) implement the action?*
Maintenance/ operations needs	*Is there sufficient capacity (*i.e.*, funding, staff, and technical support) available?* (criteria from KeysMAP project)
Political	
Political support	*Is the action politically acceptable?*
Public support	*Is there public support both to implement and to maintain the project?*
Legal	Without the appropriate legal authority, the action cannot be implemented
State and federal authority	*Is there a clear legal basis or precedent for this activity?*
Existing local authority	*Will the community(s) be liable for action or lack of action?*
Land-use policy	*Is the proposed action allowed by a comprehensive land policy?*
Economic	States and local communities with tight budgets may be more willing to undertake a mitigation initiative if it can be funded, at least in part, by outside sources. "Big ticket" adaptation actions, such as large-scale acquisition and relocation, are often considered for implementation in a post-disaster scenario when additional federal and state funding for mitigation is available
Benefit of action	*What are the costs and benefits of this action? Do the benefits exceed the costs?*
Cost of action (criteria from KeysMAP project)	*Are initial, maintenance, and administrative costs taken into account? Has funding been secured for the proposed action?*
Contributed to the economic goals	*How will this action affect the fiscal capability of the community(s)?*
Financial sustainability	*Does the action contribute to other community goals?*
Environmental	Impact on the environment is an important consideration because of public desire for sustainable and environmentally healthy communities
Effect on land/ water	*How will the action affect the environment?*

(continued)

Table 13.2 (continued)

STAPLEE category	Criteria and questions associated with each category
Consistent with community environmental goals	*Will the action need environmental regulatory approvals?*

imperiled. Vulnerability to future climate conditions was assessed for the selected species by the experts using the NOAA climate change vulnerability calculator within the MeetingSphere Group Decision Support Systems online application (www.meetingsphere.com).

Each adaptation strategy was evaluated for each indicator species to determine its effectiveness at mitigating the effects of climate change by scoring the strategy in a manner similar to the STAPLEE methodology criteria. For each species, a criteria ranking coefficient was used (1 yes, 2 maybe, 3 no) to score the potential effectiveness of the strategy at reducing vulnerability to climate change stressors. Total scores for each species were multiplied by a factor of ten and added to the STAPLEE output scores to create a spread in the resulting scores. The adaptation strategies receiving higher overall scores imply that they will be more effective at addressing the species' vulnerability(ies). In that respect, the final ranks are obtained by: STAPLEE methodology rank + (species coefficient × 10).

The final ranks were scored with a total value greater than 60 as positive (triangles), neutral with a total value less than 60 but greater than 50 (question marks), and not significant when the total value was less than 50 (circles) (Table 13.5).

To evaluate the efficacy of each adaptation strategy, an average value was calculated for each strategy and applied the same final ranking classification.

4.2 Identification of Triggers

Triggers, or "trigger points," are critical for identifying thresholds beyond which adverse outcomes occur. These are also the points at which adaptation options should have been implemented to mitigate the impacts of the stressor.

The experts identified triggers for species associated with tolerance levels for the temperature (Table 13.6) and salinity (Table 13.7). A third stressor, physical changes to the coast was based on a combination of sea level rise impacts, conversion of upland habitat types to wetland, and the shifting of mangrove habitats within the estuaries. The thresholds were identified from the scientific literature and input from species' experts.

The triggers were used to determine the risks of exposure to adverse future conditions. Using the predicted future conditions from the spatially explicit modeling outputs, the experts evaluated the degree of exposure of each indicator species to three climate stressors and ranked the significance of this forecasted exposure from "no significant exposure" to "high significance." The species chosen for further

Table 13.3 Ranking adaptation strategies related to the shoreline change stressor for Scenario 1: Plan/Trend

		Geographic area		STAPLEE methodology																		
				Social		Technical			Administrative		Political		Legal			Economic				Environment		
Strategy	Structural (S), non-structural (NS)	Tampa Bay	Charlotte Harbor	Community acceptance	Equal impacts on population	Technically Feasible[a]	Secondary impacts	Habitat Restoration	Staff competency	Maintenance/operations needs[a]	Political support	Public support	State and federal authority	Existing local authority	Land use policy S1	Benefit of action	Cost of action ($)[a]	Contributes to economic goals	Financial sustainability	Effect on land/ water	Consistent with community environmental goals	Total Score S1 (Plan/Trend)
Shoreline changes stressor																						
Erosion rate																						
Reduce shoreline hardening; increase living shorelines	S, NS	x	x	2	2	3	2	2	3	3	2	2	2	2	1	3	2	1	2	3	2	**39**
Tax breaks for reducing shoreline hardening; incentivize natural shorelines	NS	x	x	3	3	3	1	2	3	2	2	3	2	2	1	3	1	3	2	2	2	**40**
Beneficial reuse of clean dredge spoil	S, NS	x	x	1	2	2	2	2	2	2	2	2	3	1	1	2	1	3	2	2	2	**34**
Establish slow speed/ no wake zones to reduce shoreline erosion	NS	x	x	1	1	2	1	1	2	2	2	2	3	3	1	2	1	2	1	1	2	**30**

(continued)

Table 13.3 (continued)

		Geographic area		STAPLEE methodology																		
				Social		Technical			Administrative		Political		Legal			Economic				Environment		
Strategy	Structural (S), non-structural (NS)	Tampa Bay	Charlotte Harbor	Community acceptance	Equal impacts on population	Technically Feasible[a]	Secondary impacts	Habitat Restoration	Staff competency	Maintenance/operations needs[a]	Political support	Public support	State and federal authority	Existing local authority	Land use policy S1	Benefit of action	Cost of action ($)[a]	Contributes to economic goals	Financial sustainability	Effect on land/ water	Consistent with community environmental goals	Total Score S1 (Plan/Trend)
Education of homeowner associations and politicians on benefits of soft shoreline	NS	x	x	3	3	3	2	2	3	3	3	2	3	3	2	3	3	3	2	1	1	**45**
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	2	1	2	2	2	2	2	2	2	2	3	1	2	2	3	2	3	2	**37**
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools	NS	x	x	3	1	3	2	1	2	3	3	3	3	3	2	3	3	2	3	2	2	**44**

Conservation and land use policies that limit sprawl development	NS	x	x	2	2	3	2	2	2	3	1	2	2	3	1	2	1	1	2	3	2	**36**
Prohibit physical coastal structures from being built	NS	x	x	2	3	2	3	2	2	2	2	2	2	3	1	3	3	3	1	2	1	**39**
Saline wetlands extent																						
Restore properties that are purchased to reduce flooding hazards rather than just removing the structure and maintain parkland – Allow it to revert to marsh/mangrove to provide services	S, NS	x	x	2	1	3	2	2	2	2	2	2	3	3	1	2	2	2	2	1	2	**36**
Removal of barriers (political, regulatory, urban) to inland migration of habitats	S, NS	x	x	2	1	2	3	2	1	2	2	2	3	3	1	2	2	3	3	3	2	**39**
Beneficial reuse of clean dredge spoil	S, NS	x	x	1	2	2	2	2	2	2	2	2	3	1	1	2	1	3	2	2	2	**34**
Education of homeowner associations and politicians on benefits of soft shoreline	NS	x	x	3	3	3	2	2	3	3	3	2	3	3	2	3	3	3	2	1	1	**45**

(continued)

Table 13.3 (continued)

		Geographic area		STAPLEE methodology																		
				Social		Technical			Administrative		Political		Legal			Economic				Environment		
Strategy	Structural (S), non-structural (NS)	Tampa Bay	Charlotte Harbor	Community acceptance	Equal impacts on population	Technically Feasible[a]	Secondary impacts	Habitat Restoration	Staff competency	Maintenance/operations needs[a]	Political support	Public support	State and federal authority	Existing local authority	Land use policy S1	Benefit of action	Cost of action ($)[a]	Contributes to economic goals	Financial sustainability	Effect on land/ water	Consistent with community environmental goals	Total Score S1 (Plan/Trend)
Prohibit physical coastal structures from being built	NS	x	x	2	3	2	3	2	2	2	2	2	2	3	1	3	3	3	1	2	1	**39**
Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives	NS	x	x	2	1	2	2	2	2	2	2	2	2	2	1	2	2	3	2	3	2	**36**
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	2	1	2	2	2	2	2	2	2	2	3	1	2	2	3	2	3	2	**37**

Minimizing the impacts of any future development on the highest priority areas for biodiversity	NS	x	x	1	1	2	2	2	3	2	2	2	3	3	1	3	3	2	2	2	2	**38**
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools	NS	x	x	3	1	3	2	1	2	3	3	3	3	3	2	3	3	2	3	2	2	**44**
Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures	NS		x	2	2	2	3	2	3	3	2	2	3	2	2	2	1	2	2	3	2	**40**
Mangrove extent and migration																						
Minimizing the impacts of any future development on the highest priority areas for biodiversity	NS	x	x	1	1	2	2	2	3	2	2	2	3	3	1	3	3	2	2	2	2	**38**

(continued)

Table 13.3 (continued)

Strategy	Structural (S), non-structural (NS)	Geographic area		STAPLEE methodology																		Total Score S1 (Plan/Trend)
				Social		Technical			Administrative		Political		Legal			Economic				Environment		
		Tampa Bay	Charlotte Harbor	Community acceptance	Equal impacts on population	Technically Feasible[a]	Secondary impacts	Habitat Restoration	Staff competency	Maintenance/operations needs[a]	Political support	Public support	State and federal authority	Existing local authority	Land use policy S1	Benefit of action	Cost of action ($)[a]	Contributes to economic goals	Financial sustainability	Effect on land/ water	Consistent with community environmental goals	
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools	NS	x	x	3	1	3	2	1	2	3	3	3	3	3	2	3	3	2	3	2	2	**44**
Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures	NS		x	2	2	2	3	2	3	3	2	2	3	2	2	2	1	2	2	3	2	**40**
Removal of barriers (political, regulatory, urban) to inland migration of habitats	S, NS	x	x	2	1	2	3	2	1	2	2	2	3	3	1	2	2	3	3	3	2	**39**

Restore properties that are purchased to reduce flooding hazards rather than just removing the structure and maintain parkland – Allow it to revert to marsh/mangrove to provide services	S, NS	x	x	2	1	3	2	2	2	2	2	2	3	3	1	2	2	2	2	1	2	**36**
Prohibit physical coastal structures from being built	NS	x	x	2	3	2	3	2	2	2	2	2	2	3	1	3	3	3	1	2	1	**39**
Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives	NS	x	x	2	1	2	2	2	2	2	2	2	2	2	1	2	2	3	2	3	2	**36**
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	2	1	2	2	2	2	2	2	2	2	3	1	2	2	3	2	3	2	**37**

[a]Criteria coming from the first "KeysMAP" project
Easy / yes / Low 3
Medium / maybe / medium 2
Unfeasible / no / high 1
Non-structural strategy: Does not change the natural hazard but involves preventative actions such as policy or management that improve infrastructure to reduce the damages or improve coordination of resources
Structural strategy: Inhibit a natural hazard through construction such as a sea wall or physically improve a condition of the environment

Table 13.4 Habitat and the species selected by experts to represent environments for southwest Florida estuaries and coastal zones. "All systems" represents species found throughout the entire estuarine system. Superscripts indicate species that were identified as vulnerable to temperature (t), salinity (s), or coastal changes (c)

Habitat	Representative species selected
Estuarine	
Mangrove fringe	Gray snapper (*Lutjanus griseus*)^{s}
Upper estuary (freshwater to brackish water)	Red drum (*Sciaenops ocellatus*)
Lower estuary	Spotted sea trout (*Cynoscion nebulosus*)^{t,s,c}
Open water estuary	Tarpon (*Megalops atlanticus*)
Benthic estuary/seagrass	Lined seahorse (*Hippocampus erectus*)^{t,s,c}
All systems	Pink shrimp (*Farfantepenaeus duorarum*)^{c}
Coastal	
Mangrove fringe	Gray snapper (*Lutjanus griseus*)^{s}
Seagrass	White grunt
Tidal flat	Bonefish
Coastal/tidal river	Smalltooth sawfish
Bivalve reef	Red drum (*Sciaenops ocellatus*)^{t,c}
Beach/surf zone	Pompano
All systems	Striped mullet^{c}

analysis are those ranked by experts as most likely to sustain moderate or greater exposure to the stressors.

For both the temperature and salinity stressors, three species for each stressor were ranked by experts as being sensitive to exposure: these species were used as representatives of value ranges with maximum thresholds. The maximum threshold for each range of values becomes the trigger for that range, and each range with its trigger is termed a "bin." Triggers for each tolerance bin were calculated based on the 95% percentile of each tolerance groups' maximum tolerance limit (Tables 13.6 and 13.7). By using these "tolerance thresholds" as triggers for adaptation activities, the adaptation activities are implemented prior to the tolerance limit being reached.

4.2.1 Sea Surface Temperature Indicator and Trigger Development

Measurements of SST have been collected and recorded by FIM trawl-sampling data in and around Tampa Bay and Charlotte Harbor estuaries since the mid-1990s (FWRI, 2016). These data were used to determine the historical and potential future temperature profiles based on the predicted number of days that temperatures and salinities will exceed thresholds in the different estuarine habitats. For each of the representative species, GIS maps were developed to spatially depict predicted exposure of each of the sensitive species to SST under Scenario 1: Plan/Trend RCP8.5 to 2060.

Table 13.5 Ranking adaptation strategies to species prioritization – shoreline change stressor (output for Scenario 1: Plan/Trend)

Strategy	Structural (S), non-structural (NS)	Geographic: Tampa Bay	Geographic: Charlotte Harbor	TOTAL score S1 (Plan/Trend)	Coastal species: Southern stingray (Dasyatis americana) Unconsolidated Bottom – Species coefficient	Coastal species: Southern stingray (Dasyatis americana) Unconsolidated Bottom – **Final rank S1**	Coastal species: Red drum (Sciaenops occellatus) Bivalve Reef – Species coefficient	Coastal species: Red drum (Sciaenops occellatus) Bivalve Reef – **Final rank S1**	Coastal species: Striped mullet (Mugil cephalus) All Coastal Species – Species coefficient	Coastal species: Striped mullet (Mugil cephalus) All Coastal Species – **Final rank S1**	Estuarine species: Spotted seatrout (Cynoscion nebulosus) Lower Estuary – Species coefficient	Estuarine species: Spotted seatrout (Cynoscion nebulosus) Lower Estuary – **Final rank S1**	Estuarine species: Pink Shrimp (Farfantepenaeus duorarum) All Estuarine Systems – Species coefficient	Estuarine species: Pink Shrimp (Farfantepenaeus duorarum) All Estuarine Systems – **Final rank S1**	Estuarine species: Lined Seahorse (Hippocampus erectus) Benthic Estuary/Seagrass – Species coefficient	Estuarine species: Lined Seahorse (Hippocampus erectus) Benthic Estuary/Seagrass – **Final rank S1**	Average score
Shoreline changes stressor																	
Erosion rate																	
Reduce shoreline hardening; increase living shorelines	S, NS	x	x	**39**	2	**! 59**	3	**✓ 69**	3	**✓ 69**	2	**! 59**	3	**✓ 69**	3	**✓ 69**	**● 66**
Tax breaks for reducing shoreline hardening; incentivize natural shorelines	NS	x	x	**40**	2	**✓ 60**	2	**✓ 60**	2	**✓ 60**	2	**✓ 60**	3	**✓ 70**	3	**✓ 70**	**○ 67**
Beneficial reuse of clean dredge spoil	S, NS	x	x	**34**	2	**! 54**	1	**× 44**	2	**! 54**	1	**× 44**	2	**! 54**	1	**× 44**	**◆ 47**
Establish slow speed/no wake zones to reduce shoreline erosion	NS	x	x	**30**	3	**✓ 60**	3	**✓ 60**	2	**! 50**	2	**! 50**	2	**! 50**	3	**✓ 60**	**Δ 53**
Education of homeowner associations and politicians on benefits of soft shoreline	NS	x	x	**45**	2	**✓ 65**	2	**✓ 65**	3	**✓ 75**	3	**✓ 75**	2	**✓ 65**	2	**✓ 65**	**○ 68**
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	**37**	2	**! 57**	2	**! 57**	2	**! 57**	3	**✓ 67**	2	**! 57**	2	**! 57**	**○ 60**

continued

Table 13.5 (continued)

Strategy	Structural (S), non-structural (NS)	Geographic: Tampa Bay	Geographic: Charlotte Harbor	TOTAL score S1 (Plan/Trend)	Coastal species: Southern stingray (Dasyatis americana) Unconsolidated Bottom – Species coefficient	Southern stingray – **Final rank S1**	Red drum (Sciaenops ocellatus) Bivalve Reef – Species coefficient	Red drum – **Final rank S1**	Striped mullet (Mugil cephalus) All Coastal Species – Species coefficient	Striped mullet – **Final rank S1**	Estuarine species: Spotted seatrout (Cynoscion nebulosus) Lower Estuary – Species coefficient	Spotted seatrout – **Final rank S1**	Pink Shrimp (Farfantepenaeus duorarum) All Estuarine Systems – Species coefficient	Pink Shrimp – **Final rank S1**	Lined Seahorse (Hippocampus erectus) Benthic Estuary/Seagrass – Species coefficient	Lined Seahorse – **Final rank S1**	Average score
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awarness using photo and other visualization tools	NS	x	x	**44**	2	**✓ 64**	2	**✓ 64**	1	**! 54**	2	**✓ 64**	2	**✓ 64**	2	**✓ 64**	○ **64**
Conservation and land use policies that limit sprawl development	NS	x	x	**36**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	Δ **56**
Prohibit physical coastal structures from being built	NS	x	x	**39**	3	**✓ 69**	3	**✓ 69**	3	**✓ 69**	3	**✓ 69**	2	**! 59**	2	**! 59**	○ **62**
Saline wetlands extent																	
Restore properties that are purchased to reduce flooding hazards rather than just removing the structure and maintain parkland- allow it to revert back to marsh/mangrove to provide services	S, NS	x	x	**36**	1	**× 46**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	2	**! 56**	Δ **56**
Removal of barriers (political, regulatory, urban) to inland migration of habitats	S, NS	x	x	**39**	1	**× 49**	2	**! 59**	2	**! 59**	1	**× 49**	1	**× 49**	1	**× 49**	◆ **49**
Beneficial reuse of clean dredge spoil	S, NS	x	x	**34**	2	**! 54**	1	**× 44**	2	**! 54**	1	**× 44**	2	**! 54**	1	**× 44**	◆ **47**
Education of homeowner associations and politicians on benefits of soft shoreline	NS	x	x	**45**	2	**✓ 65**	2	**✓ 65**	3	**✓ 75**	3	**× 75**	2	**✓ 65**	2	**✓ 65**	○ **68**

Prohibit physical coastal structures from being built	NS	x	x	39	3	✓ 69	3	✓ 69	3	✓ 69	3	✓ 69	2	! 59	2	! 59	○ 62
Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives	NS	x	x	36	3	✓ 66	3	✓ 66	2	! 56	3	✓ 66	2	! 56	3	✓ 66	○ 63
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	37	2	! 57	2	! 57	2	! 57	3	× 67	2	! 57	2	! 57	○ 60
Minimizing the impacts of any future development on the highest priority areas for biodiversity	NS	x	x	38	2	! 58	3	✓ 68	2	! 58	2	! 58	2	! 58	2	! 58	∆ 58
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awarness using photo and other visualization tools	NS	x	x	44	2	✓ 64	2	✓ 64	1	! 54	2	✓ 64	2	✓ 64	2	✓ 64	○ 64
Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures	NS		x	40	2	✓ 60	2	✓ 60	2	✓ 60	1	! 50	2	✓ 60	2	✓ 60	∆ 57
Mangrove extent and migration																	
Minimizing the impacts of any future development on the highest priority areas for biodiversity	NS	x	x	38	2	! 58	3	✓ 68	2	! 58	2	! 58	2	! 58	2	! 58	∆ 58
Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools	NS	x	x	44	2	✓ 64	2	✓ 64	1	! 54	2	✓ 64	2	✓ 64	2	✓ 64	○ 64
Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures	NS		x	40	2	✓ 60	2	✓ 60	2	✓ 60	1	! 50	2	✓ 60	2	✓ 60	∆ 57
Removal of barriers (political, regulatory, urban) to inland migration of habitats	S, NS	x	x	39	1	× 49	2	! 59	2	! 59	1	× 49	1	× 49	1	× 49	◆ 49
Restore properties that are purchased to reduce flooding hazards rather than just removing the structure and maintain parkland- allow it to revert back to marsh/ mangrove to provide services	S, NS	x	x	36	1	× 46	2	! 56	2	! 56	2	! 56	2	! 56	2	! 56	∆ 56
Prohibit physical coastal structures from being built	NS	x	x	39	3	✓ 69	3	✓ 69	3	✓ 69	3	✓ 69	2	! 59	2	! 59	○ 62
Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives	NS	x	x	36	3	✓ 66	3	✓ 66	2	! 56	3	✓ 66	2	! 56	3	✓ 66	○ 63
Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines	S	x	x	37	2	! 57	2	! 57	2	! 57	3	✓ 67	2	! 57	2	! 57	○ 60

Table 13.6 SST indicator bins and related trigger values. All values are in C^{0}

	Low-tolerance species bin	Moderate tolerance species bin	High tolerance species bin
Upper limit (degrees C)	30.0	36.0	50
95% of tolerance	27.6	34.2	47.5
90% of tolerance	26.1	32.4	45.0
Trigger	27.6	34.2	47.5

Table 13.7 Salinity indicator bins and related trigger values. All figures are in ppt

	Low-tolerance species bin	Moderate tolerance species bin	High tolerance species bin
Upper limit (ppt)	38	45	70
95% of tolerance	36.1	42.75	66.5
90% of tolerance	32.3	38.25	59.5
Trigger	36.1	42.75	66.5

Based on the comments collected during the second workshop, the experts identified representative estuarine and coastal system fish species expected to be impacted by temperature under the predicted future conditions (Table 13.8).

The critical thermal maximum of marine organisms varies widely between fish species and is often influenced by acclimation time (Vinagre et al., 2015; Eme & Bennett, 2009; Mora & Maya, 2006; Rajaguru, 2002).

All species were assigned membership to one of the three temperature-tolerance "bins" (i.e., low tolerance, medium tolerance, high tolerance; based on spatially explicit temperature trigger maps for the representative species of that bin (e.g., Fig. 13.2 for lined seahorse).

4.2.2 Salinity Indicator and Trigger Development

The FIM program has also recorded salinity measurements trawl data in and around Tampa Bay and Charlotte Harbor estuaries at multiple sampling points since the 1990s (FWRI, 2016). Due to the plasticity of habitat used by fish species in estuarine environments, the salinity requirements during their life cycle and their saline limits are often difficult to identify for a species outside of a lab environment; however, FIM trawl data provide an important picture as to how fish species are associated with salinity profiles.

Based on the comments of biologists and ecologists attending the second workshop, three representative estuarine and one coastal system fish species are expected to have a moderate or high impact from a salinity stressor (Table 13.9).

The experts also identified a representative coastal system fish species expected to have a moderate or greater impact from a salinity stressor.

Table 13.8 Representative temperature-sensitive estuarine and coastal fish species

Representative fish species	Ecosystem represented	Temperature-tolerance bin
Estuarine		
Spotted sea trout (*Cynoscion nebulosus*)	Lower estuary	Moderate
Lined seahorse (*Hippocampus erectus*)	Benthic estuary/seagrass	Low
Coastal		
Red drum (*Sciaenops ocellatus*)	Bivalve reef	High

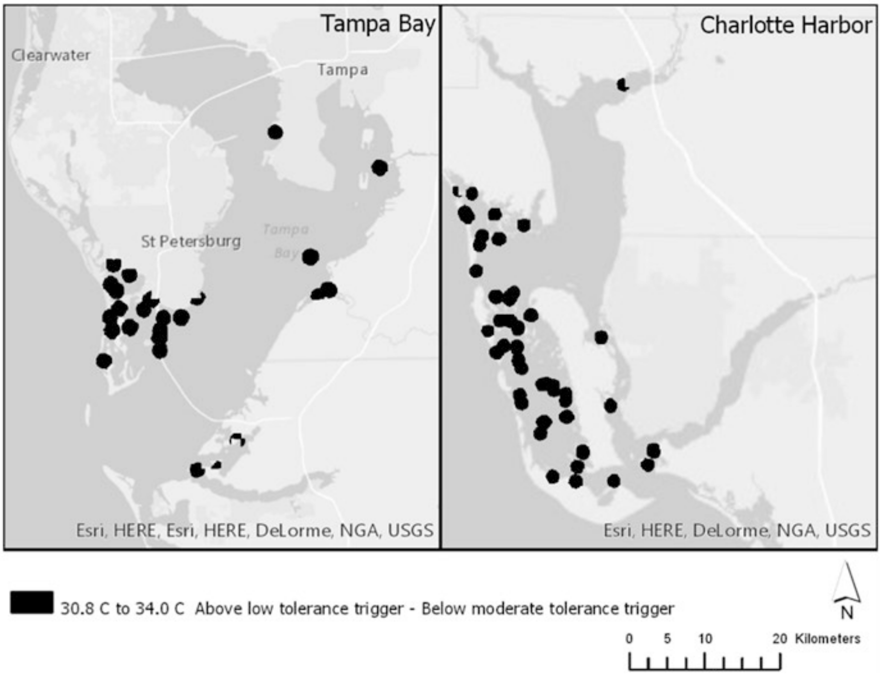

Fig. 13.2 Lined seahorse (low-temperature-tolerance species) sea surface temperature trigger map by 2020 for RCP 8.5. The black circles depict FIM sampling areas that are predicted to exceed the triggers for low-temperature-tolerance species. No locations are identified in either system where temperatures will remain below the trigger for low thermal tolerance species

All species were assigned to salinity-tolerance "bins" using the same method as that employed for the temperature tolerances. The trigger for each tolerance bin was calculated based on the 95% percentile of each tolerance groups' maximum tolerance limit (Table 13.9). Thus, the trigger is actuated before the salinity threshold is reached, allowing the necessary time for adaptation strategies to be developed, approved, and deployed.

Table 13.9 Representative salinity-sensitive estuarine and coastal fish species

Representative fish species	Ecosystem represented	Salinity-tolerance bin
Estuarine		
Gray snapper *(Lutjanus griseus)*	Mangrove fringe	High
Spotted sea trout *(Cynoscion nebulosus)*	Lower estuary	Moderate
Lined seahorse *(Hippocampus erectus)*	Benthic estuary/seagrass	Low
Coastal		
Gray snapper *(Lutjanus griseus)*	Coastal mangrove fringe	High

For each of the representative species, GIS maps were developed to depict predicted exposure of each of the sensitive species to salinity under Scenario 1: Plan/Trend RCP8.5 to 2060 (Fig. 13.3).

4.2.3 Shoreline Change Indicator

For the shoreline change stressor, potential indicators were identified to allow monitoring protocols to evaluate the impact of the shoreline change stressor mechanisms and effects. In particular, the team focused our attention on a class of physical indicators. Unlike the salinity and sea surface temperature indicators, which have one value of measurement, the shoreline change stressor according to the literature review (Berger, 1998; Berger & Iams, 1996) was selected as a combination of sea level rise impacts, conversion of upland habitat types to wetland, and the shifting of mangrove habitats within the estuaries and is based upon erosion rates, saline wetlands extent, and sea level rise.

A number of representative estuarine system fish species were identified which are expected to have a moderate or high impact from a coastal change stressor (Table 13.10).

Additional representative coastal system fish species were expected to have a moderate or high impact from a coastal change stressor.

4.2.3.1 Coastal Change Trigger Development

Erosion Rate

Potential erosion assessments were divided in to three different indicator levels for monitoring and severity assessments:

1. Severe erosion: dunes absent, vegetation absent, man-made shoreline structures, etc. (potential high erosion): 1 m/yr. loss (Manley, 2004).
2. Moderate erosion: dunes scarped or breached, narrow beach or no high-tide beach, ephemeral vegetation, erosion levels necessitating intervention, etc.: 0.6 m/yr. loss (Bush et al., 1999).

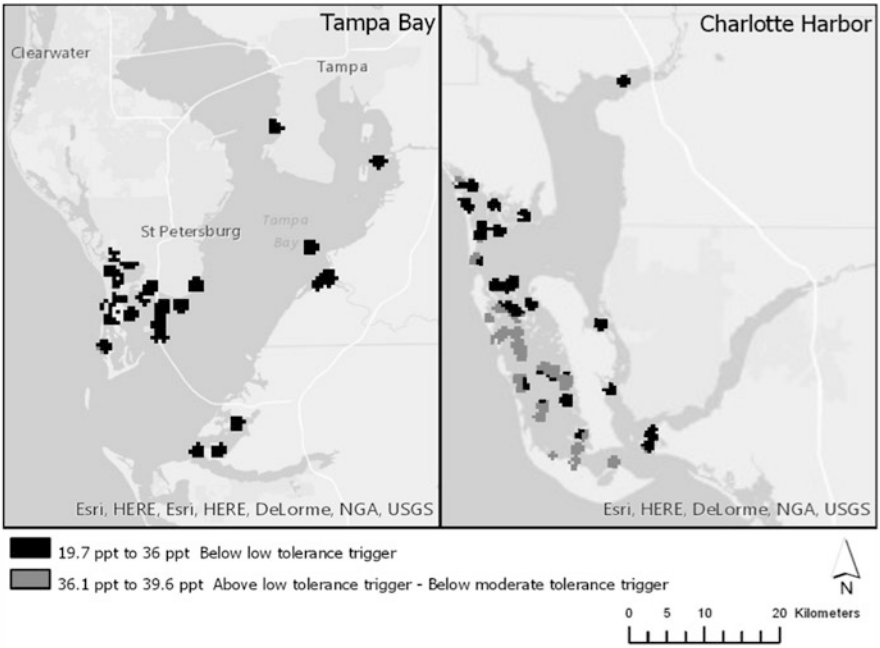

Fig. 13.3 Lined seahorse salinity low-tolerance bin trigger map by 2020 for RCP 8.5 The black circles represent FIM sampling locations where salinities are expected to remain below the low-tolerance trigger. Grey circles represent FIM sampling locations where predicted salinities will exceed the trigger for low-tolerance species

Table 13.10 Critical exposure assessment for the estuarine and coastal species representatives

Representative/ecosystem	Exposure assessment
Estuarine	
Spotted sea trout: Lower estuary	Minimal to moderate exposure
Lined seahorse: Benthic estuary/seagrass	Moderate to high exposure
Pink shrimp: All estuarine ecosystems	Moderate exposure
Coastal	
Southern stingray: Unconsolidated bottom	Minimal to moderate exposure
Red drum: Bivalve reef	Moderate exposure
Striped mullet: All coastal ecosystems	Moderate exposure

3. No erosion: accretion or long-term stability of the coastal area, dunes and beach ridges robust, un-breached wide beaches, well-developed vegetation, etc. (potential none or minimal erosion). No erosion <0.2 m/yr.; low erosion is considered to be >0.2 m/yr. (Hapke et al., 2006).

For this project, the recommended erosion trigger for the shoreline change stressor is moderate erosion, 0.6 m/yr. or greater loss of substrate.

Saline Wetland Extent

When considering the variables involved in wetland creation, permanence, and damage, it is important to monitor geological and biological parameters to assess the health and extent of wetlands as a coastal change indicator. The following variables were used to assess saline wetland extent:

1. Areal extent and distribution of vegetation, including changes in wetland boundaries (erosion, marine transgression).
2. Vegetation diversity/community structure: changes in the occurrence of particular (indicator) species or in the distribution of various plant communities within a wetland.
3. Surface morphology: (e.g., development of hummocks and hollows in a smooth Sphagnum lawn may reflect disturbance of the wetland system).

For this project, the recommended saline wetland extent trigger is a total rate of loss greater than, or equal to, a half percent annually, based on comparison to the total acreage of saline wetlands for the previous year.

Mangrove Extent, Migration, and Vertical Growth

An accurate indicator of the potential for mangrove persistence is the amount of accretion of sediment deposits within mangrove forests that create enough soil surface elevation gain to allow mangroves to keep pace with sea level rise (Krauss et al., 2013; McIvor et al., 2013). Recent calculations indicate that the global mean sea level rise, as of 2013, was 3.2 + 0.4 mm/yr., with variations in this average based on location; rates now appear to be accelerating (Krauss et al., 2013). However, when only the Florida locations were separated out of the group, and local SLR values were used, the surface elevation change ranged from 0.61 to 3.85 mm/yr. with a SLR rate of 2.1 mm/yr., indicating a higher likelihood of Florida mangroves keeping pace with local SLR impacts.

For this project, the mangrove extent indicator for the coastal change trigger is an annual increased value of vertical accretion that is equal to or less than current annual SLR measurements.

The coastal change stressor has a number of trigger subcategories, but the list of sensitive species remains the same: spotted sea trout, lined seahorse, red drum, southern stingray, and pink shrimp. The trigger maps produced for the coastal change stressor (Fig. 13.4) depict the areas of potential future saline wetlands and mangroves at 1.0 m of sea level rise (RCP 8.5 at 2060), as well as the potential distribution of sensitive species relative to wetland expansion.

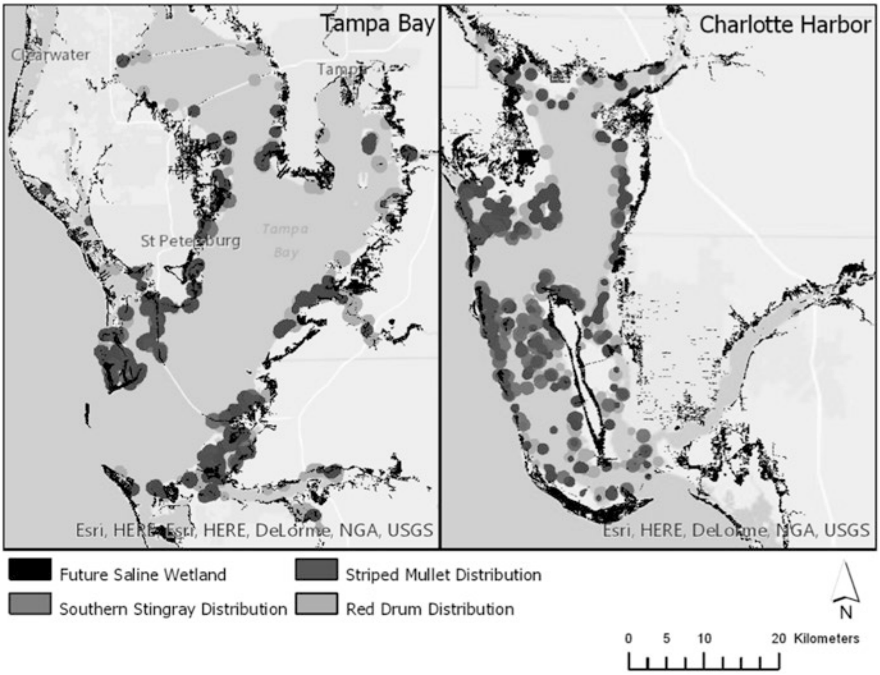

Fig. 13.4 Distribution of species sensitive to coastal change (i.e., southern stingray, striped mullet, and red drum) relative to predicted expansion of future saline wetlands and mangroves under Scenario 1: Plan/Trend by 2020 for RCP 8.5

4.3 Monitoring Tool

4.3.1 Building a Monitoring Tool to Support Adaptation Planning

The objective of the monitoring tool developed for this project was to provide decision makers with a logical and stepwise approach to identify when a trigger has been reached and then activating an appropriate adaptation strategy(ies). The trigger activation step in the monitoring tool specifically directs users to select adaptation strategies which could be successfully implemented within the framework of specific future scenarios, initializing different pathways with sensitivity to the current state of the political and environmental climate. Five key characteristics were derived to identify potential trigger activation: (1) temperature maximums, (2) salinity maximums, (3) erosion, (4) loss of wetland area, and (5) mangrove soil accretion. All of these require a monitoring program to support the collection of data and examine the timing of trigger activation.

The development of the tool identifies the entry point using existing monitoring programs as a protocol for the indicators and ongoing assessments of the information gained for each indicator. Proposed indicators for the temperature stressor are the 15-day average SST readings for the three temperature-tolerance bins; for the

Table 13.11 Monitoring tool for Scenario "Plan Trend" for shoreline change stressor (indicator: erosion rate and saline wetlands extent)

Scenario	Stressor	Indicator	Monitoring frequency	Trigger	Ecosystem	Species affected			Adaptation strategies		
Plan trend	Shoreline changes	Erosion rate	1 year	0.6 m/yr	Lower estuary ecosystem	Spotted seatrout, *Cynoscion nebulosus*	**TRIGGER MAPPING**	**STAPLEE**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 75]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines* **[FINAL RANK: 67]**
					Benthic estuary/ seagrass ecosystem	Lined seahorse, *Hippocampus erectus*			*Tax breaks for reducing shoreline hardening; incentivize natural shorelines* **[FINAL RANK: 70]**	*Reduce shoreline hardening; increase living shorelines* **[FINAL RANK: 69]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**
					All estuarine ecosystem	Pink shrimp, Farfantepenaeus duorarum			*Tax breaks for reducing shoreline hardening; incentivize natural shorelines* **[FINAL RANK: 70]**	*Reduce shoreline hardening; increase living shorelines* **[FINAL RANK: 69]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**
					Bivalve reef ecosystem	Red drum, *Sciaenops ocellatus*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Reduce shoreline hardening; increase living shorelines* **[FINAL RANK: 69]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**
					Unconsolidated bottom	Southern stingray, Dasyatis americana			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**
					All coastal ecosystems	Striped mullet, Mugil cephalus			*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 75]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Reduce shoreline hardening; increase living shorelines* **[FINAL RANK: 69]**

Scenario	Stressor	Indicator	Monitoring frequency	Trigger	Ecosystem	Species affected			Adaptation strategies		
		Saline wetlands extent	1 year	≥ 0.25% loss of previous year's wetlands total acreage	Lower estuary ecosystem	Spotted seatrout, *Cynoscion nebulosus*	**TRIGGER MAPPING**	**STAPLEE**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 75]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines* **[FINAL RANK: 67]**
					Benthic estuary/ seagrass ecosystem	Lined seahorse, *Hippocampus erectus*			*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**
					All estuarine ecosystems	Pink shrimp, *Farfantepenaeus duorarum*			*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**
					Bivalve reef ecosystem	Red drum, *Sciaenops ocellatus*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Minimizing the impacts of any future development on the highest priority areas for biodiversity* **[FINAL RANK: 68]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**
					Unconsolidated bottom	Southern stingray, *Dasyatis americana*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**	*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 65]**
					All coastal ecosystem	Striped mullet, *Mugil cephalus*			*Education of homeowner associations and politicians on benefits of soft shoreline* **[FINAL RANK: 75]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**

(continued)

Table 13.12 Monitoring tool for Scenario "Plan/Trend" for shoreline change stressor (indicator: mangrove extent, migration, and vertical growth)

Scenario	Stressor	Indicator	Monitoring frequency	Trigger	Ecosystem	Species affected			Adaptation strategies		
Plan trend	Shoreline changes	Mangrove extent, migration, and vertical growth	1 year	Annual increase in vertical accretion that is ≤ than current annual mean SLR	Lower estuary ecosystem	Spotted seatrout, *Cynoscion nebulosus*	**TRIGGER MAPPING**	**STAPLEE**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Hybrid shorelines where natural shorelines are put Oceanside of the hardened shorelines* **[FINAL RANK: 67]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**
					Benthic estuary/ seagrass ecosystem	Lined seahorse, *Hippocampus erectus*			*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**
					All estuarine ecosystems	Pink shrimp, Farfantepenaeus duorarum			*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**	*Prohibit physical coastal structures from being built* **[FINAL RANK: 59]**
					Bivalve reef ecosystem	Red drum, *Sciaenops ocellatus*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Minimizing the impacts of any future development on the highest priority areas for biodiversity* **[FINAL RANK: 68]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**
					Unconsolidated bottom	Southern stingray, *Dasyatis americana*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Define needed marine migration corridors and develop strategies on how to get those areas into conservation through incentives* **[FINAL RANK: 66]**	*Public education and outreach to foster a broad awareness of climate change issues; increase SLR awareness using photo and other visualization tools* **[FINAL RANK: 64]**
					All coastal ecosystems	Striped mullet, *Mugil cephalus*			*Prohibit physical coastal structures from being built* **[FINAL RANK: 69]**	*Determine relevance of Comprehensive Everglades restoration plan (CERP) and initiate applicable measures* **[FINAL RANK: 60]**	*Removal of barriers (political, regulatory, urban) to inland migration of habitats* **[FINAL RANK: 59]**

salinity stressor, the 30-day averaged water column salinity values for the three salinity-tolerance bins; and for the shoreline change stressor, yearly erosion rates, saline wetlands extent measurements, and mangrove vertical accretion measurements within the estuaries. When the monitoring program(s) demonstrate that the value for a specific indicator exceeds its trigger value (based on the definition of the indicator), the trigger is activated. The scenario state is the second point of entry to the tool and determines the path to move forward on. The current state of coastal development, conservation approach, and policy when triggers are reached will determine which adaptation strategies from the monitoring tool are suitable and feasible to implement to address the stressor in question.

4.3.2 Resulting Evaluation

By evaluating the information presented in the monitoring tool tables (Tables 13.11 and 13.12), it is possible to highlight which adaptation strategies are predicted to have the greatest positive effect. The tool shows the different adaptation strategies to be implemented for each trigger, and the strategies are cumulative as triggers are reached in succession. In the tables, the strategies are presented according to the final ranks resulting from the STAPLEE evaluation.

Starting with the first stressor in the table, shoreline hardening, and progressing across the table, the ranked adaptation strategies are implemented based on which triggers are turned "on." The adaptation strategies listed in the table have STAPLEE ranking values associated with them that indicate the relative importance of the strategy. For example, for the shoreline change stressor, for the "mangrove extent, migration, and vertical growth" indicator (Table 13.12), the prohibition of physical coastal structures has a higher STAPLEE score for both the scenarios. For the other two indicators ("erosion rate" and "saline wetlands extent") different strategies have the highest STAPLEE score: the improving of education and tax breaks for reducing shoreline hardening. Although it may be more complicated to monitor three indicators for one stressor, having a diverse suite of indicators better represents the variations of how shoreline change functions as a stressor to related fish species.

5 Discussion

Climate change forces a more holistic approach in all areas of management, planning, and science. Especially marine adaptation planning must be approached in a holistic manner given the need to consider the constantly changing relationship between species, their environment, and the complex environmental management and institutional decision process. As such, it becomes necessary to depart from the recognition that triggers more than slow onset constant transformational changes in the climate can be indicative to key moments to implement groups of adaptation strategies and actions. This process requires unpacking and sorting uncertainties and identifying and simulating the derailing force of key triggers that can reshape both the natural and decision context. In this study scenario-driven planning has proven to be useful in this process, but it demands substantial political will, flexibility, and investment, as complex institutions and natural forces require to rethink current norms, management strategies, and legal references. Approaches that reduce uncertainty and established systemic monitoring can guide the process of marine adaptation planning in a context where both natural and anthropogenic futures unfold in unforeseen ways. The paring marine spatial-planning scenarios and triggers with key monitoring indicators have represented in this study a valuable contribution from the environmental management perspective, as it provides a means to visualize with stakeholders the consequences of potential actions interacting with the changing environmental. In this sense, scenarios more than conventional marine management should be based not only on observational data and statistical models but also simulations that integrate experts' opinions regarding the prioritization of future adaptation strategies, beyond those based on the range of most historical observations.

5.1 Implications for Public Policy, Management, and Climate Change Adaptation

5.1.1 Policy and Management

Natural resource agencies are charged with managing their trust resources for the benefits of the stakeholders they serve. Whether it's for hunting, commercial, or recreational fishing or other recreational opportunities, stakeholders expect healthy wildlife populations that are sustainably managed (Sensu Stöhr et al., 2014). However, environmental conditions are changing in large part due to impacts to the climate system resulting in challenges to managing natural resources in a business-as-usual environment.

The effects of climate change are already being felt in the South Florida marine environment. Corals are bleaching from increased water temperatures (Wagner et al., 2010), sea levels are accelerating rapidly (Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2015), and fish and plant species' distributions are shirting northward (Perry et al., 2005). Modeling now suggests that rainfall can be expected to decrease in the southern part of the peninsula (Sinha et al., 2018) which will have significant impacts on estuarine systems (Copeland, 1966).

However, climate is not the only variable that must be accommodated when developing effective long-term management strategies to achieve coastal natural resource conservation: urban development is leading to fragmentation of habitats and impacts to nearshore waters (e.g., Airoldi et al., 2008), pollution is reducing marine biodiversity (e.g., Smith et al., 1999), coastal erosion is reducing healthy shorelines (Raabe & Stumpf, 2015) and species' suitable habitats (Fujisaki et al., 2017), invasive species are impacting native populations (Gallardo et al., 2015), and coral diseases are becoming more common and consequential (Peters, 2015). All of these impacts are influencing coastal ecosystems resulting in the inability of those ecosystems to support the biodiversity that they once did. Ultimately, the reduction in coastal biodiversity impacts the services these ecosystems provide society (Worm et al., 2006).

Of these, perhaps the most pernicious impact is the accelerating rate of sea level rise. Models are predicting that sea levels will increase in southeast Florida by 6–10 inches by 2030, 14–26 inches by 2060, and 31–61 inches by 2100 (Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group, 2015). The impacts to both the natural resources and the coastal communities which depend upon them may be devastating without the development of robust adaptation plans (Lorenzen et al., 2017). Clearly managers must be prepared if they are to ensure that the biological, social, and economic resources are to persist and thrive.

For natural resources agencies, the changes are unsettling due to the uncertainties associated with how resources will respond under these pressures. The outcomes from long-term planning become less certain with the result that priorities inevitably shift to the short-term thus becoming less strategic and more ad hoc. Ultimately, how agencies adapt to these changes will depend on how they balance short-term priorities and long-term changes (Paukert et al., 2016).

This study was designed to develop adaptation options under these uncertainties and to provide context for managers from which they can make robust decisions. Given the uncertainties, managers must use tools that anticipate possible futures under a variety of stressors.

Because of the vicissitudes associated with climate change and the inability to control the outcomes, scenario planning has been proposed as one of the more powerful approaches to provide context to managers (Peterson et al., 2002). In this study, both biological and anthropogenic variables were examined in the context of alternative future scenarios and examined the science and consequent adaption solutions that may result from these possible outcomes. In this way, managers may identify possible planning outcomes by examining alternative scenarios thereby providing a framework from which they can develop solutions.

One of the values of using scenarios is that they allow for identifying best possible adaptation strategies based on how each scenario was parameterized and what scenario materializes. For example, when planning for high salinities, the highest STAPLEE score under the Plan/Trend scenario was to increase legislative and governance capacity because this scenario recognized deficiencies in those categories. Because this scenario is essentially business-as-usual, this response argues for developing and implementing approaches that provide greater flexibility in regulatory authority (e.g., adaptive water governance: Hurlbert & Diaz, 2013). However, in the Proactive Plus scenario, the scenario already accounts for enhanced governance therefore planting shoreline cover was identified as the adaptation strategy of choice. In these examples, the most effectual adaptation option was based on the trajectory of political and planning priorities defined within each scenario.

The previous example highlights the importance of identifying the most applicable scenario. If the most reasonable scenario is not selected, or if scenarios are not employed to address uncertainty, then resources could be allocated inefficiently or ineffectively. The identification of the most reasonable scenario, however, is just one of the reasons that an effective monitoring program must be incorporated into a thorough adaptation planning program.

The southwest Florida coastal and estuarine systems, as well as the built environment, are particularly vulnerable to a changing climate given their low-lying elevation, association with tropical systems, and reliance on freshwater. Small changes can have very consequential impacts.

Because of this system-wide vulnerability, agencies must have sufficiently adaptable structures in place to address changing conditions. Policies must respond to the needs of both ecological and social systems (Paukert et al., 2016) to ensure that both are resilient in the face of emerging threats.

Unfortunately, business-as-usual management may be inevitable given its political palatability. In many cases, laissez-faire management will continue until conditions become so untenable that adaptation implementation becomes critical, a point-in-time Werners et al. (2015) term an “adaptation turning point.” The challenge is to ensure adaptation strategies are in place and ready for implementation when this trigger is reached whether the trigger is an “adaptation turning point” or another one associated with a specific strategy or vulnerability.

For the sake of efficiency, the FWC has been identifying suites of species that share common vulnerabilities and, therefore, developing adaptation strategies that may apply to many of them. However, inevitably, individual species will either slip through this coarse filter and will need to be addressed individually.

To accommodate both single and multiples species, this project purposefully focused on single species as representatives of suites of species that share similar vulnerabilities under changing climate conditions. The adaptation options that were developed undoubtedly will provide benefits to other species with similar life histories sharing similar habitats and with common vulnerabilities. For example, planting riparian vegetation will benefit both marine and terrestrial species including reptiles and birds that were beyond the scope of this project.

Developing solutions is relatively straightforward; however, implementing the solutions is compounded by social barriers addressed within the framework of the STAPLEE approach (i.e., categories related to social, technical, administrative, political, legal, economic, and environmental criteria). Yet, the challenges for effective management solutions under a changing climate must address implementation within a social context. This process must recognize that the solutions are not only technical in nature (O’Brien & Selboe, 2015) but also represent adaptive challenges (Sensu Heifetz et al., 2009).

Ensuring that robust adaptation strategies are implemented in policy is an enormous challenge. One approach is to ensure that adaptation strategies are integrated into existing instruments. For example, imperiled species management plans and species recovery plans by definition must recognize and address emerging threats (e.g., climate change), and these should reduce species’ vulnerabilities. To effectively accomplish this, a change in perception by land-use managers may be required since, in many cases, traditional training does not prepare them for changing environments and targeted efforts must be made to ensure they are prepared to make decisions under uncertainty (Doonan et al., 2017).

Because management and policy focus on social systems, approaches must be developed that ensure that both natural resources' and stakeholders' interests are met. Furthermore, because governance is concerned with rule-making systems within the context of sustainable development (Biermann et al., 2009 quoted in Plummer, 2013), their structures must be robust so that solutions can be accepted by diverse suite of stakeholders. The legal authority within statutory structures must be sufficiently flexible to adjust to changing conditions (Camacho & Glicksoman, 2016), especially within a social context (Biermann et al., 2009).

In the end, implementing adaptation strategies and ensuring that they are integrated into policy remain one of the biggest challenges to effective management. This project did not specifically address implementation; nevertheless, identifying and overcoming barriers to implementation remain one of FWC's highest priorities. In a recent FWC workshop (Benedict et al., 2018), the STAPLEE method was used to identify barriers to implementation. The inability for flexibility in governance systems under changing conditions along with governance uncertainty (Camacho, 2009) were identified as two of the largest obstacles to implementing climate adaptation strategies.

There are, however, approaches that can encourage implementation. The relatively recent popularity of adaptive management with respect to climate adaptation (Tompkins & Adger, 2004) is one solution. Unfortunately, this approach has been difficult to implement due to technical, social, and economic barriers.

Fortunately, it has not yet seen the worst of the projected changes to nearshore habitats. It is incumbent upon natural resources agencies to plan for the future as difficult as this may be. The approach outlined provides a framework for identifying adaptation strategies under considerable uncertainty and provides a way forward to conserve the many of the natural resources.

5.1.2 Adaptation Planning

Climate-smart adaptation has become a standard for climate adaptation planning for natural resources (see Stein et al., 2014). This approach integrates science and management into a cycle that includes defining the problem, examining the science, developing and prioritizing adaptation options, and examining effectiveness. For this project, the team employed that climate-smart approach but adapted it to FWC priorities. For example, it was added the concepts of dealing with uncertainty by using scenario planning to frame the future, identifying triggers that indicated when to implement the given adaptation option, and further added monitoring to identify when triggers have been reached. The triggers and monitoring additions to the cycle were included for purely practical reasons: there must be a methodology that identifies when an adaptation option should be implemented. Without this guidance, there is no way to know when to begin implementing adaptation strategies.

Clearly monitoring is a critical component of adaptation planning and implementation. In identifying which scenario emerges, there are three other reasons to monitor, and, given their distinct objectives, each may require different monitoring programs.

First, monitoring can be used to evaluate the impacts to species, habitats, and ecosystems. Generally, this is how most managers view monitoring: what is happening to a resource over time? Entire programs have been built based on this priority such as understanding the effects of climate change on species (e.g., Lepetz et al., 2009), abundance determinations for fisheries management (e.g., Schemmel et al., 2016), identifying long-term ecological changes (e.g., Kennish, 2019), and ecosystem restoration evaluation (e.g., Louhi et al., 2016). In this project, a 24-year dataset was used to understand the long-term changes to both the focal fish species in the study areas as well as the environment that supports them. This in turn helped us to build the model that from which the adaptation options were derived.

Second, monitoring programs can help inform when to implement the given adaption options (i.e., when a trigger has been reached). A well-focused adaptation program must include monitoring for triggers otherwise timing adaptation strategy implementation will be problematic.

Finally, monitoring can help evaluate the efficacy of an implemented adaptation strategy and can inform as to its continued use, modification, or abandonment. Additionally, monitoring for effectiveness helps to determine if maladaptation issues are occurring. For these reasons, monitoring is a critical component of any adaptation plan.

This study highlighted the importance of close interactions between management and science with respect to adaptation planning. Since the focus of the study was understanding what a changing climate and differing policy directives meant for suites of estuarine and coastal species and how to create approaches that address their consequent vulnerabilities, the roles of managers and scientists were inextricably linked. To illustrate this point, in this study, managers defined the goals and objectives of the project, scientists identified the species that were best suited to address the scope, and scientists provided projection on the impacts from a changing climate and policy priorities. After this part of the process, managers and scientists worked closely together to identify possible adaptation options, select the most efficacious adaptation strategies (based on STAPLEE), pinpoint triggers, and develop monitoring plans. In this process, science clearly serves the goals of management.

In addition to input from managers and scientists, it was demonstrated that science alone will not provide the guidance necessary to address the uncertainties and thus develop effective and holistic approaches to adaptation in a changing climate. Emphasis must also be placed on incorporating expert knowledge. Inevitably there will be instances where knowledge is incomplete yet crucial to inform a process and expert input can provide context for important planning decisions (Rinaudoa & Garin, 2005). In this study, a number of variables that are used to classify vulnerability in the fish species (Morrison et al., 2015) in this study were not available in the literature. However, experts provided their knowledge to help categorize the species' vulnerabilities.

Identifying possible adaptation options is a difficult task that often requires creative and, sometimes uncomfortable, idea development. All options should be considered, no matter how unconventional (Stein et al., 2014). For example, when considering adaptation options for the temperature stressor under the Plan/Trend scenario, one of the less conventional options included diverting cooler, deep water to coastal areas. Obviously, this approach requires extensive investments in engineering, the science of localized ocean circulation, and money; the feasibility of implementing this option is certainly questionable. Thus, selecting the best option(s) becomes a very important part of the process.

A high priority for this study was recognizing the importance of selecting adaptation options that were appropriate and had the highest probability of success. As described previously, the STAPLEE approach was applied to prioritize adaption options. This method accounted for technical, financial, social, and political variables as well as others. Thus, a wide diversity of societal values were incorporated into the strategy selection process. In many cases, multiple adaptation strategies will be relevant for multiple stressors; and these are accounted for in the monitoring tool.

However, the team recognize that STAPLEE scores that identify the most efficacious adaptation strategy may be overly simplistic and therefore not be realistic. In certain cases, some strategies may score highly, but one or more components may ultimately override all others. Costs may be prohibitive, "political will" may overwhelm all other considerations, and/or technical obstacles may be too considerable to effectively implement certain high-scoring strategies. Thus, results from STAPLEE need to be carefully evaluated to ensure that they are feasible.

On the other hand, some high-scoring adaptation strategies may be easy to implement. In this study, outreach and education scored very high as an approach to address erosion rate under the shoreline stressor. This is likely a very easy-to-implement strategy that will both incur little expense and likely encounter few governance/political obstacles. A post hoc analysis of the scores from STAPLEE should elucidate strategies that both are easy to implement and provide little downside (i.e., no-regrets strategies).

This project has shown that adaptation planning must be approached in a holistic manner which considers resource vulnerabilities, identifies activities that mitigate those vulnerabilities, and includes components that identify when to implement the activities. Taken together, the approach that was outlined presents a comprehensive treatment of climate adaptation planning which addresses both the interests of species conservation and societal values, both of which must be accounted for if effective species conservation is to be achieved.

Glossary

Abandonment: The decision to permanently leave or to remove existing uses from a site.

Adaptation: The process of adjusting to change, including direct activities, but also supporting legal or cultural practices.

Adaptive infrastructure: Infrastructure intended to alleviate or avoid expected changes. In terms of climate change and development, common adaptive infrastructure includes various forms of shoreline hardening/ armoring, elevating existing or new activities (e.g., houses, boat ramps). In terms of fixed public infrastructure, this can include utility changes (e.g., water desalination plants), diversification, and elevation of transportation (e.g., adding ferry routes or elevating bridges and roads). In both public and private sectors, adaptive measures can also include portable or semiportable infrastructure (e.g., movable terraces or small buildings).

Beneficial impact: Significantly increasing habitat quality or the ability of species to persist over time.

Business as usual (BAU): A common planning phrase indicating policies, practices, or rules which represent a continuation of current practices into the future. **Compatible Impact:** proposed activity has no significant impact on habitat quality or species persistence.

Comprehensive planning: Deals more with interactions between potential uses and the implications of spatial patterns.

Emission scenario: "describe future releases into the atmosphere of greenhouse gases, aerosols, and other pollutants and, along with information on land use and land cover, provide inputs to climate models" (World Meteorological Organization).

Habitat quality scale: A standard qualitative scale used within this study to normalize habitat descriptions across species and within factors used in evaluating habitat characteristics.

Impact assessment scale: A standard qualitative scale used to measure species and population impacts within this study. Assignment to individual categories can be on the basis of best professional judgment, empirical analyses, quantitative modeling, or a combination of the three.

Longer term: For purposes of this study, management activities requiring significant changes to existing institutional arrangements or large amounts of funding were categorized as longer term.

Managed relocation: A broad set of measures, which promote or require movement of fixed infrastructure. In public sector applications, these frequently include development exclusion zones and setbacks, which restrict current and future development, such as Florida's Coastal Construction Control lines. They can also include mandatory mitigation measures, such as enhanced building codes. Managed relocation can also include the nonrenewal of required permits, such as certificates of occupancy. Insurance has an important role in managed relocation. On the public sector side, rule changes to publicly subsidized insurance programs can be significant (e.g., FEMA's repeat loss policies). On the private sector side, insurance companies can adjust rates or refuse coverage in particular circumstances. Many of these measures have cumulative and indirect effects on the likelihood and affordability of siting structures in particular locations.

Management triggers: Conceptual or practice thresholds or observations which indicate that new or different courses of action are indicated. For example, the ratio of sea level rise to mangrove terrain accretion is a likely management trigger within South Florida. If sea level rise stays below the local accretion rate, one set of management responses is indicated. However, if this threshold is exceeded, a completely different set of activities might be undertaken.

Medium-term actions: For the purposes of this study, management activities which are likely feasible within 5 years given current institutional arrangements were considered as medium term.

Moderate impact: Some degradation of habitat or species populations is expected but at a level which could be mitigated on site with normal techniques.

New Representative Concentration (RCP) Pathways: "based on scenarios from four modeling teams/models working on integrated assessment modeling, climate modeling, and modeling and analysis of impacts" (World Meteorological Organization).

No-regrets actions (NR): Management activities, which are invariant relative to the range of variation expressed in scenarios. For example, critical habitat acquisition might be considered "no regrets" if and only if it is expected to continue to meet management goals under climate change.

Primary habitat: Factors/features or conditions which represent or are indicative of the best-known habitat and support its long-term persistence.

RCP 4.5 Stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100.

RCP 8.5: Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.

Recruitment: "the addition of new individuals to populations or to successive life history stages within populations".

Scenario: Bundles of consistent assumptions, facts, projections, and possible policies.

Sea Level Affecting Marshes Model (SLAMM): "simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise. Map distributions of wetlands are predicted under conditions of accelerated sea level rise, and results are summarized in tabular and graphical form".

Secondary habitat: Factors/features or conditions which represent or are indicative of known habitat but in which some essential elements are either missing or degraded. This category can include habitat, which are only used for a single part of a species life cycle.

Sectoral planning: Seeks to engage particular issues and can do so in great detail, including consideration of individual policies or rules.

Severe impact: Degradation of habitat or species population is expected beyond the ability of normal mitigation practices to remedy on site.

Stressor: A factor that cause stress to a species.

Sublegal: Unfished.

Tertiary habitat: Factors/features or conditions which represent or contain aspects of viable habitat but also have known limitations. For example, habitats which provide cover but not nesting or forage might be placed in this category.

Threshold: Proposed activity is likely to cause permanent extirpation of local habitat or species populations.

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Chapter 14
Urban River Resilience

Jaime Joaquim de Silva Pereira Cabral, Marcos Antonio Barbosa da Silva Junior, Yuri Tomaz Neves, Arivânia Bandeira Rodrigues, and José Adson Andrade de Carvalho Filho

Abstract Urban river resilience involves engineering characteristics including also social and ecological issues. Resilience can be conceptualized as the ability to recover after an impact, returning to conditions prior to the impact or adapting to new conditions. A better understanding of river complexity is necessary for analyzing resilience. The three aspects of urban river resilience can be understood as engineering resilience focuses on maintaining the stability and final efficiency of a system, ecological resilience of a river is characteristic of complex and dynamic living systems, and a socio-ecological resilience requires a transdisciplinary planning including adaptive capacity. Resilience of urban rivers and streams requires a multidisciplinary approach involving architecture, landscape design, hydrology, hydraulics, water chemistry, sociology, legislation, economics, navigation, tourism, fishing, and water sports. Some case studies of Recife City (Brazil) are presented: Capibaribe Park, Parnamirim stream, fisherwomen at Tejipió estuary, Beberibe River. Actions to improve the resilience of urban rivers help to preserve environmental conditions, improve social conditions, and can bring positive aspects to some economic activities such as fishing and tourism. The resilience of urban rivers contributes to improving the resilience of cities.

Keywords Capibaribe River · Ecological resilience · Engineering resilience · Socio-ecological resilience · Parnamirim stream

J. J. de Silva Pereira Cabral (✉)
Polytechnic School, University of Pernambuco, Recife, Brazil

Civil Engineering Postgraduation Program, Federal University of Pernambuco, Recife, Brazil
e-mail: jaime.cabral@ufpe.br; jaime.cabral@poli.br

M. A. B. da Silva Junior · Y. T. Neves · A. B. Rodrigues · J. A. A. Carvalho Filho
Federal University of Pernambuco, Recife, Brazil

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1 Introduction

Resilience can be conceptualized as the ability to recover after an impact, returning to conditions prior to the impact or adapting to new conditions. The concept of resilience was initially applied to the physical properties of materials, and in recent decades it has been expanding, being applied today to psychology, social sciences, health sciences, environment, and others. Watercourses in cities have been highly impacted over the last few decades, leading to the need to better study the resilience of urban rivers and streams.

The concept of resilience has been further developed, including the reduction of the probabilities of failures, the reduction of the consequences of failures, the improvement of recovery conditions, and the reduction of recovery time. In addition to recovering from previous conditions, resilience also involves renewal, reorganization, and adaptation to new conditions.

Other definitions of resilience have been presented keeping the focus but showing minor differences: resilience includes the domains technical, organizational, social, and economic (Bruneau et al., 2003); resilience is defined as the capacity of a system to respond to change or disturbance without changing its basic state (Walker & Salt, 2006); resilience is a complex, multidimensional challenge for urban sustainability (Ahern, 2010).

Urban rivers have multidisciplinary characteristics, and it is necessary that the inherent complexity of relationships within systems be understood. Every river has characteristics of hydraulics, hydrology, hydrochemistry and hydrobiology, erosion, and sediment transport. There are also influences of urban landscape, thermal comfort, the use of banks for various purposes, and economic aspects associated with tourism, water sports, river transport, and fishing. Each of these aspects can be impacted, and resilience can be defined for each of these aspects according to the system's recovery capacity.

In relation to urban watercourses, it is very difficult to guarantee that it will never fail and a new approach seeks to create conditions so that if there is a failure in the flow capacity of the watercourse, it is possible to live with the problem, which has been called "safe to fail." A position "safe to fail" anticipates failures and designs systems strategically so that failure is contained and minimized (Steiner, 2006).

In general, restoring ecological systems in the urban landscape would improve the adaptive capacity of cities. Ahern (2010) explained a design strategy for building urban resilience including features of urban rivers such as multifunctionality, biodiversity, social diversity, multi-scale networks, and adaptive planning. In this context, it is possible to guarantee that the resilience of urban rivers is a first step towards the resilience of cities (Nazif et al. 2021).

2 Engineering Resilience

The term that gives the name to this item has been explored by Holling (1996) in the 1990s, when he subdivided his theory on resilience in the field of ecology (Holling, 1996), started in the early 1970s, in two categories: resilience engineering and ecological resilience.

Holling (1996) stated that engineering resilience focuses on maintaining the stability and final efficiency of a system, which can be measured as the rate at which that system returns to its equilibrium after a disturbance. Gunderson (2000), in his studies, corroborates Holling (1996) when he defined the resilience applied to engineering systems as the return time to a single global balance. In other words, Laboy and Fannon (2016) also stated that engineering resilience is associated with the expected functional stability of technological systems when subjected to disruption.

Urban development on river plains has historically had some advantages such as flat and fertile areas in addition to availability of water for consumption and sanitation development (Miguez et al. 2015a); however, these areas bring with them hydraulic risks and frequent flooding (Miguez et al. 2015a, b).

At the time, the idea of hydraulic engineering was to rectify the riverbed in order that its flows could be taken downstream with greater flow speeds and shorter paths, thus gaining greater land spaces for urbanization and agriculture. But this approach has led to several flooding problems, and in recent years it has been modified to more resilient engineering that can better recover from impacts. As a result, the decisions regarding the construction of infrastructure in cities have been modified to incorporate the management of water resources in the city's rivers and streams (Wheater & Evans, 2009).

For Laboy and Fannon (2016), engineering resilience is usually focused on the technical domain and can be better understood by the R (4R) model – robustness, redundancy, resourcefulness, and rapidity, proposed by Bruneau et al. (2003), which was later adapted by Laboy and Fannon (2016) for the R (6R) model, also including "risk avoidance" and "recovery."

Several researchers have described the components of resilience concepts: robustness – it is given by the strength of the systems and their elements to support or resist stress. Anderies et al. (2004), in turn, use the concept of robustness as one of the possible analyzes of the characteristics of resilience. This concept would be able to discern, objectify, and know the fluctuations of this studied system, that is, how this system can oscillate between the stability and instability of the system in which it is inserted.

Resourcefulness is the excess or excess capacity that allows the continuous function, in case one or more elements or systems fail; these are the goals and end states of a resilient system. Redundancy refers to spare components that can be used if necessary and also refers to the excess capacity that enables continued function should one or more elementsor systems fail (Laboy & Fannon, 2016). Rapidity describes an organization's ability to detect problems and respond to them, while speed identifies the speed at which responses can occur to limit or recover from a shock, both of which are means by which resilience is achieved.

The engineering resilience components included as properties of technical and social resilience are conceptualized by Laboy and Fannon (2016) as risk avoidance must be considered in the initial planning and adaptation stage, in order to encourage the reconfiguration of the built environment according to the realities of current and future environmental forces. Recovery focuses on future adaptation, not only to limit vulnerabilities but also to meet current and future needs.

For Price (2002) and Smit and Wandel (2006), the adaptive capacity, also known as the ability to adapt, demonstrates efforts to explain the sense that resilience does not guide a sense of comfortable or ideal state, but the possibility, the ability to return to a previous situation, even if this previous state is not stable (Cabral & Cândido, 2019; Carpenter et al., 2001; Nyström & Folke, 2001; Price, 2002; Folke, 2006).

The conceptualization of the previous terms is important to assess the engineering resilience in urban rivers from multidisciplinary characteristics such as hydrology, hydraulics, erosion, and sediment transport. Each of these aspects can be impacted, and resilience can be defined for each of these aspects according to the system's recovery capacity.

Recife City is the capital of Pernambuco state in Brazil and has been constructed in an estuarine zone of 3 main rivers (Capibaribe, Beberibe, and Tejipió) with more than 100 streams meandering all over a large plain region (Fig. 14.1). Several dams have been constructed in Capibaribe River in the last decades to increase engineering resilience against floods in Recife (Fig. 14.2).

Another example of engineering resilience applied in Recife is the floodgate system (Fig. 14.3) of the Derby-Tacaruna channel (Fig. 14.1), located in the central area of the city. The channel, which began construction in the mid-1960s, was built on the site of an Old Gamboa, which connected the mangroves of the Beberibe River estuary with the mangroves on the banks of the Capibaribe River. It has a length of 5.30 km, a trapezoidal section of 45.0 m^2 (Emlurb, 2016) with the south exit, connecting with the Capibaribe River, and the north exit, connecting with the Beberibe River.

A few years after the construction of the channel, the road axis built on the banks of the channel began to suffer constant flooding that would be attributed to the various causes that overlap: the subsidence of the roadway, the increase in the waterproofing of the contribution area, the increase intensity of rain, and rising sea levels. With this scenario, the City Hall government, between 1998 and 1999, installed gates at each exit of the Derby-Tacaruna, to prevent water invasion at high tides.

The analysis of engineering resilience in urban rivers requires knowledge of hydrology, hydraulics, structural resistance of channels banks, soil support capacity, and solid waste management. In the case of Recife City, it is complex due to many factors involved. Recife is a coastal city formed by a large plain with low topographical elevations surrounded by a chain of small hills. In addition to the problems of excessive waterproofing that occurs in all large cities, Recife has problems

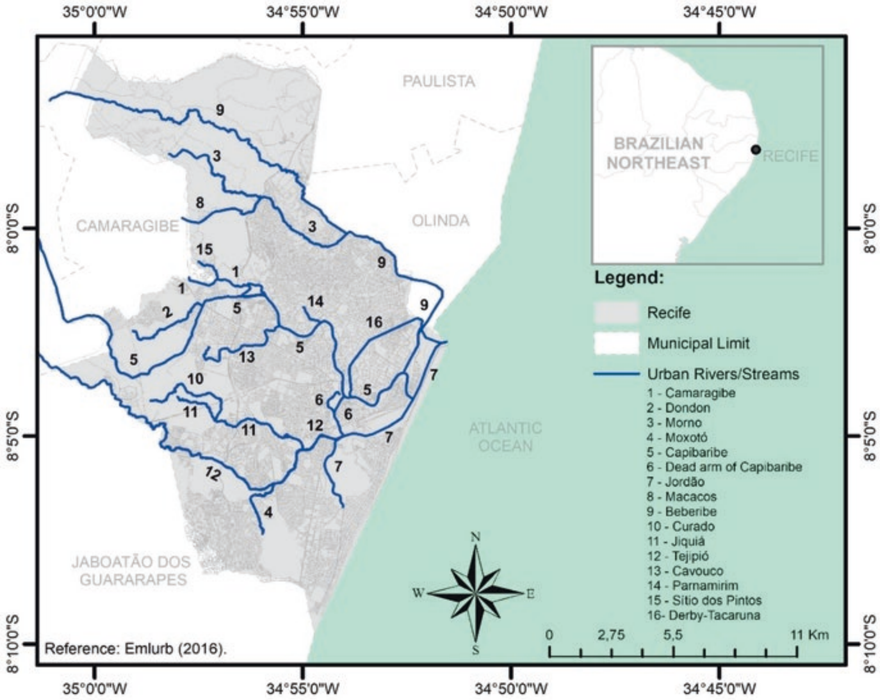

Fig. 14.1 Main urban rivers and some streams that cross the city of Recife, Brazil. (Source: authors)

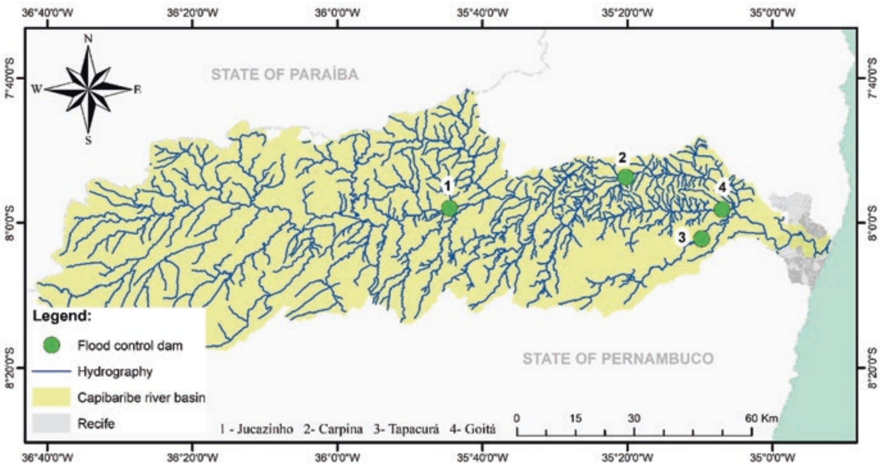

Fig. 14.2 Main dams that have been constructed to improve engineering resilience of Capibaribe River in its urban stretch against floods in Recife (Brazil). (Source: authors)

Fig. 14.3 Gate system (**a**) gate and pumping station at the north end. (**b**) Gate at the south end. (Source: authors)

of great rainfall and the risks of sea level rise, which requires more care to strengthen the resilience of urban river works.

3 Ecological Resilience

The conception of changing the morphology and natural characteristics of the rivers using rectification and channeling brought consequences such as the alarming decrease in the variety of the biota of the river and the riverside areas and floods causing great material damage and sometimes of human lives (Binder et al., 2001).

Ecological resilience of a river is characteristic of complex and dynamic living systems, and the management of urban watercourses has been changed to a multidisciplinary approach including, in addition to hydraulic aspects, fauna and flora aspects, as well as economic and social aspects for a better resilience of urban rivers and streams.

Ecological resilience is the ability of an environment to absorb disturbances and to keep its biota to a minimum so that it can develop a process of renovation, reorganization, and development of its functions (Holling & Gunderson, 2002). This systematic process in which the biological communities of an environment reorganize over a period of time after disturbances, which may have been caused by anthropogenic or natural events, is called ecological succession (Chang & Turner, 2019).

Ecological resilience is associated with activities for restoration, renaturalization, or revitalization. In the case of urban river restoration, the actions to be developed should seek to strengthen the resistance and resilience of the water body (Afonso, 2011). In the present text, the term revitalization will be used despite recognizing that other terms have been used appropriately by several authors.

Another point to think about is that for engineering resilience, quantitative methods of risk management and disaster preparedness generally focus on specific events, but for ecological problems, it is also necessary think about longer-term "stresses" and slower-moving challenges (Rockefeller, 2016).

The revitalization of rivers is the main alternative for protecting the health of ecosystems, preserving water resources, and protecting against floods. This is an idea that has been shared by several countries in the world (Kurth & Schirmer, 2014). The revitalization process goes through planning where a diagnosis of the current situation of the river is made to compare it with an ideal situation. Then the objectives must be outlined considering the ecological conditions of the riparian zones (RZ), which are essential to absorb the natural flood conditions. The fluvial morphological mapping is of fundamental importance for this process, which is a constituent element in the ecology of the aquatic ecosystem, due to its influence on flow, water quality, as well as mobility and renewal of the natural conditions of the bed and bottom aquatic biomass (Binder et al., 2001).

In parallel with the process of degradation of river ecosystems, there are probable losses of countless organisms and losses of their ecological functions in the environment. However, the resilience of these environments is strongly linked to the biota communities that survive this stress (Douglas et al., 2017). The resilience of the species is fundamental for the recovery of the balance of the ecosystem. The biota of the previously disturbed environment tends to regenerate from the stress, due to absorption capacity and survival of some components such as seeds, eggs, and microorganisms (Ayres et al., 2005) that through successive, orderly and gradual processes reach the climax community.

As mentioned by Binder et al. (2001), there are two environments that are fundamental for the revitalization of rivers and streams, the riparian zone (RZ) and the bottom zone of the riverbed, known as the hyporheic zone (HZ). The places that want to make changes in ecological systems are required to manage the resilience of the environment, through changes in development and urbanization policies, preserving the minimum of their functions in order to avoid future environmental tragedies (Adger et al., 2005), such as floods caused by the degradation of riparian zones. As a corrective effect, it is necessary to vacate the buildings in the areas of the banks so that the natural ecological conditions of the river are reestablished.

The RZ is an area located between the river and higher topography lands (Merill & Tonjes, 2014). This area is considered a transition area for several aquatic and terrestrial species helping to regulate ecological functions in both environments. RZ are areas suitable for flooding (Gregory et al., 1991) and have a great plant and biological diversity characteristic of their area (Orozco-López et al., 2018). This area is considered of great importance in water quality, in wildlife habitat, and for human recreation (Ramey & Richardson, 2017). From the hydrological point of view, the RZ maintains the health of the watershed through runoff, which occurs on its surface to water bodies and through infiltration (Orozco-López et al., 2018). The RZ is also a recognized environment for improving water due to the great microbial activity existing in the soil, in addition to its vegetation cover working to protect against erosion and control in the flood regime (Kiley & Schneider, 2005).

At the interface between the surface source and the aquifer, there is an environment known as hyporheic zone (HZ) that functions as a flow regulator between the river and the aquifer, determining the entry and exit of solutes between these environments in addition to serving as a natural filter (Ward et al., 2011). The HZ has definitions depending on the area that is studied, in geology and hydrology. Tonina and Buffington (2009) defined it as a volume of specific sediments that contains amounts of water from the surface and from the underground environment where there is an exchange of water between these two environments depending on the pressure in the riverbed and hydraulic conductivity. From a biological point of view, Dole-Olivier (2011) pointed out that the HZ is a rich environment that undergoes colonization processes for numerous invertebrates. Battin et al. (2016) also mentioned the biofilm existing in the HZ as a complex microbial community that houses a great diversity of algae, fungi, and bacteria that have an important ecological function in the ecosystem, such as the transformation and attenuation of polluting compounds.

Studies have shown the efficiency of HZ in nutrient cycling and as a natural filter capable of attenuating nitrogen, phosphorus, organic carbon (Liu et al., 2017) pharmaceutical products (Schaper et al., 2018), pesticides, and herbicides (Nagy-Kovács et al., 2018). Considered an important habitat for communities of hyporheic organisms, HZ is also a crucial environment in the life of macroinvertebrates such as fish and amphibians, where they lay their eggs that depend, in addition to shelter, on the nutrients that HZ provides for survival and maturation (Soulsby et al., 2009; Williams et al., 2010). Among the organisms that inhabit this area, the meiofauna can be highlighted, which are communities of organisms sensitive to disturbances, which make them great bioindicators of water quality. For example, the excess of nutrients, which is associated with the discharge of wastewater and organic pollution, causes changes to occur in its food chain, completely changing the structure of the community (Pacioglu, 2010).

One of the major concerns in urban rivers is the waterproofing of riverbeds, disconnecting the HZ from surface waters, impairing the hyporheic flow and its ecological functions (Bernhardt & Palmer, 2007). Although numerous studies show the functional and ecological importance of HZ for the aquatic ecosystem, this environment is one of the most threatened by human actions and one of the least protected by legislation worldwide (Mugnai et al., 2015).

The restoration of rivers aims to achieve, as close as possible, the natural state of the river and its ecological functions, admitting small levels of human disturbances. The idea is to recover the resilience of the ecosystem, recover the natural river processes, create a sustainable structure, return the beauty of the river and its banks, and bring back the natural landscape and affective relationship between the river and the population (Del Tánago & Jalón, 2007). In the case of urban river recovery, the actions to be developed should seek to strengthen the resistance and resilience of the water body (Afonso, 2011).

The functional structure and biological complexity of the environment are part of the ecological resilience of a system, both in terms of assimilation of the disturbances received and in terms of ecological succession. Understanding ecological resilience is of great importance to outline objectives and strategies in the river urbanization methodology, mitigating to the maximum the probable risks that these changes can bring.

4 Socio-Ecological or Adaptive Resilience

Despite the resilience in engineering seeks resistance and stability, urban rivers undergo many changes due to urbanization processes and economic activities that their morphological, hydrological, and biological characteristics need to change and adapt to a new situation where resilience is characterized as the search for a new balance. Socio-ecological or adaptive model of resilience recognizes that the stability domain itself is shifting (Laboy & Fannon, 2016).

In the urbanization process throughout the twentieth century, there was a great demand for space for housing and for transportation with the use of individual cars taking the space from the water, so that strangled water courses need to adapt but also requiring new spaces when the river revolts and tries to recover its old spaces, leading urban planners to rethink their plans.

If architects are to be essential social actors organizing the transformation of the built environment, social-ecological resilience is an important conceptual framework for the discourse and a good model for the interplay between the technical, ecological, and social domains (Laboy & Fannon, 2016). Socio-ecological resilience requires a transdisciplinary planning involving architecture, landscape design, hydrology, hydraulics, water chemistry, sociology, legislation, economics, navigation, tourism, fishing, and water sports.

Urban river resilience is imbricated with community resilience. In Atlanta (USA), some developments such as stadium, highways, and parking lots end up causing floods downstream in Turner Field area. A major project has been planned involving urban planners, transportation engineers, community groups, water professionals, and various government entities for implementation of green stormwater infrastructure to improve resilience both of the community and also of urban stream (Diner, 2017).

The objectives of river management based on socio-ecological resilience would be to (a) prevent the system from changing to unwanted configurations in the face of external disturbances and (b) maintain a certain configuration, which allows the system to be reorganized after a massive change (Walker et al., 2007). Disturbances can be seen, within this focus, as opportunities for change and transformation for more desired states (Walker et al., 2007; Hughes et al., 2005).

Urban systems in search of socio-ecological resilience seek to contribute to an interdisciplinary view, since the adaptation of populations requires an understanding of social and environmental relations in an integrated manner. It is a perspective that considers the challenges of simultaneously pursuing economic growth, social inclusion, and environmental responsibility. This seeks to help connect actors involved in spatial planning with a view to spatial sustainability, relating to the city's ecology, sociological architecture, as well as environmental sustainability, fueled by ecology and landscape architecture, studying restrictions and proposing drawings according to the landscape.

As examples of actions that can be applied to urban rivers, the green margins are maintained, with some low-impact urban or landscape uses. The incentive to plant covers with the protection of existing trees and the planting of new trees. The use of native species has priority of choice because they are well adapted to local conditions. Such action reduces the costs of structures for rainwater management, due to its role in water retention. In addition, it prevents flooding, filters out toxins and impurities, extends the availability of water in the dry months, and mitigates the effects of the urban heat island. The existing vegetation in the rainwater path avoids or minimizes erosion, in addition to bringing people closer to the environment that surrounds them, in search of their preservation (Andrade, 2014).

Another important action would be the definition of the limits of permanent preservation areas (PPA) for perennial and intermittent water courses and in this way to recover streams avoiding burying or channeling, which can be associated with linear parks (Andrade, 2014).

Linear parks can act as an environmental and landscape strategy with strong visual and functional appeal to the population, reversing the culture of hiding urban rivers. As an example of this rehabilitation, one can mention the recovery of the Cheonggyecheon River in Seoul, South Korea, showing how the city can modify its conceptions about urban development and restore its natural role. After the restoration, there was a great public approval for the new environmental quality of the city, the reduction of the effect of the city's heat island being one of the project's positive points.

The countless possibilities contained in the multifunctionality of the landscape constitute a factor favorable to socio-ecological resilience, given the diversification and valuation of the services offered by these complex and adaptive systems, the landscapes in their cultural and multifunctional dimensions. Tourism also presents itself as a possibility to deal with changes and contribute to socio-ecological resilience. Tourism industry needs a careful planning to avoid loss of cultural services or loss of environmental quality needed for socioeconomic development (Cunha, 2015).

Riverside communities may depend to a greater or lesser extent on the river's resources for their livelihood. These resources themselves can be diverse and incorporated into tourism, fishing, other extractive uses, and transportation. In general, the economy depends a lot on the aquatic system. If an oil spill affects a tourism location, it will also affect fish stocks and have other ecological impacts, affecting the local balance and requiring readjustment for its livelihood. Therefore, with the study of socio-ecological resilience, it is intended to address the scope of new perspectives on urban water that considers the metropolitan view of the territory, the right to the city, and the resilience of the natural environment, associated with public policies, urban and rural zoning, management of water resources, seeking integration between the landscape and the community.

5 Case Studies

5.1 Capibaribe Park in Recife

5.1.1 Thinking and Planning the City Adopting the Capibaribe River as the Backbone of a Water-Centered City

Few centuries ago, Recife City (Brazil) began its first houses at estuarine zone of Capibaribe River and other rivers that share the same estuary. The first long-lasting (and ongoing) conflict is between the city and nature, notably the fight to control water. Recife's identification with the waters of the Capibaribe River, the main watercourse that traverses it, is one of the city's most striking features (Monteiro & Carvalho, 2016).

The Parque Capibaribe project in Recife seeks to rescue the river and its importance to the city. The Parque Capibaribe project foresees revitalization of the Capibaribe River in the urban stretch within Recife as a way of better planning the city. Socio-ecological resilience is being strengthened with the creation of a system of integrated parks on the two banks of Capibaribe along 15 km of the river, including a path for pedestrians and cyclists.

Capibaribe Park will be a large linear park that revolutionizes the way people live in Recife by reconnecting them with the waters of the Capibaribe River, rescuing the hydrographic basin as the backbone of the city through areas of leisure, rest, and well-being (INCITI, 2016).

Currently, in 2020, the Capibaribe Park is in the stage of detailing the project and implementing the first activities. The work being carried out is part of the technical cooperation agreement between the Recife City Hall, through the Environment and Sustainability Secretariat and a multidisciplinary team from the Federal University of Pernambuco (UFPE).

In the urbanization process of Recife, the river channels were strangled due to irregular and even formal occupation of its banks, a process that continues today, endangering the municipality's natural drainage system and resulting in frequent flooding (Cabral et al., 2015). The park's proposals address the need to improve the hydrological, hydraulic, ecological, and social conditions of Recife's urban streams, while enhancing the natural conditions of its surroundings, mobility, and contemplative leisure.

Therefore, Parque Capibaribe also promotes a change in the mentality of the population in relation to the river, taking an innovative look at the countless possibilities of actions in the waters of Capibaribe. The park was not only thought of as a line along the watercourse. It works with a strip of at least 500 meters around each bank, which significantly expands the area of influence of the water courses.

During the process of designing the Capibaribe Park, dialogues were established to listen to the different needs and desires that each reality awakens, through conversations with associations of residents; the elderly; women; youth and children; residents of riverside communities – shellfish gatherers, boaters, and fishermen – street vendors; and people who live in the regions directly impacted by the transformations of the project (INCITI, 2016).

The basic idea is to use the Capibaribe River and its tributaries to plan a green city, which will promote reconnection with nature, through the gradual recovery of waters and riparian forests (Fig. 14.4). The river and the city will become a meeting place and opportunities, through the creation of open, collective, inclusive spaces, in the form of sustainable processes to face the challenges of a changing planet, with both climatic and economic effects (INCITI, 2016).

Various urban solutions are being planned to allow spaces for approaching the river, through footbridges that run along the banks and mangroves and piers that allow the access of small boats. It is expected that people can reach the river, travel it, cross it, and activate actions from the river.

In order to recover the feeling of belonging and ownership of people with the river and the public space, several activities were carried out with the participation of hundreds of people, over several months.

To strengthen socio-ecological resilience, it is necessary for people to participate and one of the ways is with leisure, rest, and festive activities. Figure 14.5 shows one of the activities of a river tour with music during the 2020 carnival.

To strengthen socio-ecological resilience, all those interested in participating were involved in actions to think about the environmental recovery of the river banks, encourage the organization of informal traders in the surrounding area, and develop prototypes of lighting, signage, and urban furniture, in order to transform the territory in an environment of coexistence, leisure, environmental awareness, and contemplation of the landscape (INCITI, 2016).

Fig. 14.4 Planning for the city of Recife in the coming years using the Capibaribe River as the main focus. (Source: INCITI (2016))

Fig. 14.5 River trip with music during the carnival in 2020 year. (Source: authors)

5.2 Parnamirim Stream

5.2.1 The Resilience of an Almost Dead Stream That the Community Tries to Revitalize

The Parnamirim stream corresponds to an urban tributary of the Capibaribe River; its hydrographic basin is located in the West Zone of the city of Recife (Brazil) and has a drainage area equivalent to 135.2 hectares (Braga et al., 2009). Its initial stretch suffered from the canalization and currently passes through drainage pipes. Despite that, there is still a stretch, a little more than 1 km long and 5 m wide, in which the stream runs in the open, making possible the revitalization process of this stretch (Cabral et al., 2019).

In the last few years, the stream has suffered many impacts due to the disorderly urbanization process with irregular constructions and untreated sewage discharge. In a study on the Water Quality Index, the results showed the water quality to be very bad, showing high concentrations of biochemical oxygen demand and thermotolerant coliforms and the absence of dissolved oxygen in the water. The release of sanitary sewer was pointed out as the main cause of poor quality (Cometti et al., 2019).

Cabral et al. (2019), aiming at the importance of trophic and ecological relationships that the meiofauna brought to the aquatic environment, carried out a study on the composition of the meiofaunistic community in the hyporheic zone of the Parnamirim stream, and, despite the high degree of pollution in which the stream is found, species of the Oligochaeta and Amphipoda taxa (Fig. 14.6) were found with relative abundance.

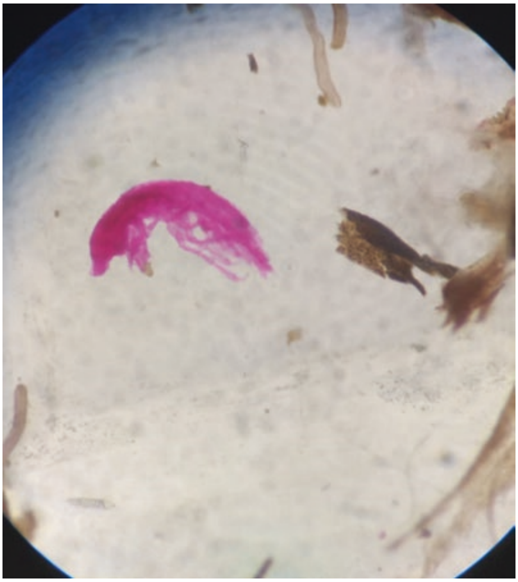

Fig. 14.6 Meiofauna Amphipoda found in the hyporheic zone of the Parnamirim stream. Visualization by a stereoscopic microscope with 4x magnification. (Source: Cabral et al. (2019))

Fig. 14.7 (**a**) Bridge over Parnamirim stream. (**b**) Zoom on the previous photo to show the turtle under the bridge, even in a sewage polluted river. (Source: authors)

In addition to meiofauna, it is possible to observe a macrofauna residing in these streams, which are the turtles. Cavalcanti, Oliveira, and Monteiro (Cavalcanti et al., 2015) carried out a survey of the fauna present in the Capibaribe River, where the presence of turtles (*Phrynops geoffroanus*) was observed in the section where the Parnamirim stream is located and highlighted the ecological aspects such as the adaptation of these animals (Fig. 14.7). Souza (2004) pointed out that this species of tortoises is carnivores and within its diet are fish, crustaceans, and insects; however,

Fig. 14.8 Largo do Holandês besides Parnamirim stream. (**a**) After installation and painting. (**b**) Social meeting at Parnamirim river bank. (Source: authors)

this species is very adaptive and can feed on seeds and fruits, and in environments degraded by anthropic actions, they even eat domestic sewage.

In the last 10 years, teachers and researchers, together with the population, have been carrying out work to raise awareness of the importance of revitalizing the stream, providing information on the advantages of recovering ecological characteristics, such as their role in draining rainwater, thermal comfort, and the environment: aesthetic and the environment for leisure purposes (Cabral et al., 2017; Preuss et al., 2020).

An interesting situation has occurred for the creation of a small square on the banks of the stream where previously there was trash and weeds. The group of residents of the neighborhood developed several actions to improve the place and the city government collaborated with the donation of seedlings to plant and the lighting of the square (Fig. 14.8).

5.3 Fishing Women in Recife City

5.3.1 The Fishing Community of the Tejipió Estuary Represents a Good Example of Socio-Ecological Resilience in the Middle of a Metropolis of 4.5 Million Inhabitants

Across the Brazilian Northeast, around 500 thousand artisanal fishermen are part of food production, reaching 75% of the fish that reach the table of more than one million families from across the region.

In the city of Recife, in Pernambuco, Brazil, there are several fishing colonies, such as the Brasília Teimosa, Ilha de Deus, Coque, and Pina communities. Artisanal fisheries are of great socioeconomic importance in the region due to local ecosystems (mangroves and coastal reefs) at estuarine zone of Capibaribe River, Beberibe River, and Tejipió River which, although they have a small number of species, they are highly productive (Fig. 14.9). According to the latest report by the Center for Research and Management of Fisheries Resources in the Northeast (CEPENE,

Fig. 14.9 Fishermen and canoes at estuary of Tejipió River, collecting sururu in Recife City, at a mangrove area in the middle of a very urbanized region. (Source: Diário de Pernambuco (2019))

2009), the institution responsible for monitoring fisheries production in the northeast, 11,000 professionals are engaged in artisanal fishing, operating a fleet of 2042 units, mostly canoes and rafts, and some motorized boats (Fox, 2010).

Deep sea fishing is generally a male activity, but in estuarine areas, women in fishing communities have been carrying out activities that involve catching fish (fishing with the hand line and small nets, collecting shellfish, oysters, and sururu), the processing of fish (salting of fish, evisceration), the maintenance and repair of fishing instruments (nets, canoe sails), and the marketing of fish (Machado, 2009). Sururu (*Mytella charruana*) is a common bivalve in Central and South America. They are around two centimeters long and generally of brown color.

Based on the analyzes carried out by Cidreira Neto (2019) on tide fishermen, it was possible to observe the forms of interaction between fishermen and the tide, resulting in a network of knowledge and wisdom, built from daily contact with this ecosystem, making each unique know-how, and of relevant importance for the continuity of the activity. Each fishing art is based on a personal expression, based on the practice and knowledge acquired by the most experienced, which is being rebuilt with each new generation that takes on this profession, adapting to the new economic, social, and environmental standards.

Shellfish fishing takes place in estuarine zone in the beach and mangrove areas, mainly at low tide, which allows the appearance of sandy/muddy banks used for collection, being carried out in social or individual groups. There are two main forms of fishing, manual, where shellfish are collected through direct extraction in the sediment and the one with the aid of artisanal equipment which increase the collection capacity (Fig. 14.10) (Silva & Martins, 2017).

Fig. 14.10 Fisherwomen treating sururu, removing the flesh from inside the shells. (Source: Diário de Pernambuco (2019))

Fishing takes place on a small scale of production, handcrafted by fisherwomen, but has great social, economic, and environmental importance. Known as tidal work, regulated by several environmental factors such as changes in salinity, pH, and temperature, fishermen and women in this activity have relevant environmental knowledge, as well as the dynamics of the harvested organism.

From an environmental point of view, as the process takes place manually, it causes minimal impacts. To assure the socio-ecological resilience, it is important to evaluate the effects of pollution, due to the unhealthiness of rivers and mangrove areas, as they can cause the extinction of the activity and the lack of fishing populations.

The work and the way of life earning a living according to the movement of the tide in the estuarine region created some very striking cultural aspects within the city. Thus, the natural space becomes socialized by these individuals; it gains diversified tones and shapes, transforming the inhabited place into an object of manifestation of subjectivities, of the social construction of meanings, and of the assimilation of practices, principles, and values that become the ethos of the community (Caetano, 2015).

In order to improve the socio-ecological resilience of the region and ensure the sustainable exploitation of fishing resources by artisanal fishing, some public policies are necessary avoiding pollution in rivers, financing the purchase of new fishing materials, encouraging tourism for knowledge of local reality, and sustaining social cohesion for the participation of the entire community.

5.4 *Beberibe River*

5.4.1 Beberibe River Presents Socio-Ecological Resilience Only Upstream

The Beberibe River is considered one of the main rivers in the Recife Metropolitan Region (Brazil). Its hydrographic basin has an area of approximately 79 km2. The use of soil in the basin is due to urban and industrial occupation, areas of Atlantic Forest and mangrove, and polyculture. The river water is used for public supply and reception of domestic and industrial effluents. Regarding the industrial activities developed in the basin, there are food products, chemistry, pharmaceutical/veterinary products, drinks, paper/cardboard, metallurgy, and perfumes/soaps/candles. Figure 14.11 shows the Beberibe River basin.

In hydrographic terms, this basin can be divided into three distinct parts which are upper Beberibe, middle Beberibe, and lower Beberibe. The upper Beberibe corresponds to the main course drainage located west of the BR-101 route. The middle Beberibe comprises the stretch between the BR-101 and the confluence with the Morno River. Between the confluence with the Morno River and the Atlantic Ocean, there is the lower Beberibe. To assess the resilience of the Beberibe River, it is important to characterize the following attributes: hydrological/hydraulic function, water quality, and aquatic life.

(a) Hydrological/hydraulic function.

- The upper Beberibe is located in an elevated region, with several perennial springs and covered with vegetation. If measures are not adopted in relation to their form of occupation, this area may suffer a strong process of anthropization, with the consequent increase in the percentage of impervious

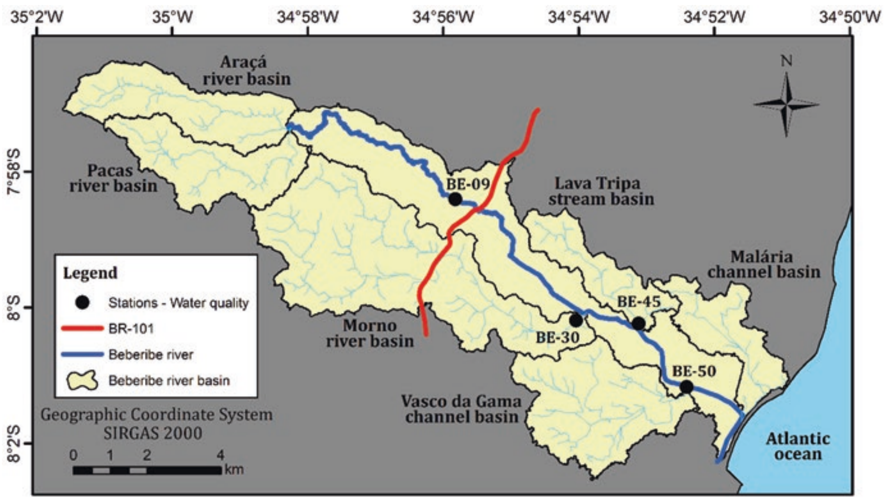

Fig. 14.11 Beberibe River basin. (Source: authors)

areas in that part of the basin with probable consequences of floods downstream.

- The middle Beberibe basin contrasts with the upper section as it presents an open valley, with flat margins, often occupied by water excesses during the rainy seasons. In these margins, the occupation process took place quite sharply, which leads the local population to a permanent condition at risk of flooding.
- The lower Beberibe basin corresponds to the most inhabited portion of the basin. The level of densification and imperviousness of some of the urban agglomerates present in the area is already close to the saturation limit.

Figure 14.12 illustrates the situation of the basin in relation to the process of land use and occupation.

(b) Water quality.

The Water Quality Index (WQI) was used to assess water quality. This index considers quality variables that indicate the release of sanitary effluents into the water body, providing an overview of the surface water quality conditions. The upstream section has good water quality, with low levels of pollution. This category includes bodies of water that present conditions of water quality compatible with the limits established for class 2 of fresh waters, whose

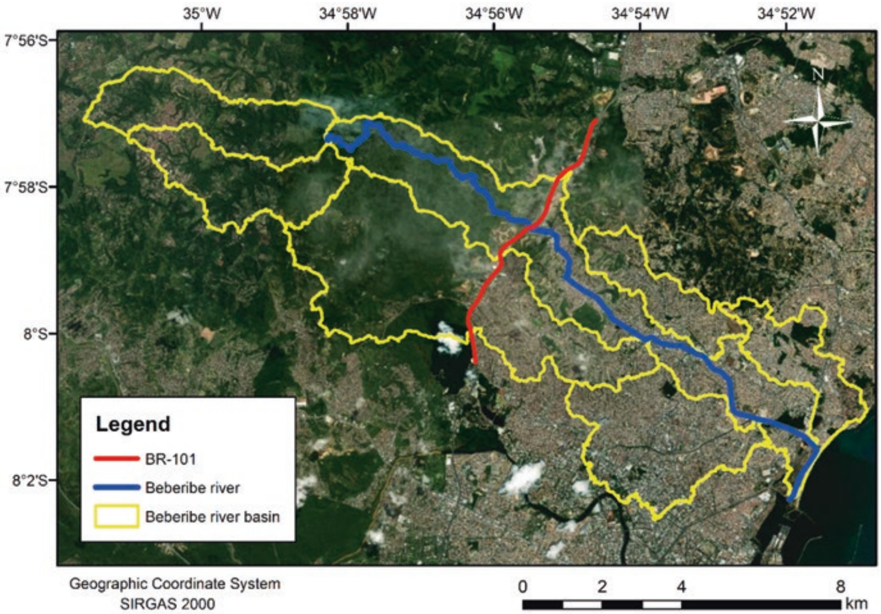

Fig. 14.12 Land use and occupation in the Beberibe River basin. Upstream stretch on the left hand side presents good vegetation cover but downstream on the right hand side is highly urbanized. (Source: authors)

main uses are the supply for human consumption, after conventional treatment; the protection of aquatic communities; recreation of primary contact such as swimming, water skiing, and diving; the irrigation of vegetables, fruit plants, parks, gardens, and sports and leisure fields, with which the public may come into direct contact; and aquaculture and fishing activity (CONAMA, 2005).

Downstream monitoring stations indicate poor water quality, with very high pollution. In this category are bodies of water that do not fit into any of the classes. Therefore, the water quality of upper Beberibe is much better than that of middle and lower Beberibe.

(c) Aquatic life.

The assessment of aquatic life with the Beberibe River was carried out using the Trophic State Index (TSI). The purpose of the TSI is to classify water bodies in different degrees of trophy, that is, it evaluates the quality of the water in terms of nutrient enrichment and its effect related to the excessive growth of algae and cyanobacteria (CPRH, 2020).

Table 14.1 shows the water quality and the trophic state for several monitoring points.

Resilience of Beberibe River: From the analyzed attributes, it is possible to infer that the upper Beberibe shows good conservation features, with characteristics close to natural conditions. For this stretch, it is observed that the river itself has the capacity to recover presenting strong resilience properties. In the middle and lower Beberibe, large impacts are observed, requiring the adoption of measures, such as the implementation of renaturalization projects, which seek to adapt the river to improve its hydraulic, social, and environmental conditions.

6 Conclusions

Resilience can be conceptualized as the ability to recover after an impact, returning to conditions prior to the impact or adapting to new conditions. Watercourses in cities have been highly impacted over the last few decades, leading to the need to better study the resilience of urban rivers and streams.

Table 14.1 Water quality and trophic state for monitoring points at Beberibe River

Parts of the Beberibe River	Station	Water quality	Trophic state
Upper Beberibe	BE-09	Little polluted	Mesotrophic (53)
Middle Beberibe	BE-30	Very polluted	Supereutrophic (65)
Lower Beberibe	BE-45	Very polluted	Eutrophic (63)
Lower Beberibe	BE-50	Very polluted	Hypereutrophic (70)

Source: CPRH (2020)

Engineering resilience in urban rivers presents multidisciplinary characteristics such as hydrology, hydraulics, water quality, erosion, and sediment transport. Each of these aspects can be impacted and resilience can be defined for each of these aspects according to the system's recovery capacity and also according to reduction of probabilities of failures, reduction of the consequences of failures, improvement of recovery conditions, and reduction of recovery time.

The revitalization of rivers improves ecological resilience protecting the health of ecosystems, preserving water resources, and protecting against floods. Two environments are fundamental for the revitalization of rivers: the riparian zone and the bottom zone of the riverbed, known as the hyporheic zone. Riparian zone is considered a transition area for aquatic and terrestrial species helping to regulate ecological functions in both environments. Hyporheic zone is important for nutrient cycling and as a natural filter capable of attenuating pollution at places where river recharge the aquifers.

Linear parks can act as an environmental and landscape strategy with strong visual and functional appeal to the population, reversing the culture of hiding urban rivers. Linear park multifunctional landscape constitutes a factor favorable to socio-ecological resilience, given the diversification and valuation of the services offered by these complex and adaptive systems.

The Parque Capibaribe project in Recife includes a linear park that seeks to rescue the river and its importance to the city. Local mobility solutions are being planned to allow spaces for approach the river and cross or walk along through footbridges, walkways, bicycle paths, and piers that allow people live and enjoy the river. Planning the park had the participation of hundreds of people, over several months to encourage the feeling of belonging and ownership of people with the river.

An interesting example of socio-ecological resilience of urban rivers can be found at a shared estuary of three rivers in Recife (Brazil). At this estuarine area, women in fishing communities have been carrying out activities that involve fishing (with the hand line and small nets); collecting shellfish, oysters, and sururu (a common bivalve in Brazilian northeast); and processing and the marketing of fish. This professional activity has passed through generations and has helped to generate jobs, maintain economic activity, preserve the environment, and contribute to the resilience of the river and the city.

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Part V
Disaster Risk Reduction Policy, Governance and Resilience

Chapter 15
Unveiling the Latent Disasters from a Holistic and Probabilistic View: Development of a National Risk Atlas

Paula Marulanda-Fraume, Omar-Darío Cardona, Mabel-Cristina Marulanda, and Martha-Liliana Carreño

Abstract The objective of the holistic risk assessment is to evaluate risk from a comprehensive perspective, integrating physical risk, or potential physical damage, linked to the happening of hazard events and socio-economic and environmental factors, non-hazard-dependent. This approach seeks to capture how these latter have an incidence on physical risk, exacerbating the negative impacts of a dangerous event, as well as affecting the capacity of the society to anticipate or resist or to respond and recover from adverse impacts. This article presents the results of the holistic evaluation obtained at the subnational level in Colombia in the framework of the Risk Atlas of Colombia of the National Unit for Disaster Risk Management (UNGRD, its Spanish acronym). The evaluation was performed using the probabilistic physical risk results derived from a multi-hazard risk assessment, with 16 socio-economic indicators available for the 1123 municipalities of Colombia. These results are relevant for comparison purposes and are also useful to identify the risk drivers associated not only with the current risk conditions but also those shaping future risk.

Keywords Risk landscape · Systemic risk · Holistic approach · Socio-economic fragility · Lack of resilience · Probabilistic risk assessment · Risk atlas · Indicators

P. Marulanda-Fraume
INGENIAR: Risk Intelligence, Bogotá, Colombia
e-mail: paula.marulanda@ingeniar-risk.com

O.-D. Cardona (✉)
INGENIAR: Risk Intelligence, Bogotá, Colombia

Instituto de Estudios Ambientales, Universidad Nacional de Colombia, Manizales, Colombia
e-mail: odcardonaa@unal.edu.co

M.-C. Marulanda
Centro de Investigación para la Gestión Integrada del Riesgo de Desastres (CIGIDEN), Santiago de Chile, Chile

BCM/IEM, Rabdan Academy, Abu Dhabi, United Arab Emirates

M.-L. Carreño
Centre Internacional de Mètodes Numèrics a L'Enginyeria (CIMNE), Barcelona, Spain

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1 Introduction

From the perspective of disasters, risk has been measured to address it as the possible economic, social, and environmental consequences derived from a natural or anthropic event. Disaster risk is not only linked to the occurrence of natural events but also – and mainly – to the prevalent conditions of vulnerability favoring the happening of disasters. However, very few analyses address risk in a comprehensive manner, and in most cases, their approach is mainly oriented toward a social characterization of vulnerability, treating it as equivalent to risk and not as a condition of susceptibility, leaving aside the fact that potential physical damage is essential when it comes to estimating risk. Therefore, the likelihood of occurrence of a negative impact, derived from a natural or anthropic event, implies the convergence of physical, natural, social, economic, and political factors that require a holistic approach where appropriate involvement is ensured for every aspect of the configuration of risk.

Sociology and political science define vulnerability as a social construction, resulting from development processes that generate it, thus setting the conditions that transform a hazard into a disaster and exacerbate its impacts. Unlike the hazard, vulnerability accumulates and prevails over time, and it is intricately linked to social aspects and the level of development of the communities. Social situations set a number of conditions that, combined with a natural event, result in disaster (Oliver-Smith, 2004).

Therefore, risk as currently configured is the result of a social process of many years, which determines the present conditions that can transform a natural event into a disaster, determining whether the exposed elements will be resilient to its effects or are vulnerable to its consequences (Cardona, 2004; Bankoff et al., 2004). Likewise, these current conditions are determining future risk. By tackling these socio-economic conditions, it is possible to increase the resilience of the communities to cope with the effects of an event, as well as the capacity to quickly recover from the impact and build back better to avoid future disasters. Poor information and communication between social actors, lack of institutional and community organization, weaknesses in emergency response, poor governance, political instability, and the insufficiency of economic well-being in a geographic area contribute to increasing risk (Ambraseys, 2010).

Although the public interest in risk assessment has increased in the last decades and it has been accepted that losses resulting from hazardous events are avoidable, up to at least some degree of human control, and therefore actions can and should be taken to prevent and reduce risk, insufficient disaster risk understanding can lead to its underestimation and therefore to a lack of actions addressed to the reduction of their impact (Jamali et al., 2022). As highlighted by the UNDP Global Report (UNDP, 2004) "Disaster risk is not inevitable, but it can be managed and reduced through appropriate development actions."

One of the main challenges related to risk assessment is to find the right ways to communicate complex issues from science to policy and to the public. Composite indicators are a tool to do so, by offering a simplified representation of a multidimensional concept. They are big pictures that allow an easier interpretation of complex issues instead of trying to find trends in many separate indicators. Indicators highlight some of the aspects of risk and contribute to the formulation and analysis of public policies and decision-making processes. However, indicators are not aimed at identifying risk management measures, which instead must be identified by integrated models and comprehensive risk analysis. Risk assessments help to facilitate risk communication, revealing the importance of introducing them in development plans.

The concept of risk is linked to decision-making; this means that risk must be measured to make decisions about the feasibility or convenience of carrying out actions to prevent it or reduce it. What is not measured cannot be managed, and therefore in defining a robust strategy for risk management, the first step is to be rigorously evaluated. Risk is a crosscutting notion, and as such it must be addressed through a comprehensive and multidisciplinary approach. Risk management decisions must focus on strategies considering both physical damage, direct impacts (hazard-dependent), and socio-economic factors (non-hazard-dependent) contributing to second-order effects and intangible impacts. Based upon this understanding, a holistic approach for risk assessment was carried out at a subnational level in Colombia for its 32 departments and 1123 municipalities, integrating physical risk resulting from a multi-hazard assessment and a set of socio-economic indicators. The results of this evaluation are presented herein.

2 The Holistic Approach

Holistic risk assessment considers, within a single conceptual framework, hazard and vulnerability, both physical, understood as the susceptibility to damage of the exposed elements, and contextual, expressed through a set of socio-economic factors. Figure 15.1 illustrates the conceptual framework applied in this evaluation. Hazards are events of potential occurrence that have a destructive effect on the exposed elements (i.e., exposure), characterized by a physical vulnerability and by contextual conditions amplifying or exacerbating physical damages that can be associated with socio-economic indicators describing lack of resilience and social fragility. The convolution of these aspects derives from the likelihood of impact (risk). The disaster itself is a manifestation of the hazard entailing a disturbed state of the exposure that must also be managed through ex post measures.

Tackling risk requires a comprehensive risk management system based upon an institutional structure that supports and promotes public policies, strategies, and corrective and prospective actions addressed to intervene the susceptible elements and conditions of society that favor the setting up or the increment of risk, as well as the created hazards (anthropogenic, technological). Likewise, as part of the risk management framework, emergency response and recovery plans based on risk assessments must be defined, allowing for a quick and effective response when a disaster occurs. For management purposes, risk studies support improved decision-making contributing to the effectiveness of risk management by inviting action and

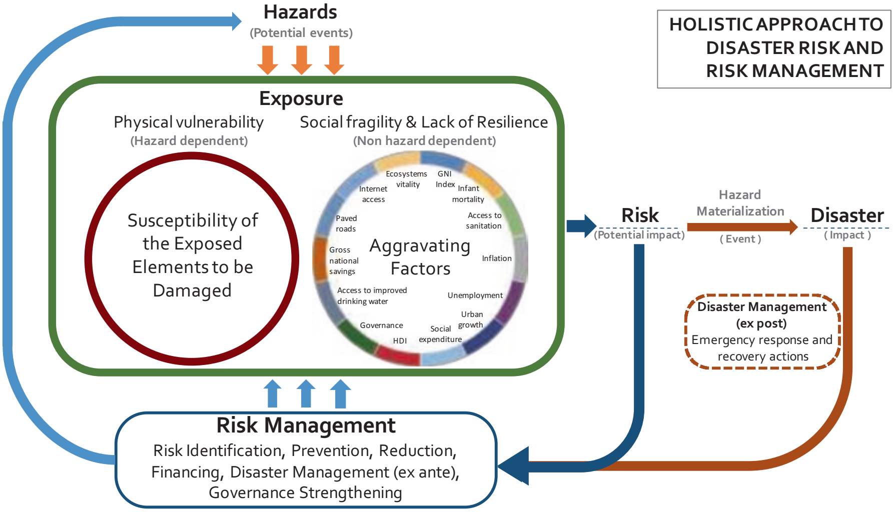


Fig. 15.1 Conceptual framework of the holistic approach to risk assessment and management (Cardona, 2001); used at UNDRR (2017) and UNGRD (2018)

identifying weaknesses of the elements exposed, as well as their evolution over time (Cardona, 2001; Carreño, 2006; Carreño et al., 2007).

Holistic evaluations of risk derived of seismic hazards and vulnerability in urban areas have been performed in recent years for different cities worldwide, Carreño et al. (2007); Birkmann et al. (2013); Marulanda et al. (2013); Jaramillo (2014); Salgado-Gálvez et al. (2016), as well as at country level, Daniell et al. (2010); Burton and Silva (2014); and at global level: UNDRR (2017), proving to be a useful way to assess, compare and communicate risk while promoting effective actions toward the intervention of vulnerability, measured at its different dimensions. This approach has also been integrated into toolkits, guidebooks, and databases for earthquake risk assessment, Burton et al. (2014); Khazai et al. (2015). Most recently, a study based on the conceptual approaches of this methodology was carried out in the USA by FEMA (2020). The results presented in this article are from the first application of this methodology at the departmental and municipal level, for the 32 departments and 1123 municipalities under the framework of the Risk Atlas of Colombia (UNGRD et al., 2018), and considering four different hazards.

The holistic risk approach robustly addresses the hazard and the contextual conditions, acknowledging their close interrelation, considering both physical aspects and intrinsic characteristics of the society that define either worse or better conditions that, in turn, amplify or reduce the impact of a hazardous event and the capacity of the communities to cope with and recover from adverse impacts. This methodology adheres to the suggestion of Cardona (2001), cited in Bankoff et al. (2004) that vulnerability originates in:

– Physical fragility or exposure: Susceptibility of human settlements to be affected by dangerous events due to their location within the area of influence and their lack of physical resistance.

– Socio-economic fragility: Predisposition to suffer harm from the levels of marginality and social segregation of human settlements, the disadvantageous conditions, and relative weaknesses related to social and economic factors.
– Lack of resilience: Limitations of access and mobilization of resources in human settlement and the incapacity to respond when it comes to absorbing the impact.

From this perspective of relative and multicriteria analysis, risk is considered as a summation of a series of potential consequences caused by factors of physical exposure (potential damage and losses) to a given hazard and the underlying factors leading to its implications and the incapacity to face them. This notion implies that undesired effects can be avoided or reduced if triggering and causal actions are intervened.

This assessment considers variables of different classes which treatment is not always easy by using functions. For this reason, it is sometimes necessary to use *proxies* or "representations," which may well be indexes or indicators. Thus, it can be said that vulnerability might be described by several components reflecting physical susceptibility and fragility (exposure) – which are dependent on the action or severity of the event – and others that reflect social fragility and lack of resilience, that is, the incapacity to anticipate, recover, and absorb the impact, which is not dependent on or conditioned by the effects and impacts of the event.

This methodology offers a simplified vision of a multidimensional concept, aiming to facilitate its interpretation from different stakeholders, promoting an articulated frame of social, economic, environmental, and cultural aspects. It is worth noting that indicators, in general, do not identify the measures of risk management since these should be conceived using integrated models. However, the main strength of this approach lies in the possibility to make a retrospective analysis by disaggregating the results to identify the factors that should be prioritized for risk reduction actions and assess the (in)effectiveness of measures taken in the past. This is the first time that a study, following the above mentioned methodology, is conducted considering hazard, exposure, and socio-economic descriptors at the subnational level for a whole country. This approach allows the identification of risk drivers associated with the socio-economic context, going beyond the physical vulnerability of the exposed assets. The results obtained in this evaluation support risk communication and benchmarking across municipalities promoting effective actions for the intervention of vulnerability conditions measured in their different dimensions.

3 The Risk Assessment Methodology

Under this methodology, total risk R_T is a function correlating the potential physical damage R_F, and the aggravating factor F. R_F is obtained from the vulnerability (physical susceptibility) of the exposed elements to hazards (defined in function of intensity during a specific period). F depends on the social fragilities and the lack of resilience, that is, how prone the system is to suffer damages and losses. Thus, total risk R_T may be understood as the combination of direct physical risk and a measure of additional risk associated with contextual conditions and it is expressed as:

$$R_T = R_F\left(1 + F\right) \tag{15.1}$$

known in the literature as Moncho's equation, where R_F and F are composite indicators (Cardona, 2001; Carreño, 2006; Carreño et al., 2007). This expression explicitly incorporates the natural, socio-natural, and anthropic character of the different aspects controlling disaster risk in a single indicator. R_F is obtained from the probabilistic risk models, while F accounts for the contextual conditions determining the proportion in which the socio-economic context of the area under analysis causes an additional risk to the physical one, i.e., its impact or indirect effects. Note that there can be no context-derived risk without physical risk (loss, damage, or direct effects), a characteristic that stems from the integral nature of the holistic assessment. Detailed information about this methodology can be found in Carreño (2006), Carreño et al. (2007), Barbat et al. (2011), and Marulanda et al. (2020).

3.1 The Probabilistic Risk Metrics

The frequency of catastrophic events is particularly low and variable according to the type of event; therefore, the historical information is generally very limited. The short history of disaster records makes it rather evident that the "worst-case" scenario is improbable to have occurred yet. Therefore, large losses are rare, and it is difficult to estimate, in statistic terms, exceedance rates for them. Their probabilities require considerable judgment (Apostolakis, 1990). In this sense, quantifying physical risk does not mean knowing risk precisely but defining the relevant uncertainties. Analytical approaches can fully represent the physical risk problem by rationally incorporating and propagating the inherent uncertainty in the occurrence of loss and impact. Probabilistic risk assessment (PRA), which all catastrophe models implement, is the most appropriate tool for this. As the occurrence of hazardous events cannot be predicted, physical risk models use sets of events to represent all possible ways in which the hazard phenomenon may occur in the area under analysis in terms of both, recurrence (frequency) and severity. Another piece to compute risk is the loss probability distribution as a function of the hazard intensity to represent the vulnerability of the exposed elements. Event-based PRA has been extensively applied to different hazards at different scales (e.g., Grossi & Kunreuther, 2005; Jenkins et al., 2012; Cardona et al., 2014; Niño et al., 2015; Salgado-Gálvez et al., 2014, 2015, 2017; Wong, 2014; Jaimes et al., 2015; Quijano et al., 2014; Bernal et al., 2017). Hazard, exposure, and vulnerability are the main components of PRA and can be defined as follows:

– Hazard model: Consists of a set of events (hazard specific), which should exhaustively represent the hazard. Each event contains the frequency of occurrence and

the distribution of spatial parameters to characterize the intensity as a random variable.
- Exposure model: Contains characteristics (metada) of each exposed element such as geographical location, replacement value, and building class. Depending on the resolution of the model, it might contain more detailed information on the exposed assets.
- Vulnerability model: Describes the vulnerability functions for each hazard type and building class. Vulnerability functions characterize the structural performance as a function of hazard intensities. Equivalently, these functions represent the probability distribution of the loss as a function of hazard intensity.

The probabilistic risk assessment quantifies potential losses resulting from a given event, as shown in Fig. 15.2.

Physical risk is usually measured by means of the expected number of events per unit time – loss exceedance rate, $\nu(p)$ – that will generate losses equal or larger than p. The total probability theorem is used to compute $\nu(p)$:

$$\nu\left(p\right)=\sum_{j=1}^{\text{Events}}\Pr(P>p\,|\,\text{Event}_i)\bullet F_A\left(\text{Event}_i\right) \tag{15.2}$$

where $Pr(P > p|\text{Event } i)$ is the probability of exceedance of the loss p given the occurrence of the event i and $F_A(\text{Event } i)$ is the annual occurrence frequency of event i. Figure 15.3 shows a flowchart of the risk assessment process (Esteva, 1967; Cornell, 1968; Cardona, 1986; Ordaz, 2000; Grossi & Kunreuther, 2005; Bernal et al., 2019).

The main risk metric from a fully probabilistic risk assessment is the loss exceedance curve (LEC), which is the most robust tool for representing catastrophe risk (e.g., Cardona, 1986; Ordaz, 2000; Grossi & Kunreuther, 2005; Marulanda et al., 2013). The LEC provides an exhaustive probability quantification of the risk problem. It is not possible to know the exact losses of a future disaster; however, with a LEC, it is possible to know the exceedance probability of any loss amount within any time frame. This information can support decision-making processes for risk reduction. Diverse risk metrics derive from the LEC such as the average annual loss (AAL) and the probable maximum loss (PML). The AAL or the pure risk premium is a compact metric with low sensitivity to uncertainty that condenses in one number the full losses occurrence process. It expresses the expected (average) loss per year considering all the events that could occur over a long time frame, including large losses over long return periods. The AAL is basically the sum of the product, for all the stochastic events considered in the loss model, of the expected losses in a specific event, and the annual occurrence probability of that event (Ordaz, 2000):

$$AAL=\sum_{i=1}^{\text{Events}}E(p\,|\,\text{Event}_i)\,F_A\left(\text{Event}_i\right) \tag{15.3}$$

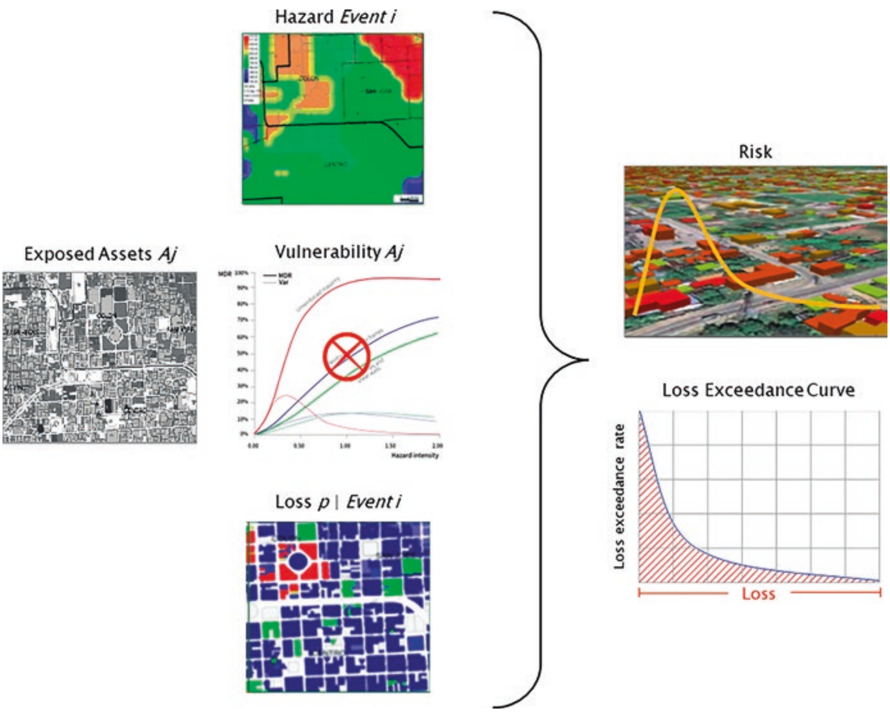


Fig. 15.2 Probabilistic risk assessment modeling scheme

where $E(P|\text{Event } i)$ is the expected loss for the event i and F_A (Event i) is the annual occurrence frequency of the event i. The PML is the maximum expected loss in a set of elements exposed for a given return period (or its inverse, annual exceedance rate). The PML curve is the inverse of the LEC.

3.2 *The Expected Losses as Physical Risk Indicators*

For this evaluation, instead of using only indicators from damage scenarios, as in the past, physical risk values were obtained from the normalization of the AAL, values resulted from the multi-hazard fully probabilistic risk assessment. The AAL is a metric that indicates the amount of funds the government or any other responsible entity would have to set aside, annually, to cover for all the potential future damage and losses. This probabilistic metric aims at compressing risk in a single number, and it is the most convenient metric for comparison purposes.

The physical risk index R_F was calculated based on the results of the probabilistic multi-hazard risk assessment considering the relative AAL of each hazard included in the evaluation (earthquake; tsunami; tropical cyclones – wind and storm surge;

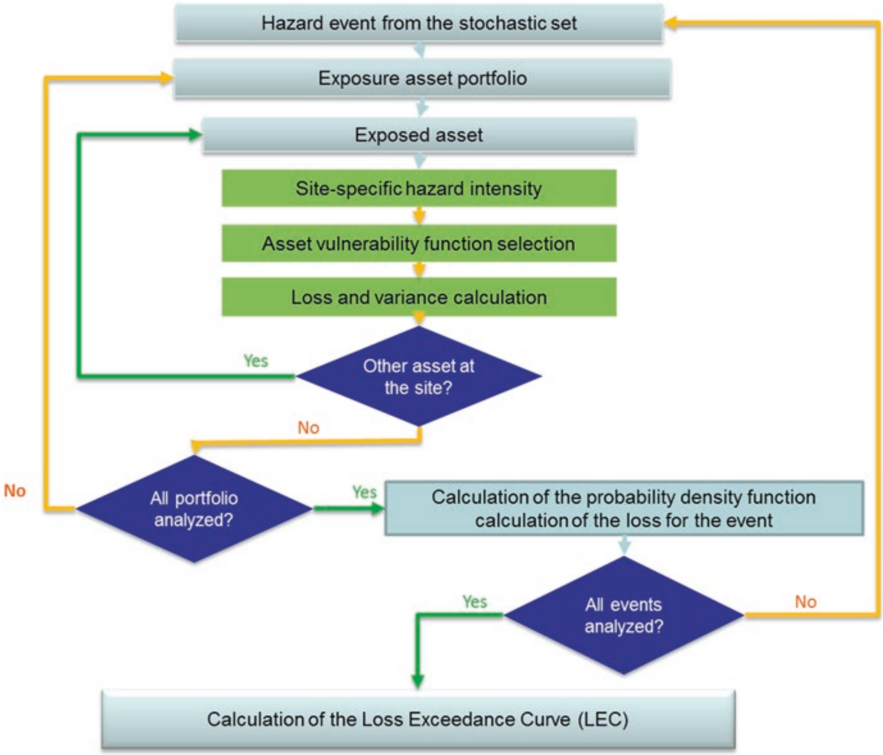


Fig. 15.3 Flowchart of probabilistic risk assessment process

and floods). The AAL is then transformed to values between 0.0 and 1.0, where the maximum value corresponds to those AAL equal to or greater than 10‰[1] (or 1%). The normalization was made using the following functions per segment:

$$R_F = \begin{cases} 2\left(\dfrac{AAL}{AAL_{\max}}\right)^2 & \text{for} \quad 0 \le AAL \le AAL_{\max}/2 \\ 1-2\left(\dfrac{AAL}{AAL_{\max}}\right)^2 & \text{for} \quad AAL_{\max}/2 < AAL \le AAL_{\max} \end{cases} \tag{15.4}$$

where AAL_{max} is the AAL maximum value of normalization (10‰)

[1] 10‰ means a loss of USD 10 per thousand (USD 1.000) of the exposed value.

3.3 The Impact Aggravating Indicators

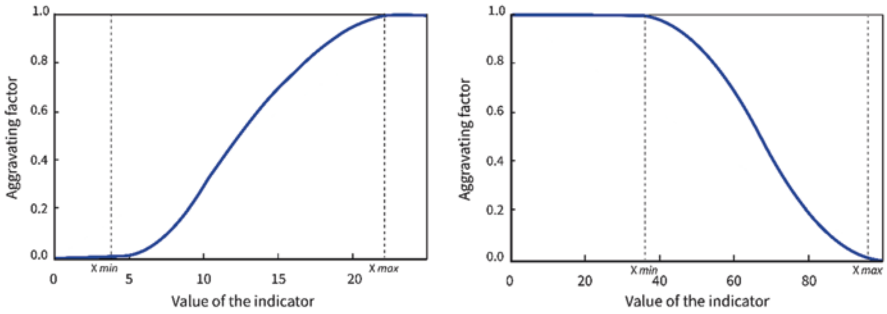
Underlying risk drivers that amplify physical risk are incorporated in an aggravating coefficient, F. This coefficient combines various aspects of society measured by indicators. These indicators are carefully selected based on expert judgment, seeking to meet the following basic characteristics: (i) robust indicators published by national sources or international agencies of broad recognition, (ii) available for all (or the majority of) the territorial unities under scrutiny, and (iii) provide direct information about or are directly related to the contextual conditions within the two categories: social fragility F_{SF} and lack of resilience F_{FR}. The aggravating coefficient F is calculated as follows:

$$F = \sum_{i=1}^{m} F_{FSi} \cdot w_{FSi} + \sum_{j=1}^{n} F_{FRj} \cdot w_{FRj} \tag{15.5}$$

where F_{FSi} and F_{FRj} are the aggravating factors; w_{FSi} and w_{FRj} are the associated weights of each i and j factor; here, it is assumed that the weight of each factor is the same; m and n are the total number of factors for social fragility and lack of resilience, respectively. In this case, eight descriptors were used to capture the social fragility conditions and the other eight to capture the lack of resilience. As expected, these indicators are generated using various techniques, with different units of measurement. Likewise, each indicator has a greater or lesser degree of association with risk, as derived from the context, depending on the value it takes in each territorial unit. In other words, the indicators are generally not commensurable as they are not expressed in equal units and are not associated with a quantitative risk scale. Therefore, a process of normalization and standardization is required to operate mathematically with the indicators and obtain consistent results. This process was made by using transformation functions.

The transformation functions can be understood as risk and aggravating probability distribution functions or as the membership functions of the linguistic benchmarking of high risk or high aggravation. The degree of association to the context-derived risk can be expressed in linguistic terms, as is it commonly done in expert-based assessment processes. In other words, an indicator of, for example, poverty has an increased association with the aggravation of physical risk (i.e., the higher the level of poverty, the greater the aggravation). It is also possible to consider a scale allowing the value of the indicator to be associated with a level of aggravation, for example, "low," "medium," or "high." However, the linguistic qualification implies a degree of association that may be related to the probability of an aggravating level for a certain range of the indicator's value. Thus, the normalization process of the indicators seeks to establish the probability that a value of an indicator is associated with a significant increase in risk.

Carreño (2006) defined a general form for the transformation of indicators by means of S functions (for increasing association indicators) or Z functions (for decreasing association indicators). Indicators are transformed independently using



In the increasing function S, a high value of the indicators results in a greater contribution to the aggravation

In the inverse and decreasing function Z, a high value of the indicator means a lesser influence on the aggravation

Fig. 15.4 Example of transformation functions S and Z

these types of functions, according to the range of values to be covered and the relevance of the indicator to reflect social fragility or lack of resilience, as appropriate. Figure 15.4 presents an example of functions S and Z.

The values on the abscissa correspond to the gross values of the indicators, while values on the ordinates correspond to the normalized value. A membership value of 0.0 means no membership (or no contribution to the aggravating coefficient), while 1.0 means full membership (or full contribution to the aggravating coefficient). X_{min} and X_{max} values are defined accordingly to the range of values covered in the territory. While the transformation process makes the indicators commensurable and establishes their association with the aggravation, it is possible that some of these indicators, or several, may have greater relative importance in explaining the contextual conditions that lead to disaster risk. For this reason, a collection of weights is established, which directly affects each indicator and measures their relative degree of importance within the context under assessment. However, due to the wide scope of this assessment, where a consensus process is not feasible, to avoid discussions about the relevance of each aspect and considering the robustness and sensitivity analysis performed by Marulanda et al. (2009), relative weights w_{FSi} and w_{FRj} that associate the importance of each of the factors on the index calculation are defined in this specific evaluation as equal, that is, it is assigned the same importance or contribution to each of the indicators intending to characterize the socio-economic dynamics of the community.

Finally, in this methodology it is assumed that the total risk, R_T, can have a maximum value of two times the physical risk. That is, according to a hypothetic case where contextual conditions are perfect and there is neither socio-economic fragility nor lack of resilience, the aggravating coefficient would be zero, and therefore the total risk may have the same value as the physical risk. On the other hand, if contextual conditions are as poor as to obtain the maximum value of the aggravating coefficient (1.0), R_T would reach twice the physical risk value. Although this assumption is arbitrary, if we consider F as the translation from the indicators to the probability of a higher impact F, interpreted as a probability cannot be higher than 1.0. However, whether the influence of the socio-economic characteristics on the magnitude of a disaster is twice, three, four, or n times is not defined here, the objective in the context of the holistic evaluation is to make manifest the impact of these characteristics and show that they can influence the assessment of the most direct effects of a destructive event (physical damage). Risk, addressed from a physical point of view, is the starting point to analyze the subsequent impacts of a disaster. Disasters resulting from natural and anthropogenic events are the damages in the built environment or on the physical means affecting people and their activities in different ways.

4 Outcomes for the Disaster Risk Atlas

The holistic approach for risk assessment was carried out at a subnational level in Colombia for its 32 departments and 1123 municipalities, integrating physical risk resulting from a multi-hazard assessment and a set of socio-economic indicators. This section presents the results obtained using the methodology in terms of R_F, F, and R_T. Detailed information about the results and the Risk Atlas of Colombia can be found in UNGRD et al. (2018).

According to the results shown in Fig. 15.5, the highest R_F values are generally found in municipalities located in areas highly prone to floods where, in many cases, the area affected by an event represents virtually the whole municipal territory. In these cases, exposure plays an important role, given the intensity of the events and the small size of the territories that, in relative terms, result affected. Another reason for these high values of potential losses can be given by the disorganized growth and the lack of proper building and land-use codes. Usually, the larger the event and the smaller or the weaker the economy, the more significant is the impact.

Vulnerability, understood as a set of conditions that create risk through a process of social construction, is linked to the deficit in the coverage of basic needs, unbalanced economic development, weak governance, limited endogenous capacities, exclusion, and limited opportunities for access to credit, among other factors, often exacerbated by pressures that concentrate the populations in areas exposed to hazards. In the search for indicators, an effort was made to include relevant aspects that reflect social fragility and lack of resilience, in terms of conditions that represent comparatively unfavorable situations for expressing the degree to which different social groups face risk in a differentiated manner, making communities more vulnerable to hazards and consequently to the degradation of their environment. Differences in vulnerability within social and physical contexts determine the selective nature of the severity of the effects of natural and anthropogenic hazards. The variables or indicators seek to cover a wide spectrum of issues that underlie the notion of risk in terms of prevalent vulnerability conditions of physical susceptibility and beyond. Following these conditions, 16 variables were selected for this evaluation, covering the 1123 municipalities of the country.

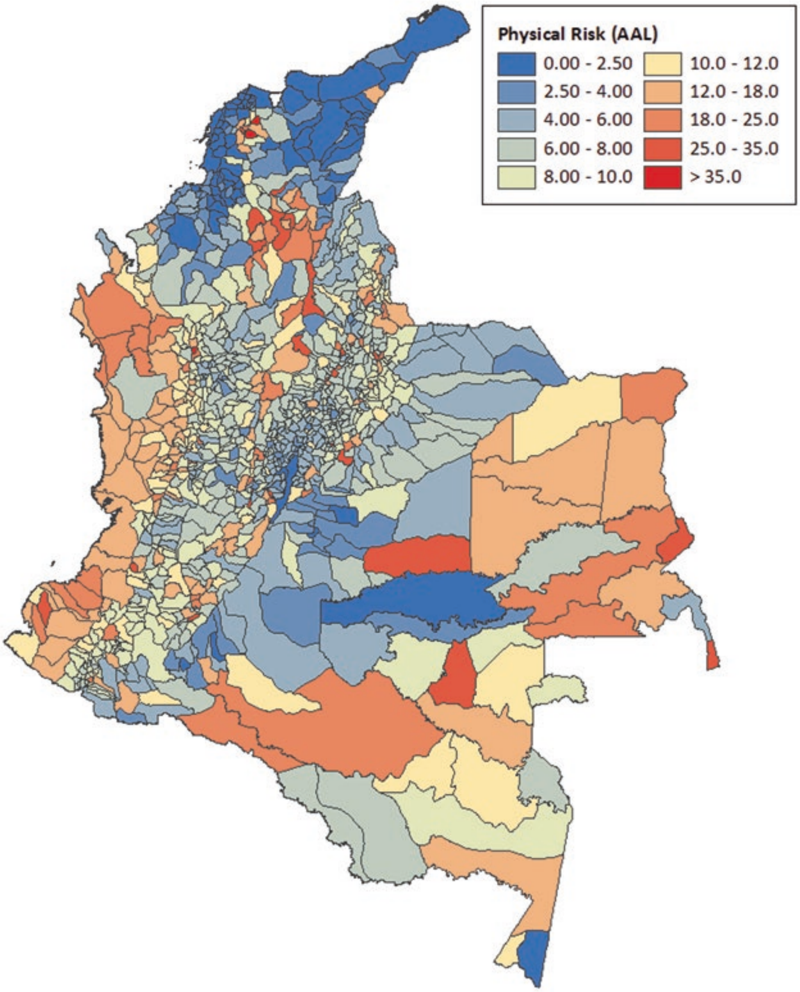


Fig. 15.5 Physical risk by municipality, AAL in relative values (‰)

Figure 15.6 shows a summary of the descriptors used in this analysis. Indicators denoted as F_{SFi} are related to social fragility, and the ones denoted as F_{LRi} are related to the lack of resilience.

These indicators seek to reflect, on the one hand, the predisposition to sustain damage due to social marginalization and segregation and to conditions of disadvantage and relative weaknesses related to socio-economic factors and on the other hand, the limitations to access and mobilize resources and the inability to face and recover from a negative impact. For example, indicators such as poverty and the unemployment rate reflect the (in)stability of the local economy, access to drinking water and other unsatisfied basic needs (UBN) reflect a situation of social marginalization, and the infant mortality rate reflects the state of health services and their

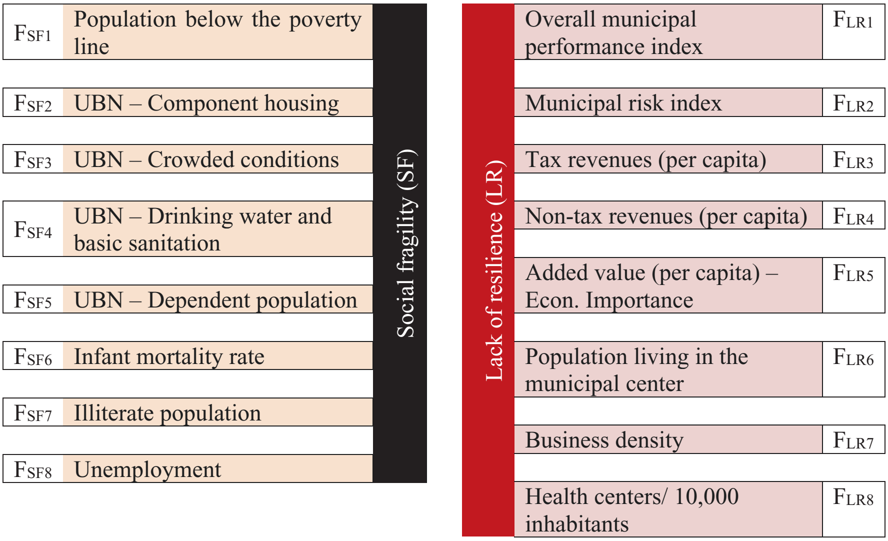


Fig. 15.6 Indicators used for the calculation of the aggravating factor *F*

ability to respond to a negative impact. On the other hand, indicators such as the quality of institutions, connectivity, and tax revenues reflect the state of governance and institutional qualities, which by being stronger, will be better able to absorb the impact, respond, and recover from a disaster. Overall, the indicators selected reflect a notion of a community's susceptibility to being negatively impacted by potentially destructive events, whatever their nature or severity. From the socio-economic perspective, the highest values belong to weaker economies, where organizational, institutional, environmental, and social conditions are also weaker, and it is reflected in this evaluation by the high values of the aggravating factor, as is shown in Fig. 15.7. Roncancio et al. (2020) presented similar outcomes regarding social vulnerability.

Figure 15.8 shows the results of total risk R_T that illustrate the important influence that the aggravating factors have on physical risk. These results depict how most of the municipalities with the higher R_T values are in areas that face serious poverty problems, overwhelmed by ill-managed governance and are often neglected by the government, such as the case of many municipalities located on the Pacific coast and in the eastern region of the country. These results reflect susceptibility in terms of physical, organizational, and poor institutional conditions that may lead to the generation or increased vulnerability.

Figure 15.9 presents the total risk assessment at the departmental scale, also calculated for analysis and benchmarking purposes at the national level.

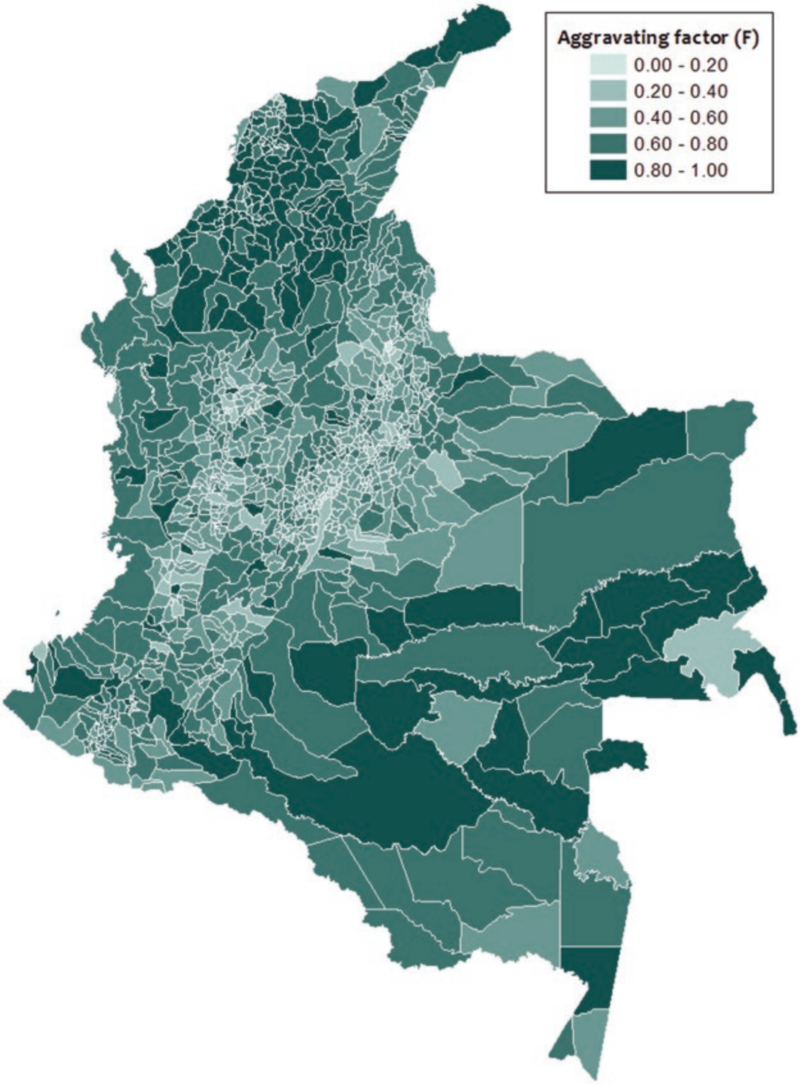


Fig. 15.7 Aggravating Factor by municipality, *F*

Table 15.1 presents the results of the holistic risk assessment by department. These results allow an overview for all of the country, useful for benchmarking purposes for national-level stakeholders.

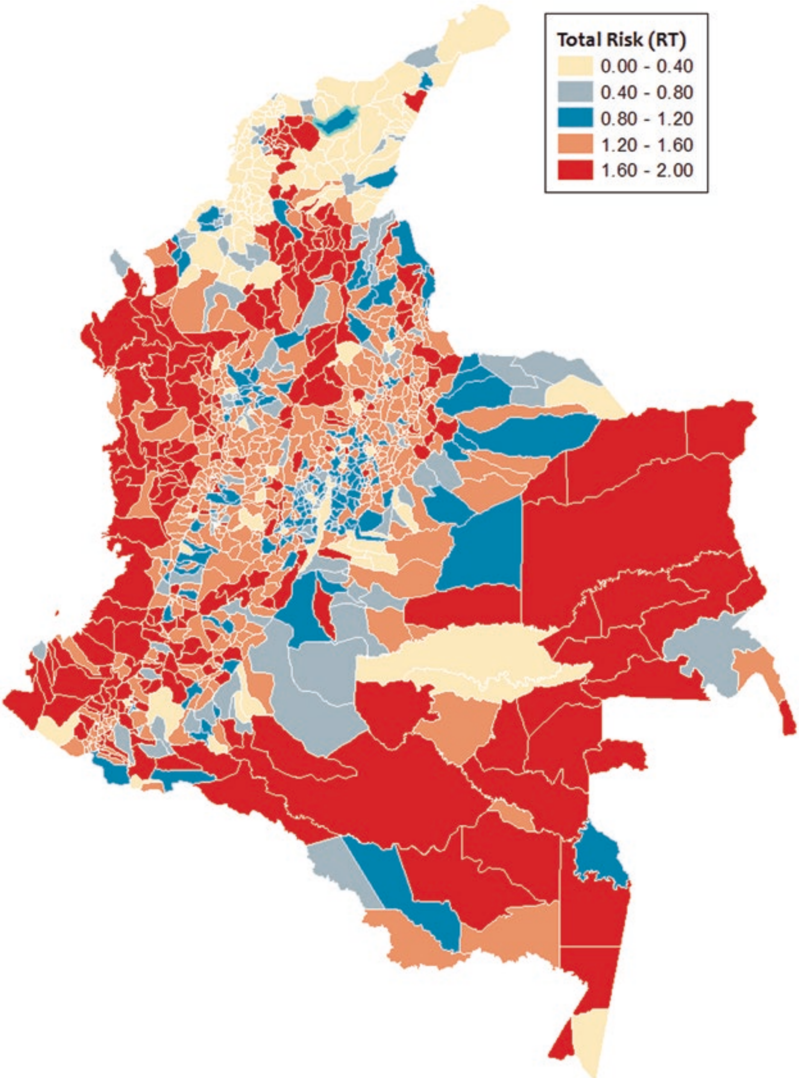


Fig. 15.8 Total risk by municipality R_T

Figure 15.10 presents the risk profile for the department of Cauca, generated under the framework of the Risk Atlas of Colombia.[2] The profile is a characterization depicting the results of a probabilistic risk assessment, including a map with the

[2] These profiles summarize the results obtained from a multi-hazard probabilistic risk assessment and a holistic risk assessment, aiming at facilitating the characterization of the departments, allowing a cross-departmental analysis for decision-making processes and the prioritization of actions for risk reduction. Department profiles can be found at UNGRD et al. (2018).

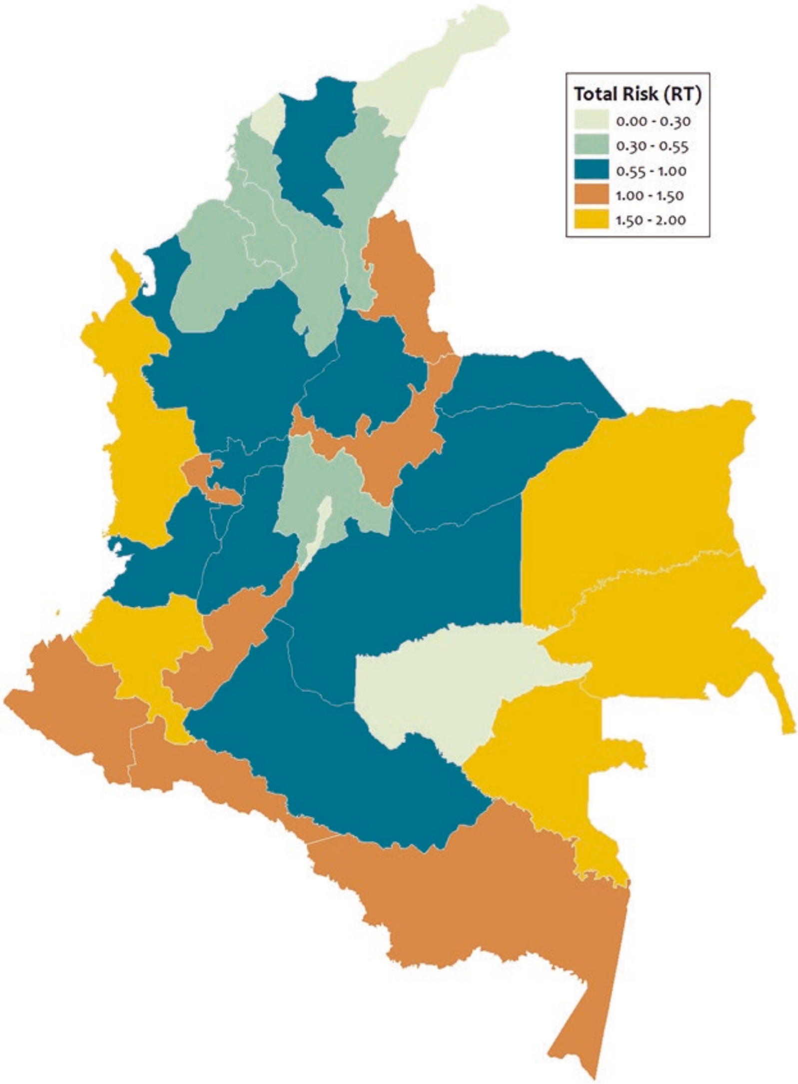


Fig. 15.9 Total risk by department, R_T

AAL relative values per municipality, graphics showing the loss exceedance probability for events of 100, 250, and 500 return periods, the contribution of each hazard to the AAL and the AAL ranking. For this department the hazard contributing the most to the AAL is earthquake, with 81.04%, followed by flood 18.19% and tsunami 0.77%. The profile also presents the PMLs (probable maximum loss) and the results of a holistic risk assessment at the departmental level, with the normalized values of the indicators used for its calculation. In Cauca, the aggravating coefficient is 0.66 that, together with its physical risk indicator value (0.96), make it one of the departments with the highest total risk level of Colombia.

Table 15.1 Results of risk assessment by department

Department	Exposed value [Col$ mill]	Multihazard AAL [Mill COP]	Multihazard AAL [‰]	Physical Risk RF	Aggravating factor F	Total Risk RT
Bogotá, D.C.	673,237,996	1,571,114	2.33	0.11	0.26	0.14
Antioquia	390,800,661	2,249,907	5.76	0.64	0.25	0.80
Valle del Cauca	206,158,652	1,245,904	6.04	0.69	0.26	0.86
Cundinamarca	142,770,958	598,105	4.19	0.35	0.23	0.43
Santander	117,600,856	655,420	5.57	0.61	0.26	0.77
Nariño	109,466,226	792,025	7.24	0.85	0.64	1.39
Cauca	80,980,218	697,753	8.62	0.96	0.66	1.59
Boyacá	65,354,569	492,024	7.53	0.88	0.36	1.19
Atlántico	94,915,760	134,340	1.42	0.04	0.38	0.06
Córdoba	89,499,737	276,138	3.09	0.19	0.62	0.31
Tolima	66,005,353	375,048	5.68	0.63	0.41	0.89
Caldas	60,518,762	392,269	6.48	0.75	0.32	0.99
Risaralda	46,033,970	294,574	6.40	0.74	0.38	1.02
Bolívar	86,893,370	280,886	3.23	0.21	0.63	0.34
Norte de Santander	44,181,140	293,876	6.65	0.78	0.49	1.16
Huila	47,239,842	362,534	7.67	0.89	0.48	1.32
Sucre	39,838,667	137,005	3.44	0.24	0.71	0.41
Chocó	29,644,140	322,495	10.88	1.00	0.70	1.70
Quindio	26,808,642	136,945	5.11	0.52	0.37	0.71
Magdalena	37,321,073	188,805	5.06	0.51	0.67	0.86
Cesar	33,650,937	110,053	3.27	0.21	0.61	0.34
La Guajira	27,460,452	61,480	2.24	0.10	0.73	0.17
Meta	20,857,744	94,596	4.54	0.41	0.34	0.55
Caquetá	28,047,658	142,341	5.07	0.51	0.68	0.86
Casanare	12,557,006	74,102	5.90	0.66	0.50	1.00
Arauca	7,749,719	36,712	4.74	0.45	0.61	0.72
Putumayo	10,110,582	74,160	7.33	0.86	0.60	1.37
Guaviare	6,271,236	15,043	2.40	0.12	0.72	0.20
Archip. San Andrés	2,497,720	9,643	3.86	0.49	0.49	0.44
Vichada	2,012,009	32,388	16.10	1.00	0.80	1.80
Vaupés	1,510,898	18,321	12.13	1.00	0.76	1.76
Guainia	664,937	13,187	19.83	1.00	0.90	1.90
Amazonas	2,055,236	12,476	6.07	0.69	0.74	1.20

As it can be seen, the evaluation performed in Colombia covered different levels of data, information, and analysis, seeking to best communicate risk to the different stakeholders involved in disaster risk management. Table 15.2 presents the results of a risk assessment at the municipal level for the 42 municipalities in the department of Cauca, which includes the multi-hazard AAL (in millions of Colombian Pesos, COP, and their relative values in ‰), physical risk, aggravating factors, and total risk. In Cauca, almost all municipalities (34) reached the R_T values higher than 1.5 and also the F values higher than 0.5, which reflects poor overall socio-economic conditions. Likewise, most municipalities obtained the maximum R_F value, indicating a high susceptibility of the built environment, resulting from poor planning, institutional weaknesses, and probable conditions social and economic disadvantage forcing populations to settle in areas expose to hazards. The results, disaggregated at the municipal level, allow drawing attention to those unfavorable situations, in turn, disaggregated in indicators, and depict the more urgent areas for intervention.

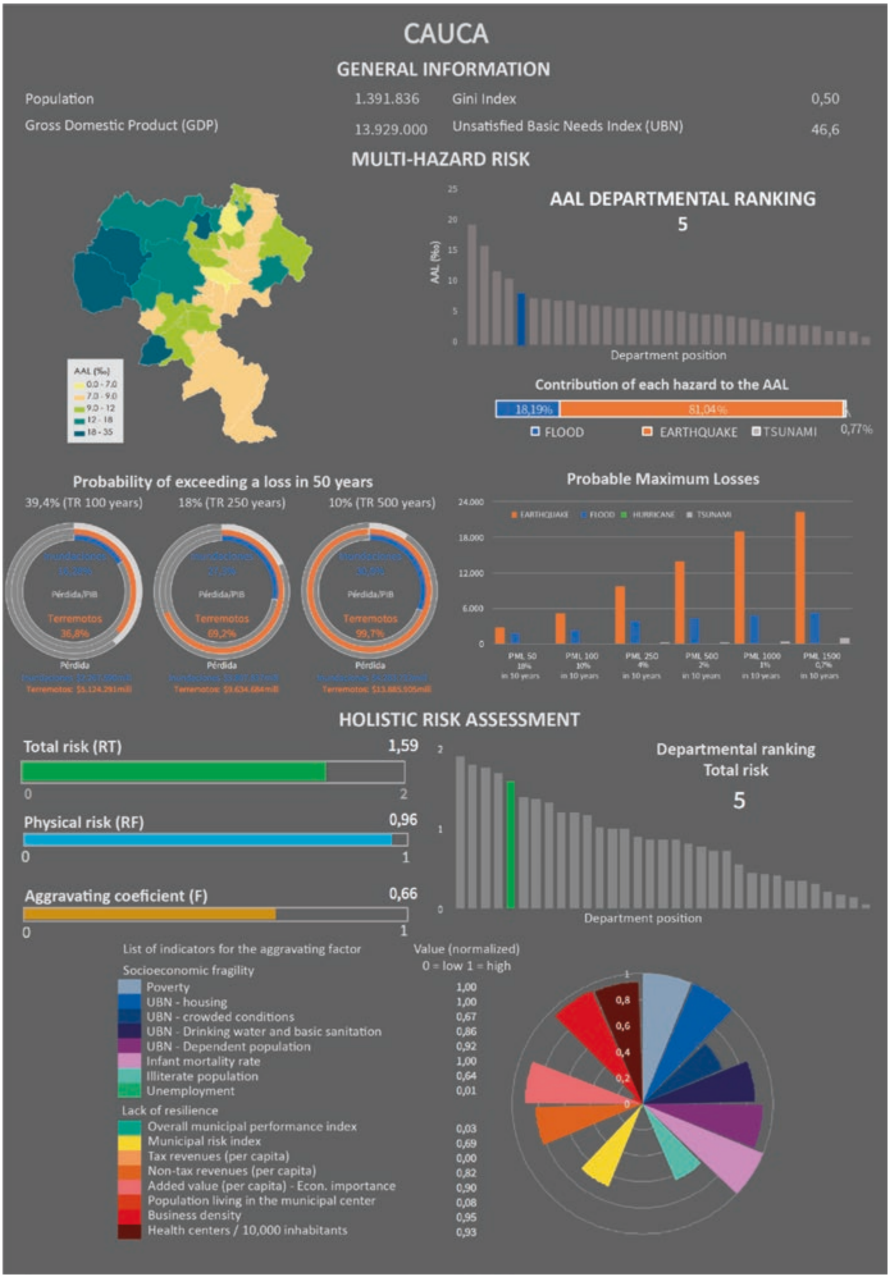


Fig. 15.10 Department risk profile depicting a holistic risk assessment, Cauca, Colombia

Table 15.2 Results of risk assessment for the municipalities of the department of Cauca, Colombia

Municipality	Multi-hazard AAL [Million COP]	Multi-hazard AAL [‰]	RF	F	RT
Argelia	$ 15,151	16.16	1.00	0.85	1.85
Sucre	$ 2,535	9.15	0.99	0.81	1.78
Suárez	$ 31,812	34.34	1.00	0.75	1.75
Mercaderes	$ 35,833	21.86	1.00	0.73	1.73
El Tambo	$ 23,749	15.88	1.00	0.73	1.73
Timbiquí	$ 15,232	18.43	1.00	0.72	1.72
López	$ 11,139	16.01	1.00	0.71	1.71
Guapi	$ 22,825	18.82	1.00	0.71	1.71
Balboa	$ 6,064	8.96	0.98	0.74	1.71
Almaguer	$ 7,904	8.62	0.96	0.77	1.70
Sotara	$ 6,148	8.99	0.98	0.72	1.68
Toribio	$ 7,128	8.65	0.96	0.73	1.67
La Sierra	$ 3,469	9.15	0.99	0.69	1.67
Paez	$ 12,305	10.26	1.00	0.66	1.66
Santa Rosa	$ 10,613	8.61	0.96	0.72	1.65
La Vega	$ 11,677	9.03	0.98	0.68	1.65
Caldono	$ 9,950	9.61	1.00	0.65	1.64
Bolívar	$ 19,258	10.60	1.00	0.64	1.64
Morales	$ 9,252	10.09	1.00	0.62	1.62
Jambaló	$ 5,294	8.80	0.97	0.66	1.61
Inzá	$ 14,227	12.18	1.00	0.61	1.61
Puracé	$ 6,519	8.35	0.95	0.70	1.61
Patía	$ 18,862	10.10	1.00	0.61	1.61
San Sebastián	$ 3,972	8.99	0.98	0.64	1.61
Miranda	$ 14,511	8.72	0.97	0.66	1.60
Totoró	$ 6,445	8.61	0.96	0.66	1.60
Buenos Aires	$ 14,436	16.59	1.00	0.59	1.59
Guachené	$ 4,251	10.23	1.00	0.59	1.59
Florencia	$ 1,805	9.24	0.99	0.60	1.59
Cajibío	$ 15,911	11.05	1.00	0.59	1.59
Rosas	$ 4,743	8.21	0.94	0.64	1.54
Piendamó	$ 12,193	8.70	0.97	0.57	1.52
Corinto	$ 8,130	8.66	0.96	0.56	1.50
Piamonte	$ 1,677	7.22	0.85	0.77	1.50
Villa Rica	$ 29,230	9.63	1.00	0.50	1.49
Padilla	$ 4,829	10.11	1.00	0.47	1.47
Puerto Tejada	$ 13,895	9.48	0.99	0.48	1.47
Caloto	$ 14,711	12.03	1.00	0.43	1.43
Timbío	$ 13,242	7.77	0.90	0.57	1.42
Silvia	$ 11,684	7.98	0.92	0.54	1.41
Santander de Quilichao	$ 40,030	6.91	0.81	0.43	1.16
Popayán	$ 175,109	5.23	0.54	0.33	0.73

5 Conclusions

This is the first time that a comprehensive holistic and total risk assessment methodology is conducted at the subnational level for a whole country. The holistic approach summarizes, in a single number R_T, the occurrence of hazard events, exposure and vulnerability, physical risk (calculated using probabilistic models that incorporate the uncertainty associated with the loss occurrence process), and the contextual conditions in which disasters might occur, as determined by aggravation coefficient F. These characteristics make R_T a unique useful index providing highly relevant information for risk management and decision-making processes. Total risk is a comparative index allowing the identification of the territorial units with the highest levels of risk, allowing identifying and prioritizing the performance of more detailed risk assessments, as well as actions and policies for effective risk management and sustainable development.

From the context-derived risk assessment, this approach allows the disaggregation of the results to determine the degree of the relative weight of the different indicators and the specific aspects they reflect, thus, identifying the areas requiring more attention when addressing risk management strategies. The analysis of these indicators and the aspects they reflect make it possible to focus efforts on nonphysical aspects of risk management. In the case of Cauca department, for instance, some of the indicators with the largest contribution to the aggravating coefficients are poverty, unsatisfied basic needs, infant mortality rate, and the lower added value per capita (economic importance).[3] This indicates, in general terms, that the economic situation of the department is unfavorable, a reality that coupled with weak institutions, condition a propensity to risk and the creation of new risk. While attacking economic inequalities is neither simple nor swift, it is possible, for example, to justify a housing improvement program, which directly faces the cause reflected in indicator F_{FS2} and indirectly F_{FS3} and F_{FS4}. Note that although it might seem obvious that housing improvement is required in many municipalities, it was not obvious that risk was exacerbated by the same aspects. Furthermore, indicators also allow for a comparison between different periods, which makes the holistic approach a useful tool for the evaluation and monitoring of risk management strategies and policies.

Although uncertainties related to physical risk assessment have been accounted for, further research is needed to incorporate the ones existing in the considered socio-economic characteristics (Burton & Silva, 2014). Those cannot be handled utilizing probability distributions. Nevertheless, it is important to highlight that sensitivity tests have been made to demonstrate the robustness of risk rankings and risk level ranges derived from the risk composite indicator Marulanda et al. (2009).

This kind of evaluation must be periodically updated to evaluate the changes in physical risk and development through time. The results obtained also allow measuring the progress toward reaching the goals established in the Sendai Framework for Disaster Risk Reduction 2015–2030 and the Sustainable Development Goals SDG, without waiting for disasters to occur. It is therefore possible to measure progress by identifying and reducing future negative effects and impacts of hazardous events in vulnerable human settings which may even allow avoiding the occurrence of disasters (Muir-Wood, 2016).

Finally, the development of Atlas of multi-hazard risk using a holistic, multisectoral, and interdisciplinary approach is a task to achieve in each country. This effort of risk science is a key step to provide the risk landscape that is emerging at different scales and sectors. Risk is really complex, systemic, and cascading, and it is necessary to take into account its distinct dimensions and interdependencies. This comprehensive perspective of risk is especially relevant for risk-informed decision-making and the way for integrated risk management and transformative adaptation, identifying and tackling the underlying causes and drivers of risk, and addressing the factors exacerbating disaster risk, with prominence given to the issues of justice and equity.

[3] Economic importance means the relative weight represented by the Gross Domestic Product of each of the departments within the country.

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