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Risk to Resilience

A Socio- Ecological Perspective on the Indian Sundarbans

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Resilient India - Disaster Free India

National Institute of Disaster Management
(Ministry of Home Affairs, Government of India)

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A Socio- Ecological Perspective on the Indian Sundarbans

Dedicated to
the Resilient Nature and Vibrant Communities of
the Indian Sundarbans

National Institute of Disaster Management
(Ministry of Home Affairs, Government of India)
Plot No.15, Pocket 3, Block-B, Sector-29, Rohini, Delhi-110042

Risk to Resilience: A Socio- Ecological Perspective on the Indian Sundarbans

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About this Book

"Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans" explores the risks, vulnerabilities, and resilience pathways of one of the world's most fragile ecosystems. The Sundarbans, a UNESCO World Heritage Site and the world's largest tidal mangrove forest, plays a vital role in disaster mitigation, biodiversity conservation, and livelihood support. However, it faces growing threats from cyclones, floods, sea-level rise, and human-induced pressures.

The primary aim of this book is to offer practical pathways for resilience-building by promoting ecosystem-based disaster risk reduction (Eco-DRR), sustainable livelihoods, and community-driven adaptation. It emphasizes the shift from reactive disaster response to proactive risk reduction.

This book is a collaborative effort of academicians, researchers, practitioners, and local communities. It features primary field research, participatory assessments, and GIS-based analysis, with insights from over 30 contributors across India. Key themes include multi-hazard risk assessment, mangrove conservation, human-wildlife conflict, and livelihood diversification.

Serving as a resource for policymakers, researchers, and development organizations, the book supports the goals of the Sendai Framework for Disaster Risk Reduction (SFDRR) and the Sustainable Development Goals (SDGs). It offers actionable insights and evidence-based strategies for disaster risk reduction, climate adaptation, and sustainable development in the Sundarbans and other vulnerable coastal regions worldwide.

Resilient India - Disaster Free India

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Foreword

The National Institute of Disaster Management (NIDM) remains steadfast in its mission to strengthen disaster risk reduction (DRR) efforts and foster resilient communities across India. This edited book titled "Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans", is collaborative initiative between NIDM and RIKA India.

The Indian Sundarbans, the world's largest contiguous mangrove forest and a UNESCO World Heritage Site, plays a critical role in maintaining ecological balance, regulating the climate, and mitigating disaster impacts. However, despite its immense biodiversity and socio-cultural importance, the region remains acutely vulnerable to multiple hazards — including cyclones, tidal surges, saline intrusion, sea-level rise, and anthropogenic pressures — which threaten both natural ecosystems and human settlements.

This publication offers a comprehensive, interdisciplinary perspective on the region's challenges and pathways to resilience. By integrating rigorous scientific research with ground-level realities, it presents actionable strategies grounded in ecosystem-based DRR, sustainable livelihoods, and community-based adaptation. These approaches are closely aligned with India's commitments under the Sendai Framework for Disaster Risk Reduction (SFDRR), the Sustainable Development Goals (SDGs), and the National Disaster Management Plan (NDMP).

A notable strength of this work is its emphasis on convergence — fostering collaboration among government agencies, academia, civil society, and local communities. Through case studies, participatory risk assessments, and map-based analyses contributed by a wide range of experts, the book highlights the necessity of multi-stakeholder engagement in addressing complex and interconnected risks.

The Indian Sundarbans illustrate both the vulnerabilities and the resilience potential of deltaic and coastal ecosystems. The lessons derived from this region extend far beyond its geographic boundaries, offering insights that can guide policy and practice in other climate-sensitive areas of India and across the globe.

I commend the editors, authors, contributors and partner institution - RIKA, India for their dedicated efforts in producing this publication. I am confident that "Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans" will serve as an invaluable resource for policymakers, planners, researchers, and practitioners committed to building a resilient and sustainable future.

(Madhup Vyas)

Preface

The Indian Sundarbans, located at the confluence of the Ganga, Brahmaputra, and Meghna rivers, is a deltaic landscape of extraordinary ecological and socio-economic importance. Spanning across India and Bangladesh, this UNESCO World Heritage Site is home to the world's largest contiguous mangrove forest and serves as a critical natural shield against cyclones, tidal surges, and other disasters. Renowned for its biodiversity, the Indian Sundarbans houses iconic species such as the Royal Bengal Tiger (Panthera tigris) and numerous endemic flora and fauna. Despite its natural richness, the region remains one of the most vulnerable areas globally, grappling with the compounded threats of climate change, human interventions, and natural disasters.

This book, "Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans," presents a holistic exploration of the vulnerabilities and resilience pathways of the Indian Sundarbans. The conceptual framework of the book emphasizes the interconnected socio-ecological dimensions of risk and resilience, highlighting how natural and human-induced factors expose the region to multiple hazards, and how local communities, governance systems, and conservation strategies contribute to resilience-building. By bringing together research, practice, and policy insights, this book aims to offer a comprehensive understanding of the Indian Sundarbans' socio-ecological systems and their capacity to adapt to a rapidly changing risk landscape.

The chapters in this book are based on primary field-based research, participatory assessments, and case studies that capture the lived experiences and local knowledge of the communities residing in the Indian Sundarbans. The research showcases contributions from scholars, NGOs, and practitioners working on diverse themes, including disaster risk reduction, human-wildlife conflict, climate change adaptation, migration, social capital, and cultural heritage preservation. Each chapter provides evidence-based insights on the socio-ecological interplay between ecosystems, human well-being, and sustainable development in the Indian Sundarbans. The participatory research approach adopted in this book ensures that community voices and lived experiences are central to the analysis.

The book has been developed as a joint publication with the RIKA India, reflecting a shared commitment to promoting multi-stakeholder engagement in knowledge generation and dissemination. To strengthen the content and ensure diversity of perspectives, two online stakeholder consultations were conducted with researchers, policymakers, and practitioners from across India. These consultations facilitated the sharing of field experiences and best practices, resulting in over 30 research papers being submitted for consideration. Following a rigorous review process, 8 research-based chapters were selected, focusing on key themes such as multi-hazard vulnerability, human-tiger conflict, mangrove degradation, migration, and socio-economic adaptation.

The book is structured into nine chapters, each delving into a specific aspect of socio-ecological resilience in the Indian Sundarbans.

- **Chapter 1: Introduction.** This chapter introduces the socio-ecological context of the Indian Sundarbans, highlighting its ecological, social, and cultural importance. It explains the region's unique risk landscape and the need for a socio-ecological approach to resilience, setting the stage for the thematic chapters that follow.
- **Chapter 2: Coastal Multi-Hazard Vulnerability Assessment of Indian Sundarbans using AHP**. This chapter presents a spatial risk analysis using the Analytical Hierarchy Process (AHP). It identifies the most vulnerable regions within the Indian Sundarbans to cyclones, floods, and erosion, providing policymakers with prioritization tools for targeted risk reduction.
- **Chapter 3: Assessing the Characteristics and Circumstances of a Community under Threat from Multi-Hazards.** This chapter analyses the socio-economic vulnerabilities of communities exposed to multiple hazards. It explores the role of livelihood security, education, and access to basic services in shaping community resilience.
- **Chapter 4: Geo-Spatial Analysis of Human-Tiger Conflict in the Indian Sundarbans.** By leveraging geo-spatial mapping, this chapter identifies the conflict-prone zones where humans and tigers interact. It offers strategies to reduce tiger encounters through community awareness, policy interventions, and buffer zone management.
- **Chapter 5: Mangrove Degradation: Escalating Disasters and Climate Risks in the Indian Sundarbans.** This chapter discusses the alarming trend of mangrove loss and its implications for disaster risk. It explores how mangrove restoration can enhance disaster preparedness and climate resilience.
- **Chapter 6: Disaster-Induced Migration in the Indian Sundarbans Islands.** Migration is explored as a coping strategy and consequence of disasters. This chapter highlights how migration influences local economies, human capital, and community resilience.
- **Chapter 7: Social Capital and Disaster Risk Reduction – A Case Study of Gosaba Block.** This chapter focuses on social capital as a resource for disaster preparedness, showing how community networks enable quick responses and effective disaster recovery.
- **Chapter 8: Cultural Heritage and Community Engagement in Indian Sundarbans Tourism.** This chapter explores the balance between tourism and conservation, showcasing how sustainable tourism can support livelihoods and promote the conservation of Indian Sundarbans' rich cultural heritage.
- **Chapter 9: Making Sundarbans Resilient: Way Forward.** The concluding chapter synthesizes the findings of previous chapters, offering policy recommendations and strategies to build resilience through community-driven, ecosystem-based approaches.

The opening chapter establishes the context by exploring the ecological, socio-economic, and cultural importance of the Indian Sundarbans, serving as a foundation for the discussions that follow. Subsequent chapters employ diverse methodologies, including GIS-based mapping, spatial analysis, and AHP-based risk assessments, to generate actionable insights for policymakers, development practitioners, and community organizations. The final chapter synthesizes the key findings and emphasizes the need for integrated, multi-dimensional strategies for disaster risk reduction, community resilience, and sustainable development.

The key message of this book is the recognition that risk and resilience are inherently socio-ecological in nature. It demonstrates how social, ecological, and economic factors are deeply intertwined in shaping vulnerability and resilience. Through case studies, participatory research, and field-based evidence, the contributors present a powerful argument for integrating community-driven, ecosystem-based approaches to reduce risk and foster resilience. By placing emphasis on local knowledge, governance systems, and adaptive strategies, the book offers a pathway for transitioning from risk to resilience in fragile ecosystems like the Indian Sundarbans.

This book aims to serve as a resource for policymakers, researchers, development practitioners, and local communities engaged in disaster risk reduction, climate change adaptation, and sustainable development. By showcasing community-based practices, field insights, and participatory methodologies, it offers practical recommendations for developing policies and interventions that support inclusive and sustainable development in vulnerable coastal ecosystems. The lessons drawn from the Indian Sundarbans have broader relevance for other deltaic and coastal regions worldwide, making this book a valuable contribution to global discourses on resilience, disaster risk reduction, and sustainable development.

As you explore the chapters of this book, we hope it inspires a deeper appreciation for the socio-ecological interdependence of risk and resilience. It is our hope that the insights shared here will catalyze further research, strengthen policy dialogues, and foster collaboration for safeguarding the future of the Indian Sundarbans and other vulnerable ecosystems. This book is a step toward transforming risk into resilience, not only for the Indian Sundarbans but for coastal and deltaic regions facing similar challenges across the globe.

Happy Reading!

Editors

Ranit Chatterjee, Garima Aggarwal, Amir Ali Khan and Rajib Shaw

Acknowledgement

This book, "Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans," is the culmination of extensive collaboration, dedication, and support from individuals and institutions who have significantly contributed to its success.

We express our deepest gratitude to **Shri Madhup Vyas, IAS, Executive Director, NIDM,** for his visionary leadership and constant encouragement throughout the development of this book. His unwavering commitment to disaster risk reduction and resilience-building has been an inspiration.

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Finally, our heartfelt thanks to the **authors and contributors** whose rigorous research and valuable insights have formed the backbone of this book. Their commitment to advancing knowledge on the Indian Sundarbans' vulnerabilities and resilience strategies has been instrumental in creating this interdisciplinary compendium, which made editors job easy.

This book is a testament to the collective effort of a diverse group of policy makers, scholars, and practitioners, united by the shared goal of fostering a resilient future for the Indian Sundarbans and its communities.

Editors

Ranit Chatterjee, Garima Aggarwal, Amir Ali Khan and Rajib Shaw

About Editors

Dr. Ranit Chatterjee

Dr. Ranit Chatterjee is the co-founder of Resilience Innovation Knowledge Academy (RIKA) and RIKA Institute, a not-for-profit arm of RIKA. He is a Visiting Associate Professor at Keio University, Japan and holds a Ph.D. in Environmental Management from Kyoto University, Japan. Trained as an architect, he also completed a Master's in Disaster Management from Tata Institute of Social Sciences (TISS), Mumbai.

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With 74+ books and over 450+ research papers on disaster management, climate change, and environment, he serves as Editor-in-Chief of Progress in Disaster Science. He has received prestigious honors, including the "Pravasi Bharatiya Samman Award (PBSA)" (2021) from the President of India and the UN Sasakawa Award (2022) for his lifetime contributions to disaster risk reduction (DRR).

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List of Abbreviations

ABSI	Access to Basic Services Index
AHP	Analytical Hierarchy Process
ASHA	Accredited Social Health Activist
BDO	Block Development Office
BITS	Birla Institute of Technology and Science
BMTPC	Building Materials and Technology Promotion Council
CBDRR	Community-Based Disaster Risk Reduction
CI	Consistency Index
CR	Consistency Ratio
CVI	Coastal Vulnerability Index
DRR	Disaster Risk Reduction
FGD	Focus Group Discussion
GIF	Global Indicator Framework
GIS	Geographic Information System
GOI	Government of India
GoWB	Government of West Bengal
GP	Gram Panchayat
HFA	Hyogo Framework for Action
HIS	Health Service Index
IDNDR	International Decade for Natural Disaster Reduction
IDW	Inverse Distance Weighting
IMD	Indian Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Strategy for Disaster Reduction
MDGs	Millennium Development Goals

MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act
NDMA	National Disaster Management Authority
NIDM	National Institute of Disaster Management
NGO	Non-Governmental Organizations
OSR	Other Sources of Revenue
PI	Parameter Index
RI	Random Index
RIKA	Resilience Innovation Knowledge Academy
SBR	Indian Sundarbans Biosphere Reserve
SDGs	Sustainable Development Goals
SFDRR	Sendai Framework for Disaster Risk Reduction
SI	Shelter Index
SPI	Sub-parameter Index
SRTM DEM	Shuttle Radar Topography Mission Digital Elevation Model
STR	Indian Sundarbans Tiger Reserve
SVI	Socio-Economic Vulnerability Index
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNISDR	United Nations Office for Disaster Risk Reduction
USGS	United States Geological Survey
VAI	Vulnerability Atlas of India
WWF	World Wide Fund for Nature

1 Introduction

1.1 Introduction

The Indian Sundarbans is a unique and ecologically significant deltaic region situated at the confluence of the Ganga, Brahmaputra, and Meghna rivers, spanning parts of India and Bangladesh. This region is home to the world's largest contiguous mangrove forest and is recognized as a UNESCO World Heritage Site due to its rich biodiversity and critical role in supporting millions of livelihoods (Mukhopadhyay et al., 2018; World Bank, 2010). The Indian Sundarbans provides essential ecosystem services, such as acting as a natural barrier against cyclones, tidal surges, and floods, while also supporting a range of livelihoods, including fishing, honey collection, and agriculture (Danda et al., 2011; Bandyopadhyay et al., 2021). The region serves as a vital habitat for endangered and iconic species like the Royal Bengal Tiger (Panthera tigris), estuarine crocodiles, and several species of migratory birds (Sarkar & Bhattacharya, 2017; Rahman et al., 2019). However, despite its ecological richness, the Indian Sundarbans faces severe threats from natural hazards, climate change, and human-induced pressures, making it one of the most vulnerable regions in the world (Chowdhury & Maiti, 2021; Rahman et al., 2020). Rising sea levels, coastal erosion, loss of mangroves, and the increasing frequency of cyclonic storms pose serious risks to both the ecosystem and local communities (Mukhopadhyay et al., 2018; Dasgupta et al., 2014).

The Indian Sundarbans serves as a natural shield against cyclones, tidal surges, and floods, offering critical ecosystem services and supporting the livelihoods of millions of people (Danda et al., 2011; Mukhopadhyay et al., 2018). However, despite its critical ecological and social value, the Indian Sundarbans faces growing multi-hazard risks driven by climate change, rising sea levels, cyclones, mangrove degradation, and human-wildlife conflicts (Chowdhury & Maiti, 2021; Hazra et al., 2002). The combined pressures of environmental and socio-economic challenges have increased the region's exposure to natural disasters, forcing communities to adopt adaptive strategies for survival. The concept of "risk to resilience" emphasizes the urgent need to shift from a reactive disaster response approach to a more proactive, community-driven, and ecosystem-based strategy that strengthens resilience (Shamsuddoha & Chowdhury, 2007; World Bank, 2010).

The socio-ecological profile of the Indian Sundarbans reflects the deep interdependence between local communities and natural ecosystems. This interdependence shapes the region's risk profile, as any disturbance in the ecosystem—such as the loss of mangrove cover—directly impacts livelihoods, health, and community well-being (Chowdhury & Maiti, 2021; Raha et al., 2013). The socio-ecological perspective adopted in this book emphasizes the need for integrated development strategies that address the vulnerabilities of both natural and human systems (Danda et al., 2011; Rahman et al., 2020). The risk profile of the Indian Sundarbans highlights the region's exposure to multiple hazards, including cyclones, tidal surges, rising sea levels, salinization, and human-wildlife conflict (Mukhopadhyay et al., 2018; Hazra et al., 2002). Compounding these risks are poverty, livelihood insecurity, and forced migration, which exacerbate the vulnerabilities of local communities (Roy & Datta, 2022; Shamsuddoha

& Chowdhury, 2007). The cascading nature of risks is evident, as one hazard (like a cyclone) can trigger other risks, such as loss of shelter, displacement, and loss of income (Srivastava & Dutta, 2019). Understanding this interconnected risk profile is essential for designing effective resilience-building strategies (World Bank, 2010; Rahman et al., 2020).

The interplay of natural and human systems in the Indian Sundarbans forms a socio-ecological system where local livelihoods, ecosystems, and disaster risks are closely linked (Chowdhury & Maiti, 2021; Danda et al., 2011). This interdependence shapes the risk landscape of the Indian Sundarbans, as disruptions to mangrove ecosystems directly affect the well-being of human communities (Hazra et al., 2002; Bandyopadhyay et al., 2021). The region faces multi-hazard risks, including cyclones, sea-level rise, coastal erosion, saltwater intrusion, and mangrove degradation (Mukhopadhyay et al., 2018; Rahman et al., 2019). These hazards have cascading impacts on livelihoods, food security, migration, and human-wildlife conflicts, making the vulnerability of the region highly complex and multi-dimensional (Sarkar & Bhattacharya, 2017; Chowdhury & Maiti, 2021). The increasing frequency of extreme weather events, such as Cyclone Aila (2009), Bulbul (2019), Amphan (2020), and Yaas (2021), underscores the growing exposure of the Indian Sundarbans to climate-induced disasters (Rahman et al., 2020; Srivastava & Dutta, 2019).

This book, "Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans," adopts a socio-ecological lens to analyze the risks, vulnerabilities, and resilience pathways of the Indian Sundarbans. It explores the interconnected nature of human and ecological systems and emphasizes the importance of community-driven approaches and ecosystem-based disaster risk reduction (Eco-DRR) (Danda et al., 2011; Roy & Datta, 2022). By addressing issues like disaster-induced migration, human-wildlife conflict, mangrove degradation, and climate change adaptation, this book proposes solutions that strengthen the capacity of both ecosystems and communities to recover from and adapt to adversities (Rahman et al., 2019; Raha et al., 2013). The insights in this book are drawn from primary field-based research, participatory assessments, and GIS-based analysis (Mukhopadhyay et al., 2018; World Bank, 2010). It integrates perspectives from diverse stakeholders, including researchers, policymakers, community representatives, and practitioners, to present a holistic view of the challenges and solutions associated with building resilience in the Indian Sundarbans (Chowdhury & Maiti, 2021; Srivastava & Dutta, 2019).

The research approach of this book is rooted in a multi-disciplinary, participatory framework, drawing on primary field data, participatory methods, and GIS-based analysis (Hazra et al., 2002; Danda et al., 2011). Extensive field research, community consultations, and participatory mapping exercises were carried out to gather evidence on local knowledge, risks, and adaptive capacities (Chowdhury & Maiti, 2021; World Bank, 2010). This collaborative effort was supported by contributions from scholars, academicians, and practitioners from across India (Roy & Datta, 2022). Over 30 research papers were submitted, of which 8 were rigorously reviewed and selected for inclusion in the book (Mukhopadhyay et al., 2018). Contributions from diverse authors provide regional and multi-disciplinary perspectives, enhancing the credibility, depth, and applicability of the findings (Rahman et al., 2020; World Bank, 2010).

The contribution of this book towards resilience-building is significant, as it provides a comprehensive framework for disaster risk reduction, ecosystem-based adaptation, and sustainable development (Shamsuddoha & Chowdhury, 2007; World Bank, 2010). By focusing on risk to resilience as a transformative process, the book offers innovative, evidence-based solutions for policymakers, researchers, and development agencies (Danda et al., 2011; Rahman et al., 2020). It emphasizes the importance of community empowerment, capacity building, and participatory governance as the pillars of resilience (Sarkar & Bhattacharya, 2017).

1.2 Defining Indian Sundarbans

In this book, the Indian Sundarbans is defined as the portion of the Indian Sundarbans delta that falls within the territorial boundaries of India. While the Indian Sundarbans spans both in India and Bangladesh, the focus of this book is solely on the Indian region. The Indian Sundarbans is situated in the southern part of West Bengal, covering an area of approximately 9,630 sq km of mangrove forests and an additional 5,400 sq km of inhabited and agricultural land. It encompasses parts of the South 24 Parganas and North 24 Parganas districts and is managed under the framework of the Sundarban Biosphere Reserve. This region is globally recognized as a UNESCO World Heritage Site due to its rich biodiversity and ecological significance. It is characterized by a unique tidal halophytic mangrove ecosystem, which supports diverse flora and fauna, including the iconic Royal Bengal Tiger (Panthera tigris), estuarine crocodiles, and various bird, fish, and amphibian species. The Indian Sundarbans is distinct from the Bangladesh Indian Sundarbans, both in terms of its administrative framework and its approach to conservation and livelihood management.

1.3 The Importance of the Indian Sundarbans

1.3.1 Geographical Location and Significance

The Indian Sundarbans, spanning the border of India and Bangladesh, is the world's largest tidal halophytic mangrove forest, covering approximately 10,000 square kilometers (Mukhopadhyay et al., 2018). This UNESCO World Heritage Site is shaped by the confluence of the Ganga, Brahmaputra, and Meghna rivers, forming a vast and dynamic deltaic landscape. It serves as a critical natural buffer against coastal disasters and provides essential ecosystem services that support millions of inhabitants (World Bank, 2010; Hazra et al., 2002). The Indian Sundarbans is a biodiversity hotspot that plays a vital role in coastal protection, carbon sequestration, and sustainable livelihoods (Dasgupta et al., 2014). Its dynamic hydrological system is driven by tidal fluctuations, which shape the habitat and support diverse aquatic, terrestrial, and estuarine ecosystems (Mukhopadhyay et al., 2018).

1.3.2 Ecological Importance and Unique Biodiversity

The Indian Sundarbans is renowned for its ecological importance and rich biodiversity, making it one of the world's most important natural habitats. It is home to a wide array of fauna and flora, including the iconic Royal Bengal Tiger (Panthera tigris), estuarine crocodiles (Crocodylus porosus), Irrawaddy dolphins (Orcaella brevirostris), and numerous bird and fish species (Sarkar & Bhattacharya, 2017; Rahman et al., 2019). The mangrove forests serve as a breeding ground for fish, crabs, and shrimp, supporting the socio-economic livelihood of local communities (Chowdhury & Maiti, 2021).

Apart from its biodiversity, the Indian Sundarbans plays a significant role in carbon sequestration and shoreline stabilization, mitigating the effects of climate change and coastal erosion (Hazra et al., 2002; Raha et al., 2013). The mangrove root systems reduce tidal wave energy, serving as a natural barrier against cyclones, tidal surges, and flooding (Danda et al., 2011). This ecological defence system has proven to be a lifeline for local communities, especially during extreme weather events such as Cyclone Amphan (2020) and Cyclone Yaas (2021), which caused widespread devastation in the region (Rahman et al., 2020; Mukhopadhyay et al., 2018).

1.3.3 Socio-Economic Relevance to Local Communities

The Indian Sundarbans supports the livelihoods of over 4.5 million people in India alone, providing access to natural resources like fish, honey, crabs, and timber (Chowdhury & Maiti, 2021; Danda et al., 2011). These livelihood activities are directly linked to the health of the mangrove ecosystem, making its conservation essential for human resilience (Roy & Datta, 2022). Local communities rely on

sustainable harvesting practices and traditional knowledge for honey collection, fishing, and subsistence agriculture (Raha et al., 2013). Women play a significant role in crab harvesting, fish processing, and household management, reflecting the gendered dimensions of livelihood dependence in the Indian Sundarbans (Chowdhury & Maiti, 2021). However, recurring cyclones, rising sea levels, and salinity intrusion have threatened agriculture, forcing people to shift from farming to non-farm-based livelihoods (Dasgupta et al., 2014). The loss of livelihood opportunities has further driven forced migration and displacement, making livelihood diversification and sustainable tourism key strategies for supporting local communities (Roy & Datta, 2022; Shamsuddoha & Chowdhury, 2007).

1.3.4 Culture, Heritage, and Socio-Ecological Identity of the Indian Sundarbans

The culture and heritage of the Indian Sundarbans are deeply embedded in its socio-ecological landscape. The communities living in this region, often called "people of the tide", have developed a way of life that is deeply connected to the rhythms of the natural environment (Danda et al., 2011). The worship of Bonbibi, a forest deity revered by both Hindus and Muslims, is central to the cultural identity of the Indian Sundarbans (Rahman et al., 2019; Sarkar & Bhattacharya, 2017). Bonbibi Jatra, a traditional folk theatre performance, depicts the story of human-tiger encounters and reinforces the community's belief in coexistence with wildlife. These practices foster an understanding of the human-wildlife relationship, shaping local conservation ethics and inspiring efforts to protect biodiversity (Sarkar & Bhattacharya, 2017).

The natural heritage of the Indian Sundarbans is a major driver of eco-tourism, attracting tourists for wildlife safaris, birdwatching, and mangrove tours (Chowdhury & Maiti, 2021). Its designation as a UNESCO World Heritage Site and Ramsar Wetland of International Importance highlights its global recognition as a region of outstanding ecological, cultural, and heritage value (World Bank, 2010). Promoting sustainable tourism in the Indian Sundarbans can create alternative livelihood opportunities for local communities, reduce their dependence on forest-based resources, and foster resilience (Roy & Datta, 2022).

1.3.5 Rising Threat of Multi-Hazards

The multi-hazard risk profile of the Indian Sundarbans includes threats from cyclones, floods, tidal surges, and salinity intrusion (Hazra et al., 2002; Mukhopadhyay et al., 2018). Over the past two decades, the region has experienced major cyclones, such as Aila (2009), Bulbul (2019), Amphan (2020), and Yaas (2021), causing widespread devastation, livelihood loss, and displacement (Rahman et al., 2020; Roy & Datta, 2022). Rising sea levels, driven by climate change, have intensified coastal erosion and salinity intrusion, further threatening agriculture and livelihoods (Dasgupta et al., 2014; World Bank, 2010). The destruction of mangroves due to illegal logging and aquaculture expansion has left communities more exposed to disasters (Raha et al., 2013; Chowdhury & Maiti, 2021).

Human-wildlife conflict, especially with the Royal Bengal Tiger, poses additional challenges. Honey collectors and fishers who venture into tiger habitats often face life-threatening encounters, further complicating the balance between conservation and livelihoods (Sarkar & Bhattacharya, 2017; Rahman et al., 2019). These multi-hazard risks have a cascading impact on local communities, driving displacement, migration, and the need for alternative livelihoods (Roy & Datta, 2022; Srivastava & Dutta, 2019).

1.3.6 Global Recognition and Protection

The Indian Sundarbans holds a position of global importance as a UNESCO World Heritage Site and a Ramsar Wetland of International Importance (World Bank, 2010). These designations underscore the region's ecological, cultural, and heritage value, placing it under international scrutiny for its

conservation, management, and sustainable use. These recognitions promote global funding, research collaborations, and conservation programs to protect the biodiversity and livelihoods of the Indian Sundarbans (Danda et al., 2011).

1.3.7 Historical Context of the Indian Sundarbans

The history of the Indian Sundarbans is marked by the evolution of its deltaic system, colonial interventions, and the impacts of natural disasters. The formation of the delta is rooted in millennia of sediment deposition from the Ganga-Brahmaputra-Meghna River system, creating an ideal habitat for mangrove ecosystems (Mukhopadhyay et al., 2018). During the colonial era, large tracts of mangrove forests were cleared for agriculture and aquaculture, altering the natural landscape (Hazra et al., 2002). In the post-colonial era, conservation efforts were initiated, but challenges such as illegal logging and mangrove degradation persisted (Raha et al., 2013). Disasters like Cyclone Aila (2009), Amphan (2020), and Bulbul (2019) reshaped the socio-ecological fabric of the Indian Sundarbans, highlighting the need for integrated disaster risk reduction (Rahman et al., 2020).

1.4 Defining Risk and Resilience in the Indian Sundarbans Context

The Indian Sundarbans faces a multi-hazard risk environment, where natural hazards such as cyclones, floods, and storm surges are compounded by human-induced pressures like mangrove deforestation, land-use changes, and unplanned urbanization (Hazra et al., 2002; Chowdhury & Maiti, 2021; Raha et al., 2013). These factors collectively increase the vulnerability of local communities while reducing the ecosystem's ability to function as a natural barrier (Mukhopadhyay et al., 2018; Danda et al., 2011). The loss of mangroves, for instance, exposes the coastline to tidal surges, erosion, and storm impacts, thereby intensifying the risks for human settlements and biodiversity hotspots (Raha et al., 2013; Bandyopadhyay et al., 2021).

In this context, risk is defined as the probability of adverse impacts on both the human population and natural ecosystems. Risk arises from the exposure of people and assets to hazards, combined with their vulnerability due to socio-economic conditions, lack of preparedness, and declining ecosystem services (Shamsuddoha & Chowdhury, 2007; World Bank, 2010). In the case of the Indian Sundarbans, cyclones like Aila (2009), Amphan (2020), and Yaas (2021) exposed the vulnerabilities of local communities, leading to displacement, loss of livelihoods, and destruction of critical infrastructure (Rahman et al., 2020; Roy & Datta, 2022). The low-lying topography and the shrinking landmass due to coastal erosion make the region particularly susceptible to storm surges and rising sea levels (Chowdhury & Maiti, 2021; Dasgupta et al., 2014). Furthermore, the cumulative effects of climate change, such as rising sea levels, salinity intrusion, and coastal erosion, compound the region's multi-hazard risk profile (World Bank, 2010; Hazra et al., 2002).

On the other hand, resilience is the capacity of the socio-ecological system of the Indian Sundarbans to absorb, adapt, and recover from shocks while maintaining its essential functions (Danda et al., 2011; Chowdhury & Maiti, 2021). Resilience in this context extends beyond disaster response to emphasize the capacity to anticipate, withstand, and transform in response to long-term pressures such as climate change, rising sea levels, and livelihood shifts (Shamsuddoha & Chowdhury, 2007; Mukhopadhyay et al., 2018). A resilient system is one that maintains its core functions, such as food production, habitat support, and disaster mitigation, despite repeated shocks (Hazra et al., 2002; World Bank, 2010).

Building resilience in the Indian Sundarbans requires strengthening the ability of both ecosystems and communities to withstand hazards and recover more effectively. The socio-ecological perspective of resilience acknowledges that human well-being and ecosystem health are deeply interconnected (Danda et al., 2011; Roy & Datta, 2022). For instance, communities that shift from unsustainable

livelihoods (like overfishing) to alternative, sustainable livelihoods (like ecotourism, crab farming, or honey collection) demonstrate a form of social-ecological resilience (Raha et al., 2013; Roy & Datta, 2022). These livelihood transitions reduce pressure on natural resources while also improving community well-being and economic security (Chowdhury & Maiti, 2021; Mukhopadhyay et al., 2018).

Ecotourism and community-based conservation initiatives are key examples of strategies that foster social-ecological resilience. By creating employment opportunities in tourism-related activities, such as guided tours, homestays, and local crafts, communities reduce their dependence on forest-based livelihoods, which are more vulnerable to hazards and wildlife conflict (Danda et al., 2011; Sarkar & Bhattacharya, 2017). Community-based conservation initiatives, such as mangrove reforestation and wetland protection, strengthen the natural buffers that protect human settlements from cyclone-induced storm surges and floods (Raha et al., 2013; Mukhopadhyay et al., 2018).

Technological advancements and innovative risk assessment tools play a critical role in resilience-building. Geospatial analysis, early warning systems, and participatory mapping are used to identify high-risk areas, prioritize mitigation measures, and plan disaster response efforts (Hazra et al., 2002; Mukhopadhyay et al., 2018). For example, GIS-based hazard mapping enables local authorities to assess the exposure of vulnerable settlements to cyclone paths, tidal surges, and areas of potential salinity intrusion (Danda et al., 2011; World Bank, 2010). This information is crucial for designing early warning systems and evacuation protocols, ensuring timely and efficient disaster response (Shamsuddoha & Chowdhury, 2007; Roy & Datta, 2022).

The concept of resilience also extends to institutional and governance frameworks. Local governance plays a vital role in supporting disaster risk reduction (DRR) policies, strengthening early warning systems, and promoting community-based disaster preparedness (CBDP) (Chowdhury & Maiti, 2021; Shamsuddoha & Chowdhury, 2007). By empowering local communities through participatory decision-making, disaster preparedness and response strategies become more context-specific, inclusive, and locally relevant (Roy & Datta, 2022). Participatory governance also promotes social learning, allowing communities to develop their own localized strategies for risk reduction and resilience-building (Chowdhury & Maiti, 2021).

The concept of transformative resilience is particularly relevant to the Indian Sundarbans, where communities must adopt adaptive livelihood strategies to cope with long-term environmental change. Mangrove reforestation, sustainable tourism, crab farming, and vocational training are examples of adaptive responses that reduce dependence on high-risk, resource-intensive livelihoods (Raha et al., 2013; Danda et al., 2011). Building transformative resilience requires a combination of policy reforms, livelihood diversification, and community-based interventions (Roy & Datta, 2022; World Bank, 2010). By adopting these approaches, the Indian Sundarbans can shift from a landscape of risk to a landscape of resilience and sustainability (Shamsuddoha & Chowdhury, 2007; World Bank, 2010).

This book, "Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans," explores the diverse factors influencing risk and resilience. By presenting practical insights into how local knowledge, community participation, conservation policies, and technological tools can be leveraged to reduce risk and build resilience, this book highlights pathways for strengthening the socio-ecological systems of the Indian Sundarbans (Danda et al., 2011; Rahman et al., 2019). The book focuses on evidence-based solutions and draws on primary field research, participatory methodologies, and geospatial analysis to assess the factors that shape risk and resilience. It emphasizes the need for inclusive governance, community empowerment, and the adoption of ecosystem-based disaster risk reduction (Eco-DRR) frameworks. By prioritizing these approaches, the Indian Sundarbans can become a global model for resilience-building (Shamsuddoha & Chowdhury, 2007; World Bank, 2010).

1.5 The Socio-Ecological Perspective: A Holistic Approach

Traditional disaster risk management (DRM) approaches have historically focused on human vulnerabilities, often overlooking the crucial role that natural ecosystems play in enhancing resilience (Shamsuddoha & Chowdhury, 2007; World Bank, 2010). The socio-ecological perspective addresses this gap by recognizing the interdependence between human and ecological systems, where changes in one system have direct and cascading impacts on the other (Danda et al., 2011; Chowdhury & Maiti, 2021). In the Indian Sundarbans, for instance, the health and density of mangrove forests directly affect the level of protection offered to local communities against cyclones, tidal surges, and coastal erosion (Hazra et al., 2002; Mukhopadhyay et al., 2018). The ability of mangroves to reduce wave energy and trap sediments is widely recognized as one of the most cost-effective and nature-based solutions (NBS) for disaster risk reduction (Raha et al., 2013; Dasgupta et al., 2014).

However, this socio-ecological relationship is a two-way dynamic. Unsustainable human activities, such as overharvesting of forest resources, illegal logging, and aquaculture expansion, reduce the resilience of mangrove ecosystems, thereby increasing the vulnerability of human settlements to climate-related hazards (Raha et al., 2013; Chowdhury & Maiti, 2021). These activities compromise the ability of mangrove forests to act as a natural barrier, leading to increased exposure to storm surges, erosion, and tidal floods (Hazra et al., 2002; Mukhopadhyay et al., 2018). As a result, the socio-ecological perspective calls for a holistic approach to disaster risk reduction that addresses both human and ecological vulnerabilities in a mutually reinforcing manner (Shamsuddoha & Chowdhury, 2007; World Bank, 2010).

By adopting a socio-ecological perspective, this book emphasizes the importance of ecosystem services as a key component of resilience. The concept of ecosystem services highlights how natural systems provide essential services that contribute to human well-being and disaster mitigation. The following examples illustrate the role of socio-ecological interactions in resilience-building:

- **Mangroves as natural buffers:** The mangrove forests of the Indian Sundarbans act as natural storm barriers, reducing wave energy, stabilizing shorelines, and mitigating the impacts of cyclones and storm surges (Hazra et al., 2002; Mukhopadhyay et al., 2018). Their ability to dissipate wave energy has been proven to significantly reduce the intensity of cyclonic impacts, as seen during Cyclone Amphan (2020) (Rahman et al., 2020; Roy & Datta, 2022). Protecting and restoring mangroves is seen as a nature-based solution (NBS) to disaster risk reduction and climate change adaptation (Dasgupta et al., 2014; Raha et al., 2013).
- **Fisheries as livelihoods:** The estuaries, rivers, and mangrove wetlands of the Indian Sundarbans provide a rich breeding ground for fish, crabs, and prawns, supporting the livelihoods of thousands of fishers and local communities (Chowdhury & Maiti, 2021; Danda et al., 2011). Fishing serves as an essential livelihood option, especially when agriculture becomes non-viable due to salinity intrusion and waterlogging (Dasgupta et al., 2014; Mukhopadhyay et al., 2018). Sustainable fisheries practices reduce community dependence on mangrove resources and promote livelihood diversification, which is a critical component of resilience-building (Raha et al., 2013; Roy & Datta, 2022).
- **Biodiversity as ecological capital:** The Indian Sundarbans is home to the Royal Bengal Tiger, estuarine crocodiles, Irrawaddy dolphins, and numerous migratory birds, which contribute to the region's ecological balance and promote eco-tourism-based livelihoods (Sarkar & Bhattacharya, 2017; Rahman et al., 2019). The health of this biodiversity ensures the long-term sustainability of the Indian Sundarbans as a natural capital asset (Danda et al., 2011; Chowdhury & Maiti, 2021). Community-based conservation initiatives, such as mangrove reforestation and tiger

conservation programs, help maintain this balance while offering livelihood benefits through eco-tourism and conservation employment (Sarkar & Bhattacharya, 2017; Roy & Datta, 2022).

This socio-ecological approach calls for participatory research and community engagement as a fundamental strategy for risk reduction and resilience-building (Shamsuddoha & Chowdhury, 2007; Roy & Datta, 2022). Through participatory research, this book documents how local communities co-exist with natural ecosystems and leverage them to reduce risk, diversify livelihoods, and enhance well-being (Chowdhury & Maiti, 2021; Danda et al., 2011). Participatory research methods, such as community-based participatory mapping and participatory risk assessments, are crucial for identifying risk-prone areas and co-developing context-specific resilience strategies (Hazra et al., 2002; Mukhopadhyay et al., 2018). For example, participatory mapping exercises have helped identify vulnerable settlements at risk of cyclones and rising sea levels, enabling communities to develop better evacuation protocols and early warning systems (Shamsuddoha & Chowdhury, 2007; World Bank, 2010).

The co-ownership of risk reduction strategies through community participation ensures that interventions are locally relevant, culturally acceptable, and socially inclusive (Danda et al., 2011; Rahman et al., 2019). Such participatory approaches foster a sense of community ownership, which is essential for the sustainability and long-term resilience of socio-ecological systems (Roy & Datta, 2022; Chowdhury & Maiti, 2021). By involving communities in decision-making processes, it becomes possible to develop community-driven disaster preparedness plans and create early warning systems that are more accessible and actionable for local populations (Shamsuddoha & Chowdhury, 2007; Rahman et al., 2020).

This book highlights how the adoption of a socio-ecological perspective can bridge the gap between ecosystem conservation, disaster risk reduction, and sustainable development (Danda et al., 2011; World Bank, 2010). By promoting community-based disaster risk reduction (CBDRR), ecosystem-based disaster risk reduction (Eco-DRR), and participatory research, this approach ensures that risk reduction strategies are comprehensive, equitable, and community-centered (Chowdhury & Maiti, 2021; Rahman et al., 2019). The book emphasizes that resilient ecosystems create resilient communities, and both human well-being and ecosystem health are intertwined in the broader framework of sustainable development (Shamsuddoha & Chowdhury, 2007; World Bank, 2010).

1.6 Rationale and Objectives of the Book

The Indian Sundarbans exemplifies the complexities of balancing ecological preservation with socio-economic development in a climate-sensitive region. Its unique vulnerabilities and adaptive strategies offer valuable insights into resilience-building, making it an ideal focus for interdisciplinary research. The rationale for this book lies in the urgent need to address the region's compounded vulnerabilities while fostering resilience at multiple levels.

1.6.1 Objectives

This book aims to delve into the intricate interplay between ecological systems, human societies, and disaster risks in the Indian Sundarbans. It seeks to:

- Highlight the critical challenges posed by natural and anthropogenic disasters in the region.
- Explore the socio-economic, cultural, and ecological dimensions of resilience and vulnerability.
- Present case studies, empirical data, and community narratives to enrich understanding and policymaking.
- Offer actionable insights for ecosystem conservation, disaster risk reduction, and sustainable development.

The book underscores the pressing need for interdisciplinary collaboration to address the complexities of multi-hazard risks and their cascading effects on ecosystems and communities.

1.6.2 Research Gaps and Significance

This book identifies and addresses critical research gaps, including the lack of integrated approaches to disaster risk reduction, the limited application of community-based conservation strategies, and insufficient attention to socio-cultural resilience. Its multidisciplinary framework enhances the knowledge base for stakeholders, informing policies and practices that align with both local realities and global sustainability goals.

1.6.3 Need for This Book

The Indian Sundarbans represents a microcosm of the global struggle against climate change, biodiversity loss, and socio-economic inequalities. Despite its significance, research on this region has often been fragmented and siloed. This book addresses this gap by synthesizing diverse perspectives from scholars, academicians, and professionals across India. By doing so, it creates a holistic understanding of the region's vulnerabilities and resilience pathways, providing a roadmap for sustainable development and disaster risk management.

1.7 Structure of the Book

This book, "Risk to Resilience: A Socio- Ecological Perspective on the Indian Sundarbans", is structured into nine chapters each focusing on a critical dimension of socio-ecological resilience in the Indian Sundarbans and address the multifaceted challenges and dynamics of the Indian Sundarbans region. Each chapter offers unique insights into critical issues, drawing from diverse methodologies and perspectives, and collectively contributes to understanding the intricate balance from risk to resilience in the Indian Sundarbans.

1.7.1 Brief of Chapters

Chapter 1: Introduction

The opening chapter provides an overview of the Indian Sundarbans' ecological, socio-economic, and cultural significance, introduces the concept of socio-ecological resilience and highlighting the region's challenges due to multi-hazard risks. It establishes the rationale for this collaborative research and introduces the core themes explored in the subsequent chapters.

Chapter 2: Coastal Multi-Hazard Vulnerability Assessment of Indian Sundarbans using Analytical Hierarchy Process

This chapter employs the Analytical Hierarchy Process (AHP) to identify and assess areas most vulnerable to coastal hazards such as cyclones, floods, and erosion. By leveraging spatial data, it offers practical tools for policymakers to prioritize mitigation strategies and enhance disaster preparedness in high-risk zones.

Chapter 3: Assessing the Characteristics and Circumstances of a Community under Threat from Multi-Hazards

This chapter delves into the socio-economic and cultural dimensions of vulnerability in the Indian Sundarbans. It explores how local communities adapt to multi-hazard threats, providing insights into their coping mechanisms, resilience strategies, and the broader implications of environmental challenges on their daily lives.

Chapter 4: Geo-Spatial Analysis of Human-Tiger Conflict in Indian Sundarban

Through geo-spatial analysis, this chapter investigates the intensifying human-tiger conflict in the Indian Sundarbans. It identifies conflict hotspots, examines the causes rooted in habitat loss and human dependence on forest resources, and suggests strategies for mitigating such conflicts while conserving biodiversity.

Chapter 5: Mangrove Degradation: Escalating Disasters and Climate Risks in the Indian Sundarbans

This chapter focuses on the critical role of mangroves in disaster mitigation and their alarming degradation due to anthropogenic and climatic pressures. It discusses the cascading effects of mangrove loss on biodiversity, disaster risks, and community livelihoods, advocating for urgent conservation and restoration efforts.

Chapter 6: Disaster-Induced Migration in the Indian Sundarban Islands

This chapter examines the socio-economic and environmental drivers of disaster-induced migration in the Indian Sundarbans. It highlights the adaptive strategies of displaced communities and calls for policy frameworks that address migration as both a challenge and a response to escalating vulnerabilities.

Chapter 7: Social Capital and Disaster Risk Reduction- A Case Study of Gosaba Block of Indian Sundarbans, India

Using the Gosaba Block as a case study, this chapter underscores the role of social capital in disaster risk reduction. It illustrates how community networks and trust facilitate disaster preparedness, response, and recovery, offering valuable lessons for fostering resilience in vulnerable regions.

Chapter 8: Cultural Heritage and Community Engagement in Indian Sundarbans Tourism: Balancing Preservation and Development

This chapter explores the intersection of cultural heritage and sustainable tourism in the Indian Sundarbans. It highlights the potential of community-driven tourism to promote economic growth while preserving the region's unique ecological and cultural assets, emphasizing the importance of inclusive and sustainable development practices.

Chapter 9: Conclusion

The concluding chapter synthesizes the insights and findings of the preceding chapters. It emphasizes the importance of integrating vulnerability reduction, resilience-building, and sustainable development into policies and practices. Recommendations for diverse stakeholders aim to ensure a resilient and sustainable future for the Indian Sundarbans.

1.7.2 Significance of Collaborative Research

The complexity of the Indian Sundarbans' challenges necessitates interdisciplinary and multi-institutional collaboration. This book represents a collective effort involving researchers, policymakers, and local stakeholders to generate actionable insights. This book benefits immensely from the breadth of topics and the collaborative efforts of scholars, academicians, and professionals from across India. By integrating diverse perspectives, methodologies, and case studies, it presents a holistic understanding of the Indian Sundarbans. The collective research addresses critical gaps and provides actionable insights, making this compilation not just a repository of knowledge but a guide for sustainable development, disaster risk management, and resilience-building in one of the world's most vulnerable yet remarkable ecosystems.

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2 Coastal Multi-Hazard Vulnerability Assessment of Indian Sundarbans Using Analytical Hierarchy Process

Treesa Joseph, Abin Varghese, Sreelakshmi Prakash, Joice K. Joseph and Baiju K.R.

Abstract

Natural hazards are occurring more frequently and with greater intensity, making the unique and fragile ecosystem of the world's largest mangrove forest, the Indian Sundarbans, highly susceptible. Tropical cyclones, floods, coastal erosion, storm surges, climate change, pollution, overexploitation, and population pressure are significant environmental hazards that severely impact life in the delta. Unplanned and unsustainable human settlements and activities, such as agriculture and infrastructure development, contribute to habitat destruction, deforestation, and further degradation of the Indian Sundarbans. Therefore, coastal vulnerability must be evaluated holistically, considering both physical and socio-economic factors, to develop a plan for increased resilience and sustainability.

In this study, the coastal vulnerability index was evaluated based on three components: exposure, sensitivity, and adaptive capacity, considering fourteen parameters using the Analytical Hierarchy Process (AHP). Geospatial technologies were used to map regions prone to multiple hazards in the Indian Sundarbans. According to this study, the southern community development blocks are particularly vulnerable due to their proximity to the Bay of Bengal and the frequent occurrence of natural disasters. The highly vulnerable zone covers 26% of the study area, including blocks like Namkhana, Patharpratima, and Haroa. Blocks such as Jaynagar I and Jaynagar II fall into the less vulnerable category, covering 8% of the study area. This study also offers concrete recommendations and policy suggestions for technology-based conservation of the Indian Sundarbans.

Keywords: *Indian Sundarbans, Coastal Vulnerability Index, Multi-hazard, Analytical Hierarchy Process, Vulnerability, Resilience*

2.1 Introduction

Vulnerability is a dynamic, scale-dependent, and multi-dimensional concept encompassing physical, social, environmental, economic, and political dimensions. It refers to "the degree to which geophysical, biological, and socio-economic systems are susceptible to and unable to cope with climate change" (Füssel et al., 2006; IPCC, 2007). Vulnerability is also broadly defined by the Intergovernmental Panel on Climate Change (IPCC, 2014a; 2014b) as "a function of exposure, sensitivity, and coping capacity." Coastal areas, as highly productive and transitional zones, are particularly vulnerable to climate-induced natural hazards such as storm surges, tsunamis, coastal inundation, cyclones, rising sea levels, and shifting shorelines. Coastal vulnerability is closely linked to the socio-economic conditions of a region and manifests from both natural phenomena and human activities (Sahana et al., 2019).

Spatio-temporal data, combined with geographic information technology, has become essential in disaster risk management strategies (Van Western, 2013). Increased disaster impacts are a result of the rising frequency of extreme hydro-meteorological hazards linked to climate change (Abhay et al., 2019). Moreover, countries that contribute insignificantly to global climate change are often the most susceptible to its effects. Emphasizing hazard assessment, element-at-risk mapping, vulnerability assessment, and risk assessment can help minimize disaster losses. Different approaches to vulnerability incorporate physical, social, economic, and environmental dimensions (Van Western, 2013). The Coastal Vulnerability Index (CVI) is used to quantify areas at risk due to environmental and socio-economic hazards (Ghosh and Mistri, 2021). Gornitz was the first to apply CVI analysis to explore the shoreline sensitivity of the eastern coast of the United States due to rising sea levels (Fuentes et al.,

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2022). Islam et al. (2016) assessed coastal multi-hazard vulnerability using geospatial technology along the Ganges deltaic coast of Bangladesh, employing seven physical parameters and a framework to prioritize actions. Kumar et al. (2010) conducted a coastal vulnerability assessment for Orissa state on India's east coast, calculating the CVI using eight relative risk variables, marking it as the first such study for this part of the Indian coastline; tsunami run-up and coastal elevation were included as important additional variables.

The unique geographical features, socio-economic structure, and ecological significance of delta regions make them particularly susceptible to multiple disasters. Key factors contributing to disaster vulnerability in delta regions include geographical position, rapid urbanization and population density, economic reliance on single livelihoods such as fishing or agriculture, inadequate infrastructure, socio-economic disparities, limited resource access, insufficient healthcare, and biodiversity loss (Alexander, 1997; Li et al., 1998; Xue, 1993). Contemporary practitioners, from scientific researchers to policymakers, are now considering the protection of delta regions by recognizing their crucial roles in ecosystem services, food security, natural disaster prevention, socio-economic stability, climate change mitigation, and cultural and historical significance.

The Indian Sundarbans face multiple hazards, including storm surges, floods, erosion, cyclones, sea level rise, subsidence, and saltwater intrusion (Sahana and Sajjad, 2019; Ali et al., 2019; Bera and Maiti, 2021). Ghosh (2017) conducted a case study on erosion hazard, vulnerability, and risk assessment at the Muriganga–Saptamukhi estuarine interface in the western Indian Sundarbans. Ali et al. (2019) analysed cyclone risk by assessing vulnerability, hazard evaluation, and mitigation capacity using GIS techniques. Ghosh and Mistri (2022) studied the Matla-Bidya interfluve area, focusing on cyclone-induced coastal vulnerability, livelihood challenges, and mitigation measures. Bera et al. (2021) examined risk reduction on Sagar Island due to climate vulnerability and economic determinants through a geospatial approach. Although many studies have explored the impact of individual environmental hazards—such as floods, storm surges, tropical cyclones, and coastal erosion—on coastal vulnerability, a multi-hazard assessment remains a novel approach. This study focuses on assessing vulnerability due to multiple hazards rather than a single hazard, incorporating various climatic, physical, environmental, economic, and social variables to provide a holistic view of spatial vulnerability (Ghosh and Mistri, 2021).

According to Mondal et al. (2021), numerous locations on Earth experience multiple hazards with cascading effects, making multi-hazard modelling essential for accurate assessment. Basic research on vulnerability is key for implementing coastal zone management guidelines and disaster relief policies (Szlafsztein and Sterr, 2007). With natural disasters becoming more frequent and severe, the coastal population of the Indian Sundarbans is highly vulnerable, placing significant strain on impoverished communities. This situation is exacerbated by the fact that less than half of the population (44%) in the delta lives below the poverty line (Ghosh and Mistri, 2021). Thus, for effective risk reduction and to enhance the community's coping capacity against coastal hazards, a comprehensive mitigation approach, supported by spatial vulnerability assessment, is essential (Ghosh and Mistri, 2021). Remote sensing is now a crucial tool for monitoring such changes, with geo-information science playing a vital role in hazard and risk analysis (Van Western, 2013).

Four socio-economic and seven physical-geological indicators were used to create the socio-economic vulnerability index (SVI), the physical vulnerability index (PVI), and the coastal vulnerability index (CVI), all of which were employed to assess the coastal vulnerability of the Puducherry coast through the analytical hierarchical process (Murali et al., 2013). Studies underscore the critical importance of vulnerability assessment to mitigate aftereffects and improve understanding of threatening factors.

Additionally, the analytical hierarchy technique has been used to map disaster risk in various Indian districts susceptible to natural and climate-induced disasters (Chakraborty and Joshi, 2016).

2.2 Study Area

The world's largest mangrove forest, the Indian Sundarbans, extends over 6,017 km^2 in Bangladesh and over 4,260 km^2 in West Bengal, spanning the districts of North 24 Parganas and South 24 Parganas (Figure 2-1). It is bounded by the Hooghly River to the west, the Ichamati-Kalindi-Raimangal region to the east, the Bay of Bengal to the south, and the Dampier Hodges line to the north (Kundu et al., 2018). The Indian Sundarbans (21°32′N 88°05′E–22°40′N 89°00′E) were formed because of the combined action of the Meghna, Ganges, and Brahmaputra rivers (Sreelekshmi et al., 2020). There are people living on 54 islands in the delta, which comprise 19 community development blocks. This vast mangrove ecosystem, situated along marine and terrestrial interfaces, provides critical ecosystem functions.

The monsoon season lasts from June to September, with annual precipitation between 2,500 and 3,000 mm. The maximum and minimum temperatures range between 25 and 35°C and 12 and 24°C, respectively (Giri et al., 2014). The weather is predominantly humid, and tidal levels seasonally vary from 4 to 6.5 m (Banerjee, 2008).

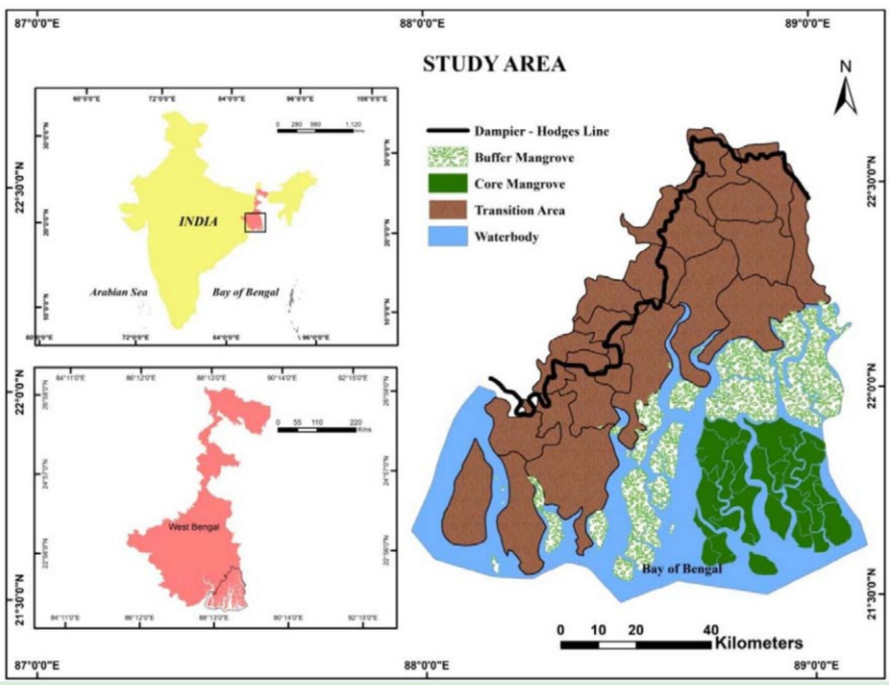

Figure 2.1: Study area (Source: Dr. Satheesh Centre for Remote Sensing and GIS)

2.3 Materials and Methods

Geographic Information System (GIS) and remote sensing technologies were used to map the areas of the Indian Sundarbans that are vulnerable to coastal multi-hazards. The Analytical Hierarchy Process (AHP) was used to perform the analysis. A total of fourteen parameters were considered, and the exposure, sensitivity, and adaptive capacity indices, which measure vulnerability were evaluated. SRTM DEM downloaded from USGS was used as an elevation data source. SRTM DEM was used to create the slope, utilizing a raster surface in the 3D analyst tool. Using the hydrology function in the spatial analyst tool, the drainage network was acquired from the SRTM DEM, and the drainage density was calculated

using the line density tool in ArcGIS (Ghosh and Mistri, 2021). The coastline was extracted using Laplacian filter through image enhancement technique and a coastal proximity map was generated with Euclidean distance (Ghosh and Mistri, 2021). IDW interpolation was used to calculate rainfall. Rainfall deviation was calculated using Eq. (1) (Ali et al., 2019)

Equation 1: Rainfall deviation

$$Rainfall\ deviation = \frac{(Recorded\ rainfall - average\ rainfall)}{average\ rainfall} x\ 100$$

The average rainfall was taken as 1700mm from Indian Meteorological Department (https://mausam.imd.gov.in/imd_latest/contents/index_rainfall_state_new.php#) and rainfall deviation was calculated. Cyclone tracks were taken from the joint typhoon warning centre, and line density tool was used to find cyclone track density. Flood inundation risk was determined by assessing the spatial flooding of several blocks that were less than 1 to 6 meters, and the exposure index was found (Ghosh and Mistri, 2021). Demographic data was used to find the block wise vulnerability. Similarly, sensitivity index and adaptive capacity indices are found. All the layers were reclassified and ranked based on the weights assigned to each indicator through the analytical hierarchy process.

2.3.1 Flood Inundation Risk

The ArcGIS raster calculator was used for spatial queries of each flooding scenario (1 m–6 m), with the assumption that if elevation is below the anticipated level, every pixel of the expected level will submerge. For every block, the proportion of inundation regions at various flood levels was computed. For every block, the flood inundation risk was calculated using the square root of the product mean algorithm. using Equation 2 (Sahana and Sajjad, 2019)

Equation 2: Flood inundation risk (FIR)

$$FIR = \sqrt{\left(\frac{(a \times b \times c \times d \times e \times f)}{6}\right)}$$

Where a, b, c, d, e, and f represent the area of the block in percentage under one, two, three, four, five, and six meters of inundation, respectively. Based on the flood inundation risk index, five classes of flood hazard were obtained using the 20th, 40th, 60th, and 80th percentile, respectively (Sahana and Sajjad, 2019).

2.3.2 Analytical Hierarchy Process (AHP)

To ascertain weightage according to the relative importance of the indicator for decision-making, Professor Thomas L. Saaty introduced a semi-quantitative technique called the analytical hierarchy process (Saaty, 1990; Yin et al., 2013; Ghosh and Mistri, 2021). It considers subjective and objective factors in the decision-making process (Yalcin, 2008; Kumar and Anbalagan, 2016). A nine-point ordinal scale is used to assign weights to the elements and choices in a hierarchy that represent a complex decision-making problem (Table 2-1).

A matrix with equal rows and columns is created using components or the classes they belong to, and scores are noted. If the vertical axis factor is greater than the horizontal axis factor, the resulting value falls between 1 and 9 and in the other direction between reciprocals 1/2 and 1/9 (Kumar and Anbalagan, 2016). Matrix calculation gives factor weights regarding eigen vectors (Saaty 1980; Yalcin, 2008).

Table 2.1: Satty's (1990) numerical scale of importance for analytical hierarchy process preference (Ghosh and Mistri, 2021)

Scale	Numerical rating	Reciprocal
Extremely importance	9	1/9
Very to extremely strong importance	8	1/8
Very strongly importance	7	1/7
Strongly to very strongly importance	6	1/6
Strongly importance	5	1/5
Moderately to strongly importance	4	1/4
Moderately importance	3	1/3
Equally to moderately importance	2	1/2
Equally importance	1	1

Saaty (1980) formulated consistency index (CI) as Equation 3

Equation 3: Consistency Index (CI)

$$CI = \frac{\lambda max - n}{n-1}$$

Where λmax is the largest eigen value of the considered matrix and n is the total number of sub indicators. Random index is taken from the table 2-2. To measure the consistency of the entire hierarchy, the consistency ratio was calculated using Equation 4

Equation 4: Consistency Ratio (CR)

$$Consistency\ Ratio\ (CR) = \frac{Consistency\ Index\ (CI)}{Random\ index\ (RI)}$$

The rank wise subjective evaluation of pairwise comparison matrix is considered consistent for decision making if the value of consistency ratio is equal to or less than 0.1 (Ghosh and Mistri, 2021).

Table 2.2: Random consistency index (RI) (Saaty, 1980; Ghosh and Mistri, 2021)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.5

The sub-indices value was calculated using Eq. (5)

Equation 5: Sub-Index

$$sub - index = \sum_{i=1}^{n} w_i \times u_i$$

where w is the weight of each indicator and u is the value of each indicator and n is the total number of indicators, i = 1,2,3 .... n

By employing the averaging method to combine various sub-indices, the final composite vulnerability index is generated. The equation (Eq.6) for calculating the disaster vulnerability was as follows

Equation 6: Vulnerability

$$V = \frac{[E+S+(1-AC)]}{3}$$

where V, E, S, and AC represent vulnerability, exposure, sensitivity, and adaptive capacity, respectively (Chakraborty and P.K. Joshi, 2016)

Table 2.3: Pairwise comparison matrix for exposure

Factors	Elevation	Slope	Drainage density	Proximity to coastline	Rainfall deviation	Cyclone track density	Flood inundation risk	Normalised eigen (weight)
Elevation	1	2	1/3	1/5	1/7	1/6	1/8	0.032
Slope	1/2	1	1/3	1/6	1/8	1/7	1/9	0.023
Drainage density	3	3	1	1/3	1/6	1/5	1/7	0.053
Proximity to coastline	5	6	3	1	1/5	1/3	1/6	0.097
Rainfall deviation	7	8	6	5	1	3	1/3	0.243
Cyclone track density	6	7	5	3	1/3	1	1/5	0.153
Flood inundation risk	8	9	7	6	3	5	1	0.399
CR=0.081					Maximum eigen value= 7.644			

Table 2.4: Pairwise comparison matrix for sensitivity

Sensitivity	Household density	Population density	Percentage of child population	Normalised eigen (weight)
Household density	1	3	5	0.633
Population density	1/3	1	3	0.261
Percentage of child populati on	1/5	1/3	1	0.106
CR= 0.0332	Maximum eigen value= 3.038			

Table 2.5: Pairwise comparison matrix for adaptive capacity

Adaptive capacity					
Factors	**Permanent house**	**Literacy rate**	**Workforce participation**	**Banking facility**	**Normalised eigen (weight)**
Permanent house	1	3	5	7	0.558
Literacy rate	1/3	1	3	5	0.263
Workforce participation	1/5	1/3	1	3	0.122
Banking facility	1/7	1/5	1/3	1	0.057
CR=0.043	Maximum eigen value = 4.117				

Table 2.6: Geographical coverage of various classes of thematic factors

SI No	Type	Classes	Category	Area (km^2)	Area (%)
EXPOSURE					
1	Slope (degree)	Oct-27	Very low	0.9108	0.02
		06-Oct	Low	17.62	0.4
		04-Jun	Moderate	138.63	3.17
		02-Apr	High	1282.59	29
		0-2	Very high	2913.35	66.8
2	Elevation (m)	Oct-42	Very low	25.66	0.5
		06-Oct	Low	427.71	9
		04-Jun	Moderate	1098.92	25
		02-Apr	High	1591.36	36
		0-2	Very high	1214.86	27.86
3	Proximity to coastline (km)	100-125	Very low	264.09	6
		75-100	Low	1076.57	24
		50-75	Moderate	1024.72	23
		25-50	High	885.78	20.3
		0-25	Very high	1094.26	25.09
4	Rainfall deviation (mm)	<1	Very low	3401.04	78
		01-Jun	Moderate	363.27	8
		06-Dec	High	568.76	13.04
		Dec-17	Very high	24.86	0.57
5	Cyclone track density (km/sq.km)	0-0.07	Very low	3739.06	85
		0.07-0.14	Low	313.21	7.1
		0.14-0.21	Moderate	293.6	6.73
		0.21-0.28	High	9.68	0.2
		0.28-0.31	Very high	2.73	0.06
6	Drainage density (km/sq.km)	0-0.6	Very low	11	0.2
		0.6-1.33	Low	225.32	5.1
		1.33-1.93	Moderate	553.4	12
		1.93-2.7	High	3100.41	71
		2.7-3.41	Very high	467.66	10.72
7	Flood inundation risk	0-9.44	Very low	763.17	17.5
		9.44-29.56	Low	893.91	20.5
		29.56-58.82	Moderate	1133.16	25.9
		58.82-152.38	High	1012.87	23.2
		152.38-285.18	Very high	555.12	12.73
SENSITIVITY					
8	Population density	<1000	Low	2772	63
		1000-1500	Moderate	1038.11	23.81

SI No	Type	Classes	Category	Area (km^2)	Area (%)
		1500-2000	High	447.99	10.27
		2000-2500	Very high	99.9	2.2
9	Household density	<200	Low	2551	58
		200-300	Moderate	1062.45	24.3
		300-400	High	644.54	14.7
		400-500	Very high	99.9	2.2
10	Child population	<11	Very low	167.58	3.84
		Nov-13	Low	2040.49	46.8
		13-15	Moderate	1000.13	22.9
		15-17	High	894.62	20.51
		>17	Very high	255	5.85
ADAPTIVE CAPACITY					
11	Workforce participation rate	<35	Low	775.74	17.79
		35-40	Moderate	2324.98	53.3
		40-45	High	926.85	21.2
		>45	Very high	330	7.5
12	Permanent house facility	01-Oct	Very low	624.02	14.31
		Oct-20	Low	1892.33	43
		20-30	Moderate	1003.56	23.01
		30-40	High	464.36	10.6
		40-50	Very high	422.56	9.69
13	Banking facility	<20	Low	769.47	17.64
		20-30	Moderate	891.82	20.4
		30-40	High	1746.01	40
		40-50	Very high	950	21.8
14	Literacy rate	<55	Very low	345.8	7.93
		55-60	Low	804.22	18.44
		60-65	Moderate	1282.12	29.4
		65-70	High	585.03	13.41
		70-75	Very high	1341.06	30.75

Table 2.7: Geographical coverage of vulnerability in Indian Sundarbans

SI No	Category	Area (km^2)	Area (%)
1	Very low	351.17	8.1
2	Low	154.88	3.6
3	Moderate	1680.91	38.7
4	High	991.16	22.8
5	Very high	1163.88	26.8
Total		**4342**	**100**

2.4 Findings and Discussion

ArcGIS software was used to generate a coastal vulnerability map, which demonstrated that the research area under study is vulnerable to many coastal hazards, with cyclones being the most frequent occurrence. Very low, low, moderate, high, and very high were the categories used to categorize the vulnerability zones.

2.4.1 Exposure

The exposure index was calculated using the following factors: elevation, slope, drainage density, distance from the coast, rainfall deviation, density of cyclone tracks, and flood inundation risk. Elevation of the area ranges from 0 to 42m. As the elevation of the region under study decreases, vulnerability increases. 27.86 % of the study area falls under the very highly vulnerable category and it accounts for 1214.86 km^2, the very low vulnerability category covers 25.66 km^2 area, which is only 0.5% of the study area. The slope dependents indirectly on vulnerability and the region with a gentle slope is more vulnerable. Most of the area under study (66.8%) is in the highly vulnerable category, covering about 2913.35km^2. The farther one gets from the coast, the less vulnerable one becomes. The very high vulnerability category (0-25 km) includes 25.09% of the research region with an area of 1094.26 km^2. 264.09 km^2 area is in very low vulnerable zone, accounting for 6% of the study area. Vulnerability increases with an increase in rainfall deviation. The highly vulnerable category consists of 13% of the study area which includes 568.76 km^2 area (Table 2.6; Fig. 2.2). The region with more cyclone track density is more vulnerable than regions with low cyclone track density. 2.73 km^2 area is under the very high vulnerability category, which is 0.06% of the study area, and 6.73% remains in a moderately vulnerable zone with 293.60 km^2 area. As the drainage density in an area increase, so does vulnerability. A very high sensitivity zone, spanning 467.66 km^2, makes up 10.72% of the research region. Areas with high flood inundation risk are the regions with the highest vulnerability. Approximately 12.73% (555.12 km^2) of the area is classified as having very high vulnerability and 17.50% under the very less vulnerable category with 763.17 km^2 area (Table 2.6; Fig. 2.3)

The vulnerability map of the exposure index is categorised into five categories. 24.41% of the research area is in the zone of very high vulnerability, covering an area of 1052 km^2, which includes blocks of Namkhana, Haroa, Hingalganj, Patharpratima, and very less vulnerable category consists of 8% of the area which is about 367.64 km^2. It includes Jaynagar I and Jaynagar II. The high vulnerability zone makes up 41.26% of the area under the study covering Canning II and Hasnabad, 24.4% in a moderate vulnerability zone and 1.2% in less vulnerability zone. The areas with higher vulnerability are due to lower elevation, gentle slope, proximity to the coastline, high flood inundation risk and cyclone track density (Table 2.6; Fig. 2.4).

2.4.2 Sensitivity

Sensitivity denotes the extent to which a system is susceptible to natural hazards (Ghosh and Mistri, 2021). Population density, household density and percentage of child population were considered to find sensitivity. Population density is the number of people per square kilometre area and household density is the household count per square kilometre area (Ghosh and Mistri, 2021). As the density of the population in an area increase, vulnerability increases. Around 2.2% of the area under the study is densely populated and it falls in a very high vulnerability zone with an area of 99.9 km^2. Over 2.2% of the area has high household density, which accounts for about 99.9 km^2, indicating very high vulnerability. The higher percentage of the child population signifies high vulnerability in the region. Around 5.85% (255 km^2) of study area falls under very highly vulnerable zone. From the map of sensitivity index, 12% of the study area (547.94 km^2) is in the very highly vulnerable category which includes Haroa, Canning I

and 42% of the area is having moderate vulnerability. Higher vulnerability is due to increased density of households and population in the area (Table 2.6; Fig. 2.4).

2.4.3 Adaptive Capacity

It's the potential ability of the system to use available resources, skills, and technology to resist the adverse impact of hazards (Ghosh and Mistri, 2021). The population that is actively employed in the economy is measured by workforce participation. Individuals who have access to banking services, education, and with permanent housing are more resistant to environmental hazards. As the adaptive capacity of the population increases, vulnerability decreases. Around 17.79 % (775.74 km^2) of the area under the study is in a very high vulnerability zone due to low workforce participation. While considering the population with permanent houses, 14.31% (624.02 km^2) of the region is in a highly vulnerable zone. Regarding banking facilities, 17.64% (769.47 km^2) of the region is in a very high vulnerability zone. While considering the literacy rate, around 7.93% (345.8 km^2) of the region is in a highly vulnerable category, and 30.75% (1341.06 km^2) falls in a less vulnerable category.

Considering the adaptive capacity index, it is found that 22% of the area, which is 965.47 km^2, has a meagre adaptive capacity and accounts for very high vulnerability in the area, including Basanti, and Kultali. It was also found that the 422.56 km^2 area, about 9.69%, lies in a very less vulnerable category due to its higher adaptive capacity in regions like Hasnabad and Haroa. Facilities such as permanent housing and banking facilities increase the adaptive capacity in the area (Table 2.6; Fig. 2.4).

2.4.4 Coastal Vulnerability Index

The vulnerability map of the Indian Sundarbans is categorized as very low, low, moderate, high and very high. The very highly vulnerable zone covers 26% of the study area (1163.88 km^2), including Namkhana, Patharpratima, Haroa, and Hingalganj blocks. Lower elevation, high flood inundation risk and gentle slope make this region more vulnerable. 22.7% of the area falls in the high vulnerability category which extends over an area of 991.16 km^2; it includes Gosaba and Sandeshkhali blocks and 38% in the moderately vulnerable category. Kultali, Canning, Basanti, Sagar blocks are under the moderately vulnerable category due to lower adaptation capacity and high exposure to coastal hazards. 8% of the region, or 351.17 km^2, is classified as extremely less vulnerable because it is less exposed to coastal hazards and has fewer sensitivity elements. And 3% under less vulnerability zone which is about 154.88 km^2, it includes Jaynagar I and Jaynagar II blocks (Table 2.7; Fig. 2.5).

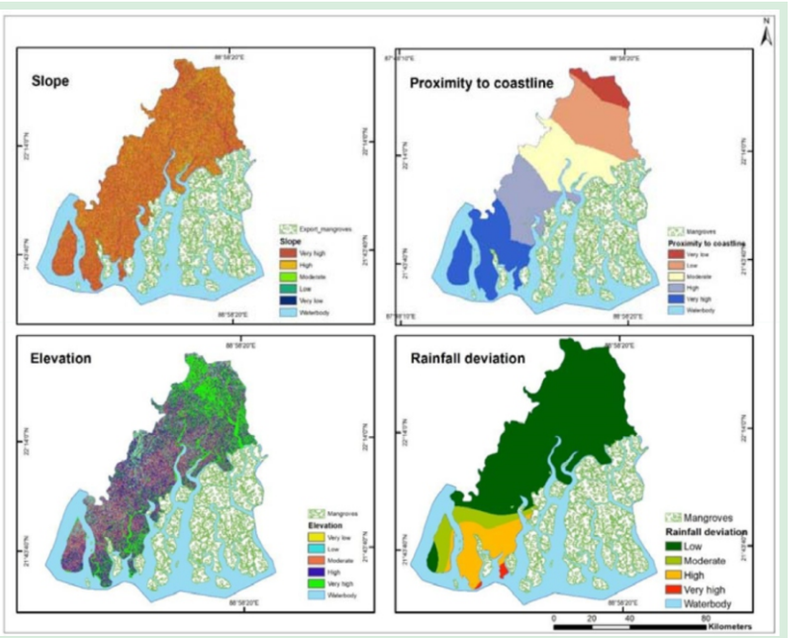

Figure 2.2: Vulnerability map for exposure
(Dr. Satheesh Centre for Remote Sensing and GIS)

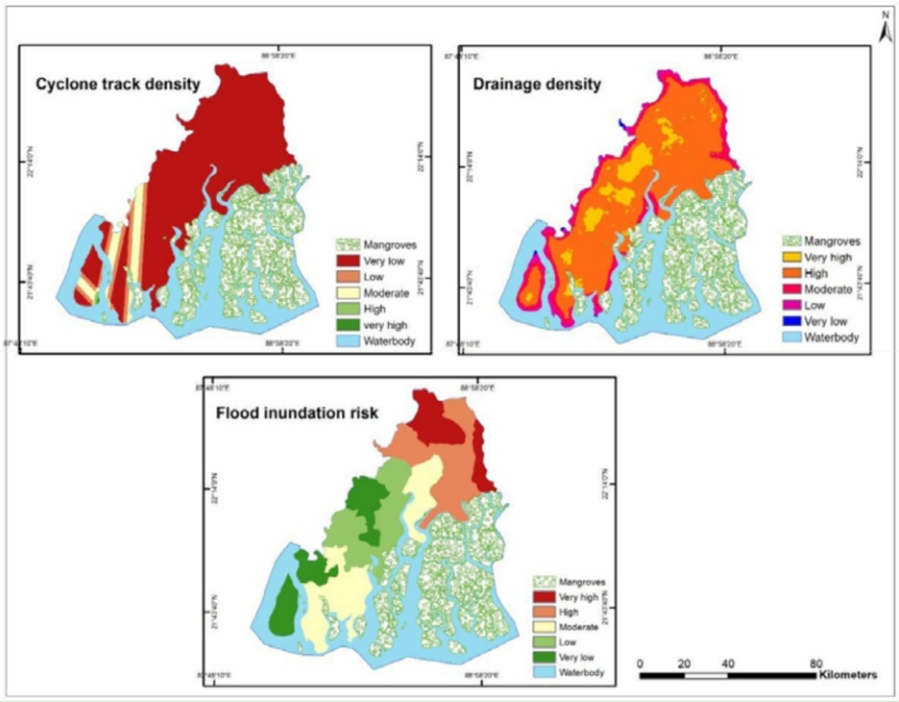

Figure 2.3: Vulnerability map for exposure (Dr. Satheesh Centre for Remote Sensing and GIS

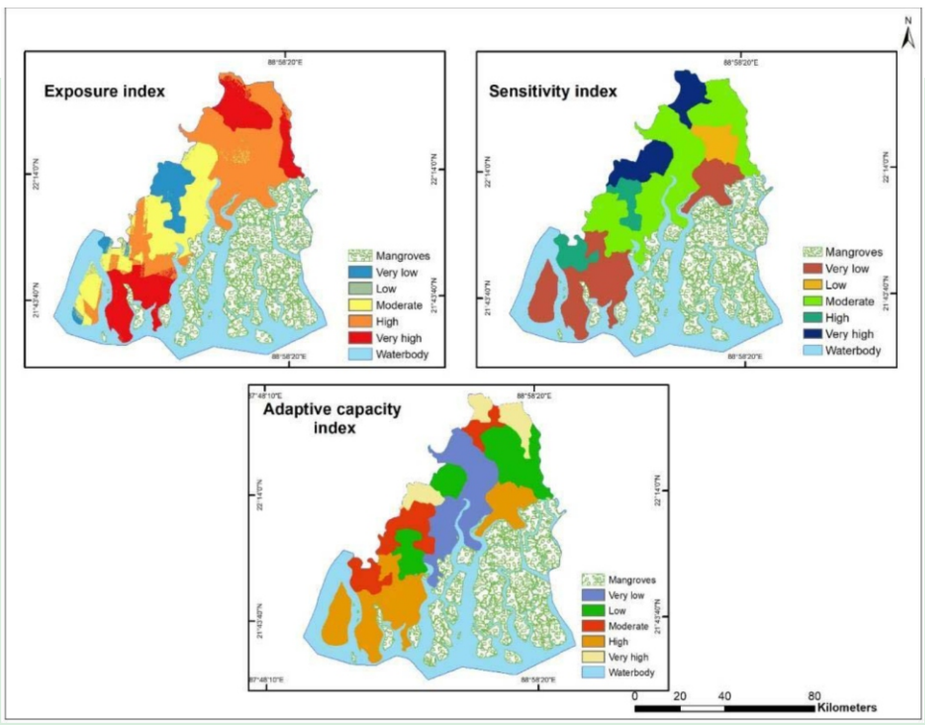

Figure 2.4: Vulnerability map for indices (Dr. Satheesh Centre for Remote Sensing and GIS)

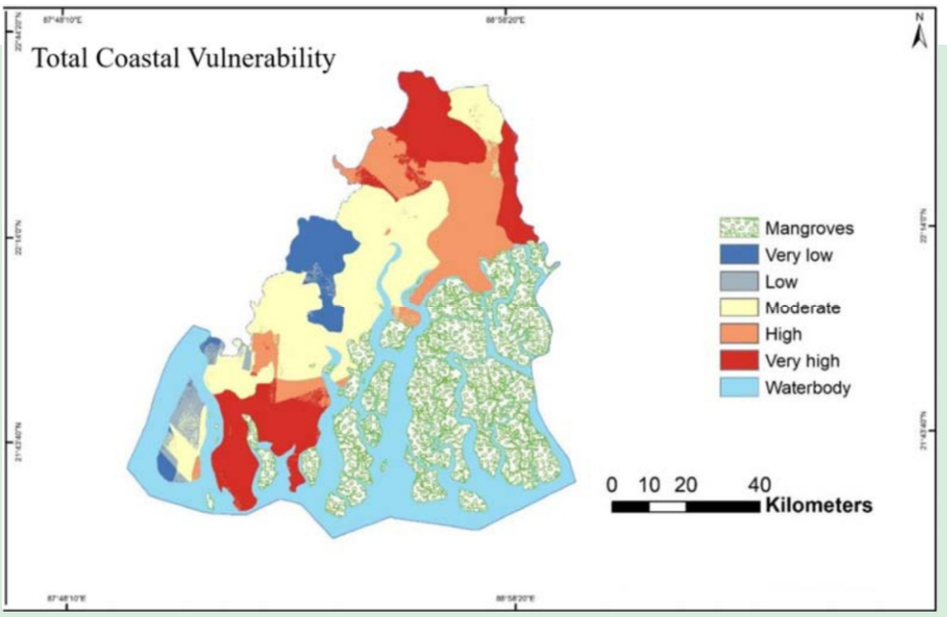

Figure 2.5: Vulnerability map for total coastal vulnerability
(Dr. Satheesh Centre for Remote Sensing and GIS)

2.5 Conclusion

The spatial vulnerability of the area was analysed considering fourteen parameters. The exposure, sensitivity, and adaptive capacity subindices were considered to delineate the coastal vulnerability using the analytical hierarchy process and geospatial techniques. The relative significance of each parameter determines the vulnerability of a region. A vulnerability map was prepared for each sub-index, and a coastal vulnerability map was prepared. For a more accurate assessment, storm surge height can be included. The study demonstrates how extremely vulnerable the southern community development blocks are due to the vicinity of Bay of Bengal and recurring natural hazards. The very highly vulnerable zone covers 26% of the area (1163.88 km^2) and the blocks like Namkhana, Patharpratima, and Haroa are in this category due to low elevation, gentle slope and very high flood inundation risk. Blocks such as Jaynagar I, and Jaynagar II are in the very less vulnerable category, which includes 8% of the study area with an area of 351.17 km^2 due to high adaptive capacity and less sensitivity, which helps in building resilience against hazards. Since the Indian Sundarbans are more prone to natural disasters such as storm surges, coastal erosion, floods, and cyclones; delineating vulnerability is very significant to reducing the risk and planning mitigation measures sustainably. Construction of cyclone shelters, early warning systems can be some of the short-term management strategies to increase resilience of the system. Mangrove restoration, scientific land use planning to reduce salinity and embankment restructuring are some of the long-term management strategies.

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Statements and declarations

No other journal is considering publishing the content, nor has it been published and according to the writers, there isn't a conflict of interest.

2.6 Summary of Chapter

The chapter titled "Coastal Multi-Hazard Vulnerability Assessment of Indian Sundarbans Using Analytical Hierarchy Process (AHP)" assesses the vulnerability of the Indian Sundarbans-a fragile ecosystem threatened by various natural hazards. It highlights the environmental and socio-economic challenges faced by the region, including tropical cyclones, floods, erosion, and climate change impacts.

Using the Coastal Vulnerability Index (CVI) methodology, the study evaluates three major components: exposure, sensitivity, and adaptive capacity. Fourteen parameters were considered within these components, ranging from physical indicators (elevation, slope, proximity to the coastline) to socio-economic indicators (population density, literacy rates, and housing stability). Geospatial tools and the Analytical Hierarchy Process (AHP) were utilized to map the region's most susceptible to multi-hazards, identifying that the southern blocks are particularly vulnerable due to their proximity to the Bay of Bengal and recurrent disasters.

The findings reveal that approximately 26% of the Indian Sundarbans fall within a very highly vulnerable zone, mainly concentrated in areas close to the coast. The study provides policy recommendations for mitigating risks, emphasizing the importance of cyclone shelters, early warning systems, and mangrove restoration to bolster resilience. This assessment underscores the need for comprehensive, technology-based strategies to conserve the Indian Sundarbans and safeguard its communities against the increasing threats of climate-induced hazards.

The key findings of the chapter are as follows:

1. **High Vulnerability in Southern Regions:** The southern blocks of the Indian Sundarbans, close to the Bay of Bengal, are particularly vulnerable to multiple natural hazards, such as tropical cyclones, floods, and coastal erosion. Approximately 26% of the study area is categorized as very highly vulnerable.
2. **Critical Exposure Factors:** Low elevation, gentle slope, proximity to the coast, high flood inundation risk, and cyclone track density are identified as major contributors to vulnerability. Areas with low elevation are especially susceptible to saline water intrusion and flooding.
3. **Sensitivity Due to Population Density:** High population and household density, along with a significant proportion of child population in certain blocks, increase the region's sensitivity to hazards, as denser populations face greater risks during disasters.
4. **Limited Adaptive Capacity:** Many areas in the Indian Sundarbans have low adaptive capacity, especially where workforce participation, literacy, and access to permanent housing and banking facilities are limited. This reduces the community's ability to withstand and recover from hazards.
5. **Recommendations for Risk Mitigation:** The study emphasizes the need for a multi-pronged approach to risk reduction, including the construction of cyclone shelters, early warning systems, mangrove restoration, and scientific land-use planning. These measures aim to enhance resilience and reduce the impacts of recurring hazards on local communities.

This assessment underscores the urgent need for sustainable coastal management and adaptive strategies to protect both the Indian Sundarbans ecosystem and its vulnerable communities.

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3 Assessing the Characteristics and Circumstances of a Community Under Threat from Multiple Hazards

Manisha Bhor and Keya Mitra

Abstract

South 24-Parganas in West Bengal, India, is a multi-hazard-prone district. It is part of the Ganga Delta system and home to the ecologically fragile Indian Sundarbans biodiversity region. An economically vulnerable population inhabits this district, relying on agriculture and fisheries for their livelihoods. Despite facing recurrent natural disasters, they are deeply connected to their social and cultural roots and reluctant to migrate to safer environments. The Vulnerability Atlas of India (VAI) indicates that the entire district is highly vulnerable to a range of hazards. However, there is considerable variation in the intensity and impact of these hazards, necessitating a more nuanced understanding of vulnerability than what is provided by the VAI.

This study was conducted in five coastal blocks with riverine edges, which are more vulnerable to tidal surges and floods. Twelve broad parameters and forty-nine sub-parameters were integrated into a Composite Vulnerability Index (CVI), ranging from 0 (indicating lowest vulnerability) to 1 (indicating highest vulnerability). A two-stage Expert Opinion-based Analytic Hierarchy Process (AHP) was used to assign weights to the parameters and sub-parameters. The CVI tool was applied at the village level in the study area, where questionnaire surveys were carried out, and scores were assigned for each sub-parameter. The most economically marginalized communities across spatial scales were prioritized based on their evaluated vulnerabilities.

A careful study of the different contributing sub-indices to the overall block CVI provides essential insights into systemic weaknesses that can be addressed to reduce overall vulnerability. For example, in Kultali, although the number of physicians is adequate, the greater distance from healthcare facilities and the lower number of paramedical staff have increased the Health Service Index (HSI) value, indicating greater vulnerability. An improvement in the HSI would reduce the CVI of the block. Thus, the CVI and its contributing sub-parameter indices can guide vulnerability reduction in communities in a prioritized manner.

Keywords: *South 24 Parganas, Multi-Hazard, Composite Vulnerability Index, Community resilience, Mitigation Strategies*

3.1 Introduction

3.1.1 Concept

Vulnerability, in its broadest sense, refers to the potential for loss, with or without spatial dimensions. It is shaped by the level of exposure to risks and the capacity of systems to respond and adapt. The realization of the need for disaster risk reduction began with the United Nations' declaration of the International Decade for Natural Disaster Reduction (IDNDR) from 1990 to 1999, marking a global call to mitigate disaster risks (General, UN, 1990). Following this, the Hyogo Framework for Action (HFA) (2005–2015) served as a global blueprint for reducing disaster risks, aligning with the Millennium Development Goals (MDGs) aimed at poverty alleviation and improvements in health, education, and the environment (ISDR, 2011).

In 2015, the MDGs transitioned to the Sustainable Development Goals (SDGs) under the 2030 Agenda for Sustainable Development, which emphasized resilience and inclusivity (UN, 2015b). Concurrently, the Sendai Framework for Disaster Risk Reduction (SFDRR) replaced the HFA as the leading global framework for disaster risk reduction (UN, 2015a). The SFDRR aligns closely with the SDGs, integrating its priorities into multiple SDG targets.

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The SFDRR introduced a dual perspective on vulnerability: exposure to natural hazards and the socio-economic resilience of communities, encapsulating adaptive and coping capacities. This perspective underscores the need to integrate physical and social dimensions into vulnerability assessments to develop effective mitigation strategies.

3.1.2 Relevance to Study Area

This study focuses on understanding the vulnerabilities of communities living in multi-hazard-prone coastal blocks within the South 24 Parganas district of West Bengal, India. The district, part of the Indian Sundarbans delta system, is particularly exposed to cyclones, tidal surges, and riverine flooding. A Composite Vulnerability Index (CVI) is proposed, combining hazard exposure with physical, social, and economic parameters to develop a nuanced understanding of vulnerabilities.

The CVI is envisioned as a village-level tool to prioritize action areas, enabling planners to design targeted interventions for vulnerability reduction. By combining empirical data with spatial analysis, this approach offers a comprehensive framework for assessing and addressing vulnerabilities in geographically and socio-economically diverse contexts.

3.1.3 Reasons for Choosing This Study Area

The eastern coastline of India is significantly more vulnerable to cyclonic storms and depressions than the western coast, with the South 24 Parganas district experiencing a high frequency of severe cyclonic events (Cyclone | NDMA, n.d.). Covering over 9,960 square kilometres, the district lies along the eastern seaboard near the Bangladesh border and is a key component of the Indian Sundarbans delta. This region is ecologically fragile and socio-economically vulnerable, with communities heavily dependent on agriculture and fisheries for their livelihoods (BMTPC, 2019).

Key Vulnerabilities:

- Cyclonic Impacts: The district frequently faces cyclones, such as Aila (2009), Bulbul (2019), Amphan (2020), and Yaas (2021), which have devastated infrastructure, livelihoods, and ecosystems. For example, the super cyclone Amphan in May 2020 damaged over 59 kilometres of embankments and sea dykes (AFR, 2020).
- Flooding and Salinization: Cyclonic storms often cause saltwater intrusion into agricultural and pisciculture lands, reducing productivity and forcing communities to adapt or migrate.
- Erosion and Embankment Failures: Changing River courses and eroding protective embankments pose persistent threats, exacerbating vulnerabilities.

Despite these recurrent disasters, ground surveys revealed that the inhabitants maintain a strong connection to their cultural roots and are often reluctant to migrate to safer locations. This resilience, though commendable, underscores the need for targeted interventions to reduce risks while preserving their socio-cultural fabric.

The Vulnerability Atlas of India (VAI) identifies South 24 Parganas as one of the most hazard-prone districts in the country. However, vulnerabilities are not uniform; variations in geographical, social, and infrastructural factors necessitate a granular, village-level understanding. This nuanced approach is critical for informed planning and the equitable allocation of resources to address systemic weaknesses and reduce overall vulnerability (BMTPC, 2019).

3.2 Study Area

3.2.1 District Overview

South Twenty-Four Parganas was established on 1st March 1986 following a recommendation by the administrative reforms committee chaired by Dr. Ashok Mitra (GoWB, 2021a). The district was formed through the separation of Greater 24 Parganas into two distinct districts: South 24-Parganas and its sister district, North 24-Parganas. South 24-Parganas is the largest and most populous district in West Bengal. Spanning latitudes 22°33′45″ N to 21°29′00″ N and longitudes 89°04′50″ E to 88°03′45″ E, it covers an area of 9,960 square kilometres (GoWB, 2021b).

The district, which comprises 29 administrative blocks, lies within the vast Ganga delta. This region exhibits characteristics of both active delta-building processes and a mature stage of geomorphic development (Basu, 2022; Akter et al., 2016; Bhattacharya, 1999). Thirteen of these blocks-Sagar, Namkhana, Kakdwip, Pathar Pratima, Kultali, Mathurapur-I, Mathurapur-II, Joynagar-I, Joynagar-II, Canning-I, Canning-II, Basanti, and Gosaba-fall within the ecologically sensitive Indian Sundarbans, delineated by the Dampier-Hodges Line, which marks the northernmost limit of tidal fluctuations (Bhattacharya, 1999). Situated in a funnel-shaped bay head on India's eastern seaboard, the district occupies a unique geographical position (World Bank, 2015).

South 24-Parganas hosts approximately 1,600 square kilometres of the fragile Indian Sundarbans Biosphere Reserve (SBR) and 2,600 square kilometres of the Indian Sundarbans Tiger Reserve (World Bank, 2015) With a population density of 819 persons per square kilometre-significantly higher than the global average of 62 persons per square kilometre-the district is one of the most densely populated regions in India. The elevation of the district ranges from 1 meter in the active southern delta to a maximum of 5 meters above mean sea level in the northern, more mature delta areas (Akter et al., 2016).

The southern part of the district is crisscrossed by a network of rivers and tidal creeks, forming a labyrinth of islands. Major distributaries in this region include the Bidyadhari, Matla, Raimangal, Saptamukhi, Bartala, Haribhanga, Thakuran, Mridanga Bhanga, Gosaba, and Hooghly rivers (Office of DM, Govt. of West Bengal, 2021). Sea tides feed these distributaries, creating a dynamic deltaic system that floods twice daily, with tidal incursions extending over 100 kilometres inland (Dhara et al., 2016).

3.2.2 Study Area

The present study was conducted in five coastal blocks within South 24-Parganas district (Figure 3.1). All these blocks have riverine boundaries, making them highly vulnerable to tidal surges and floods. Their proximity to the sea exposes them to frequent low-pressure weather systems, ranging from depressions to severe cyclonic storms. Additionally, these blocks are located at distances of 78–110 kilometres from the state capital, Kolkata, and lack direct connectivity through modern transport infrastructure. Access to these blocks requires multi-modal transportation systems, including roads, train networks, and ferry services. For instance, Sagar Island is accessible only via riverine routes.

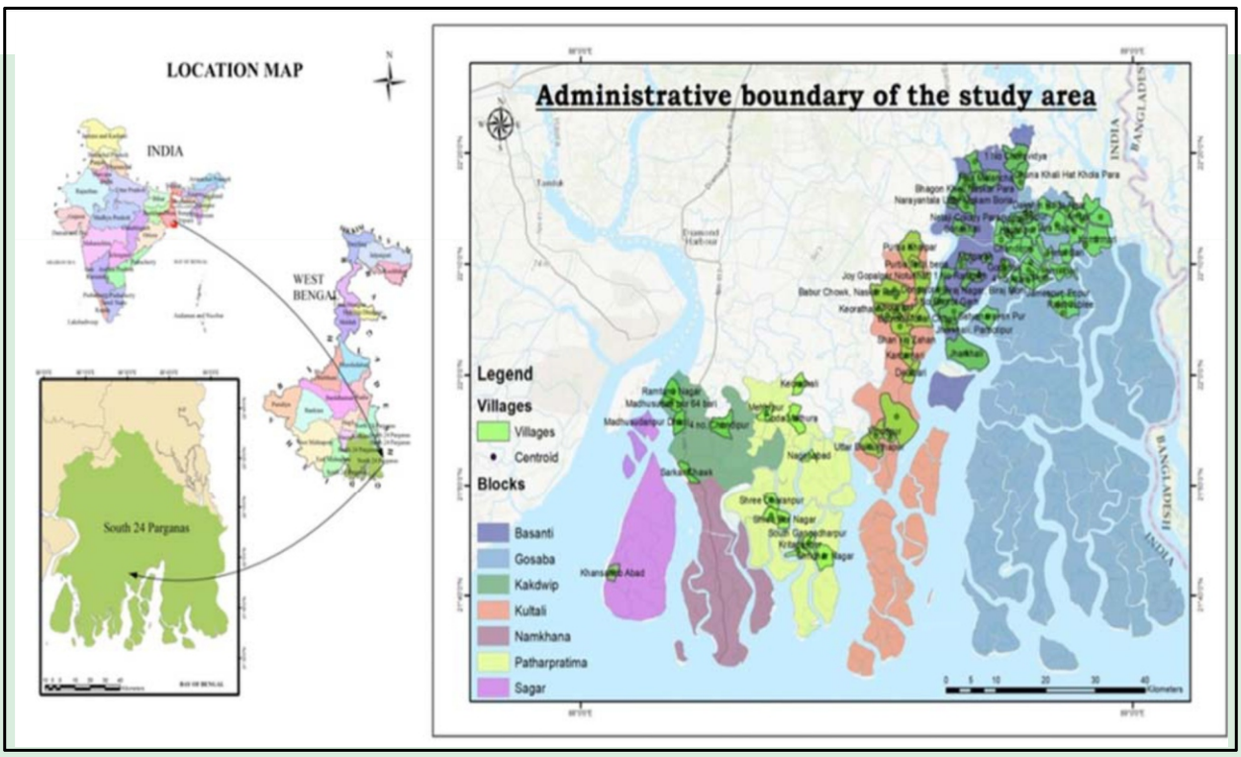

Figure 3.1: South 24 Parganas district coastal blocks Source - Author composition

3.3 Methodological Framework

3.3.1 Context

Defining and evaluating situational criteria for indicators is essential to understanding and addressing the demographic and socioeconomic backwardness of the deltaic region. A participatory approach, combined with field investigations and a thorough literature survey, offers a robust framework for developing methodologies and selecting relevant indicators. The vulnerability of an area is influenced by its geographical location, environmental deficiencies, and the level of economic and social development. Regions that are underdeveloped, heavily reliant on conventional resources, and lacking resilient systems are inherently more vulnerable (Cutter et al., 2003; Birkmann, 2006).

This study employed a two-pronged approach, consisting of a desktop literature review and a field-based reconnaissance survey. The desktop review provided an understanding of vulnerability concepts and global perspectives. A preliminary review of research literature, media reports, and consultations with domain experts, coupled with pilot site visits conducted during November–December 2018, informed the selection of parameters for conceptualizing vulnerability at the block level. These parameters were further refined to include weighted elements of physical exposure, household characteristics, and literacy levels, which are inherent capacities that enhance communities' ability to cope with hazards (Wisner et al., 2004).

Figure 3.2: a) Mud house with thatched roof; b) Mud walls with tile roof supported by stilts

Figure 3.3: c) Fish cultivation is an important source of livelihood; d) Paddy cultivation is a leading source of livelihood

Figure 3.4: e) Fishing trawlers that set out to the Bay of Bengal; f) Commuters also include domestic animals

Figure 3.5: g) Weak structural condition of the jetties drawing urgent attention for repair;
h) Local ferry service and jetties maintained by local authorities

Figure 3.6: i) Water transport managed by the State Government; j) Unmetalled and metalled roads

Figure 3.7: k) Betel leaf farming; l) Timber collection

Figure 3.8: m) Jute sticks used in white coal briquettes-an alternate source of energy;
n) Multi-faceted cyclone shelter to save lives during a cyclone.

Figure 3.9: o) Computer training centre to expand awareness and keep up-to-date with state-of-the-art technology;
p) Daily commuters availing ferry service braving every risk.

Literature Review and Pilot Survey

The literature review facilitated the development of a macro-level understanding of vulnerability, highlighting international methodologies and frameworks such as the Hyogo Framework for Action (HFA) and the Sendai Framework for Disaster Risk Reduction (SFDRR). Pilot surveys provided insights into block-level conditions and exposed the varying degrees of hazard exposure across the region. Discussions with domain experts informed the assignment of weights to the selected parameters, reflecting collective wisdom and field observations. This process led to the creation of block-wise hazard maps, which revealed that blocks adjoining the Bay of Bengal exhibited higher vulnerabilities. Over 50% of the district's blocks were identified as highly exposed to multiple hazards, underscoring the need for targeted interventions (Birkmann, 2007; Wisner et al., 2012).

Granular Analysis and Composite Vulnerability Index

While block-level analysis provided a broad understanding of vulnerabilities, it lacked actionable insights for disaster risk reduction at the village level. Consequently, this study adopts a more granular approach, focusing on six coastal blocks within the multi-hazard-prone district of South 24-Parganas. A Composite Vulnerability Index (CVI) was developed to assess vulnerabilities at both village and block levels. This index integrates multiple indices tailored to meet specific objectives across spatial scales. The CVI approach considers the dynamic nature of vulnerability and emphasizes the need for geographically precise analyses to enable planners and policymakers to prioritize interventions effectively (Gall, 2007; Adger, 2006).

Evaluation Framework

The methodology outlined in this study provides a systematic framework to evaluate the backwardness of demographic and socioeconomic dimensions at the micro-level. Village-level analysis is particularly valuable for identifying the most vulnerable areas, thereby supporting evidence-based planning and resource allocation. By fostering mutual interest at smaller geographical units, the study aims to improve the prioritization of indicators and promote actionable plans for vulnerability reduction (Birkmann, 2006; Adger, 2006).

3.3.2 Selection of the Parameters

Disasters consist of three primary components: hazards, vulnerabilities, and capacities. All the blocks in the study area have riverine boundaries and are part of the Ganga Deltaic System, which increases their exposure to natural hazards. Their proximity to the Bay of Bengal subjects them to low-pressure weather systems, ranging from deep depressions to severe cyclonic storms. The low elevation and gentle slopes of the terrain allow floodwaters to stagnate, rendering the blocks particularly vulnerable to tidal inflows from the sea. Over the past decade, the region has consistently suffered damages from flooding, high wind speeds, and cyclonic storms (UNISDR, 2005; Akter et al., 2016).

These factors comprise two essential elements of the hazard exposure dimension of vulnerability: the physical profile and the hazard profile. The vulnerabilities of communities residing in hazard-prone areas are often the result of systemic weaknesses, while their capacities derive from systemic strengths.

In this study, community vulnerabilities are conceptualized through demographic factors such as age, gender, nutrition, and education, as well as available capacities like access to healthcare, all-weather roads, temporary shelters, hazard awareness, warning systems, and housing. Vulnerabilities and capacities vary widely across socio-cultural contexts. For instance, gender-based vulnerabilities often place women at a greater disadvantage during hazardous events, and age-related vulnerabilities leave the elderly more susceptible to adverse impacts due to physical and mental impairments (Wisner et al.,

2004). Conversely, financial resources, alternate employment opportunities, good health, and adequate nutrition represent capacities that mitigate vulnerabilities.

Critical infrastructure, such as temporary shelters, healthcare facilities, educational institutions, government assistance programs, and aid from non-governmental organizations (NGOs), plays a pivotal role in reducing vulnerabilities. Additionally, effective disaster risk reduction (DRR) mechanisms—such as community awareness programs, participatory approaches, and technological advances for early hazard warnings—are key to fostering capacity building (Cutter et al., 2003; Wisner et al., 2012).

The parameters for this study were selected with guidance from the Sustainable Development Goals (SDGs) and the Global Indicator Framework (GIF), both of which are designed to assess global progress toward achieving resilience and sustainability goals. These parameters are deeply informed by international milestones in disaster risk reduction, starting with the International Decade for Natural Disaster Reduction (IDNDR) (1990–2000), the Millennium Development Goals (MDGs) (2000-2015), the Hyogo Framework for Action for DRR (HFA) (2005–2015), the Sendai Framework for Disaster Risk Reduction (SFDRR) (2015-2030) and the 2030 Agenda for Sustainable Development (UN General Assembly, 2015).

The 2030 Agenda for Sustainable Development encompasses 17 SDGs and 169 targets, which aim to "shift the world onto a sustainable and resilient path" while ensuring that "no one is left behind." Issues such as poverty, gender and age inequities, lack of access to basic services, and inadequate nutrition are critical components of the SDG targets. In July 2017, the Global Indicator Framework (GIF) was adopted by the UN General Assembly to compile statistical performance indicators aligned with the SDGs. For this study, the GIF was instrumental in guiding the selection of parameters, given the region's vulnerabilities and significant hazard exposure (UN, 2017).

3.3.3 Selected Parameters

The author identified twelve broad parameters through questionnaire surveys and a literature review to develop the Composite Vulnerability Index (CVI) at both the village and block levels in the study area (Figure 3.10). As previously discussed, the development of the CVI also drew on the Sustainable Development Goals (SDGs) to create a comprehensive list of parameters and sub-parameters (Table 3.1).

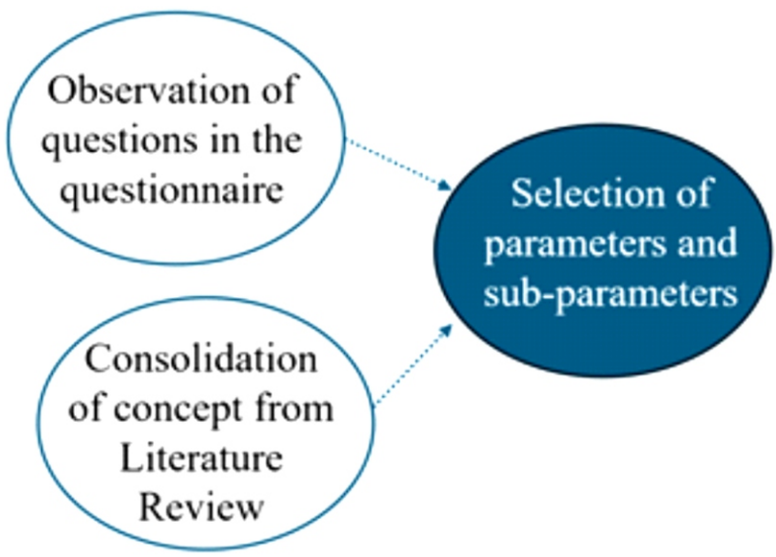

Figure 3.10: Selection of Parameters

Table 3.1: List of Parameters and Sub-Parameters

Sl.	Parameter	Sub-parameters			
1	Physical Profile	Elevation (LP DAAC, n.d)	Slope (Ramesh et. Al., 2020)	Wind Speed (TRMM., n.d.)	Precipitation (TRMM., n.d.)
2	Hazard Profile	Earthquake (Asc., 2024; Wbdmd., 2020)	Flood (BMTPC, 2019; NDMA, 2008)	Cyclone (NDMA, 2008)	
3	Household Nutrition	Age (Sameer, 2021; PAHO, 2012))	Gender (Commission, 2007' Moh et. al., 2017)	BMI (Kubala, 2021)	Number of family members (GOI, 2011, Takeda et. al., 2004)
4	Health Services and Infrastructure	Condition of Health Care System (Source: Survey)	Proximity of hospital (Nicholl et. Al., 2007)	Number of Doctors present (Public Health, WB n.d.)	Number of assistant workers present (ATIWB, n.d.)
5	Education and Vocation	Number of literate family members (Kampelmann et. al., 2018)	Vocational training to earn from other sources (Gradingstates, 2014)	Completion rate of education (Lebedinski et. Al., 2014; Berger & Fisher, 2013; Frankenberg., 2013)	
6	Education Infrastructure	Proximity of schools (TOI, 2020; PTI, 2022)	Condition of schools (Chouhan et. al., 2022)		
7	Family Financial Condition	Per Capita Income (DISD, n.d.)	Families with one source of income	Amount of Loan (UNCTAD, n.d.)	
8	Employment	Status of employment (Samhsa, 2017)	Agriculture and fisheries-based Livelihood (Burley, 2020)	Member of Self-Help Group (Swain et. Al., 2010)	
9	Disaster Risk Reduction Actions	Awareness	Temporary shelter	Proximity of temporary shelter	Experience of floods and cyclones
		Warning messages received through mobile, etc. (Cowan et. al., 2014)	Shelter provided during last flood/cyclone event (Xu et. al., 2006)	Flood, cyclone damages to dwelling unit	Ability to rebuild
		Willingness to stay back despite adversities (Land & Hummel, 2013)	Knowledge about local NGOs (Oneindia, n.d.)	Number of NGOs working in the village/block (Oneindia, n.d.)	Whether receiving help from an NGO (Oneindia, n.d.)
10	Shelter	Building material of house (Jain, 2015)	Condition of the house (Mathew, 2024)	Damaged by any disaster (Nikkanen et. al, 2021)	
11	Access to basic services	Access to safe drinking water	Power supply	Condition of the road	
12	Government Assistance	Government assistance in cash or kind or both (Morduch et. al., 2002)	Existence of any development schemes (Donner & Rodriguez, 2011)	Awareness about government policies (Donner & Rodriguez, 2011)	Whether employed under MGNREGA
	Whether taking the help of any government policy				

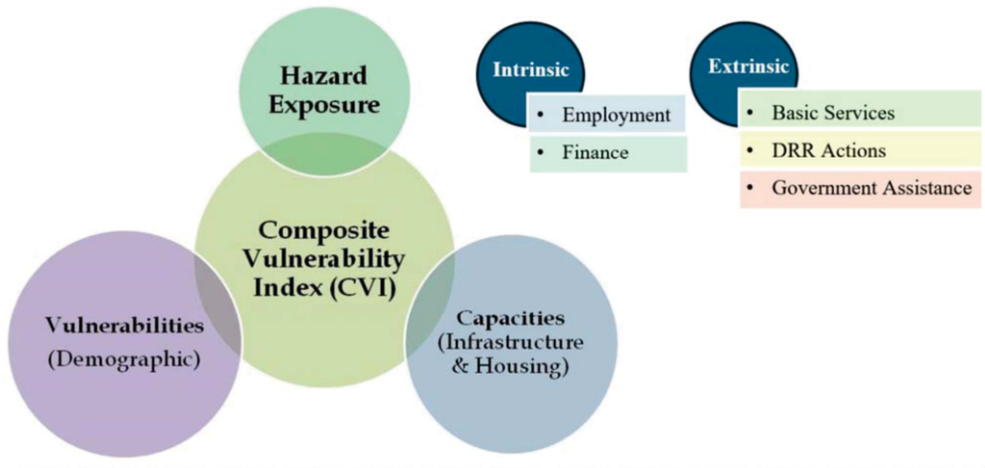

Figure 3.11: Conceptual Framework

The CVI integrates twelve broad parameters and forty-nine sub-parameters, with scores ranging from 0 (indicating the lowest vulnerability) to 1 (indicating the highest vulnerability). A two-stage expert opinion-based Analytic Hierarchy Process (AHP) was employed to assign weights to the parameters and sub-parameters. The CVI tool was applied at the village level in the study area, where questionnaire surveys were conducted with 253 respondents across 74 villages in five blocks. Scores were assigned for each sub-parameter, and the most economically marginalized communities were prioritized based on their evaluated vulnerabilities across spatial scales (Table 3.2).

Table 3.2: Composite Vulnerability Index (CVI) in the Blocks

Blocks	CVI
Basanti	0.898
Gosaba	0.876
Kakdwip	0.822
Kultali	0.904
Pathar Pratima	0.771

3.4 Findings and Discussion

All the blocks were found to have high levels of vulnerability, as expected. However, the contributing factors to these CVIs varied across the different blocks. It is evident that all the blocks studied exhibit significant vulnerability, with the Composite Vulnerability Index (CVI) ranging from 0.772 (least vulnerable) in Pathar Pratima to 0.904 (most vulnerable) in Kultoli, where the CVI scale ranges from 0 (indicating least vulnerability) to 1 (indicating highest vulnerability).

A careful examination of the different contributing sub-indices in Table 3.3, graphically represented in Figures 3.4 to 3.8, and spatially depicted in Figure 3.9, provides valuable insights into systemic weaknesses that can be addressed to reduce overall vulnerability.

Table 3.3: Contributing Sub-indices to the Composite Vulnerability Index

Village		Basanti	Gosaba	Kakdwip	Kultoli	Pathar Pratima
Physical Profile	(P1)	0.101	0.099	0.088	0.099	0.106
Hazard Profile	(P2)	0.078	0.08	0.075	0.08	0.076
Household Nutrition	(P3)	0.004	0.004	0.005	0.005	0.004
Health Services and Infrastructure	(P4)	0.053	0.053	0.054	0.053	0.041
Education and Vocation	(P5)	0.037	0.042	0.037	0.038	0.036
Education Infrastructure	(P6)	0.025	0.018	0.02	0.024	0.018
Family Financial Condition	(P7)	0.067	0.06	0.051	0.057	0.053
Employment	(P8)	0.059	0.064	0.069	0.064	0.032
Disaster Risk Reduction Actions	(P9)	0.079	0.079	0.068	0.079	0.072
Shelter	(P10)	0.12	0.108	0.105	0.119	0.101
Access to basic services	(P11)	0.233	0.215	0.205	0.223	0.19
Government Assistance	(P12)	0.041	0.054	0.044	0.063	0.042
Composite Vulnerability Index		**0.898**	**0.876**	**0.822**	**0.904**	**0.771**

3.4.1 Kultali

Eighteen villages were surveyed in the Kultali Block through respondent surveys and observations. Kultali is the block with the highest vulnerability (0.904), where the parameters **Access to Basic Services and Shelter** have been the main contributing factors to the block's vulnerability. Four out of the eighteen surveyed villages did not have access to safe drinking water. The unavailability of safe piped water and poor road conditions significantly contribute to the high vulnerability. The supply of electrical power to all the villages does not significantly lower the index for the **Access to Basic Services** parameter. The villages of Uttar Boikunthapur, Bamon Mollar Chowk, 3 No. Jala Beria, Paschim Mal Barh, Purba Khalpar, Keorathali, Kholartori, 36 Number, Mandaler Lat, and Dongajora are in the most vulnerable position regarding the supply of safe drinking water. The road conditions in Uttar Boikunthapur, Nagenabad, Vinodpur, 1 No. Madhusudanpur, Deulbari, Bamon Mollar Chowk, Paschim Mal Barh, Purba Khalpar, and Meriganj need improvement.

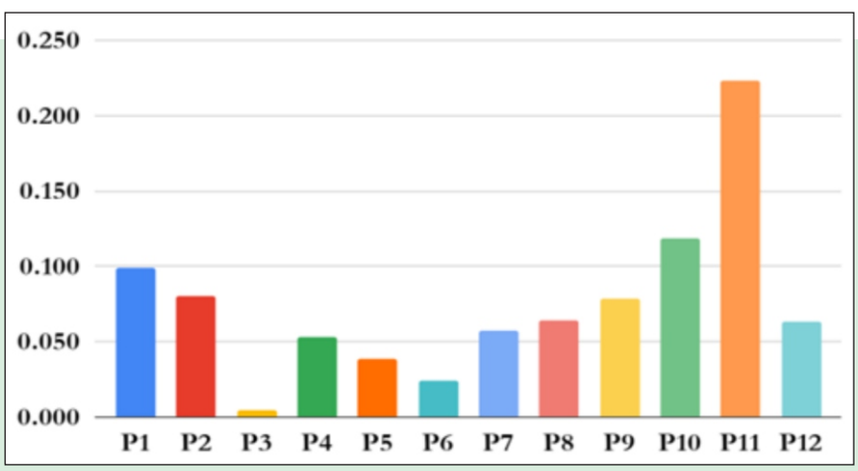

Figure 3.12: Different contributing sub-indices for Kultali

In Kultali, the vulnerability arising from Parameter 10 (Shelter) is due to the presence of temporary construction materials, the sub-optimal condition of the dwellings, and a history of past damage from natural disasters. The use of temporary materials such as mud and thatch has contributed to higher

vulnerability for all the villages in this block. None of the residents reported their houses to be in good condition, which is a telling confirmation of the dwellings' vulnerability. Only 2 of the 18 surveyed villages had no instances of natural disaster-induced damage to houses; the rest had experienced damage from natural disasters. The respondents stated that they did not have the ability to rebuild damages caused to their dwelling units. Despite the losses incurred in past disaster events, none of the respondents expressed a willingness to relocate to less vulnerable locations.

In Kultali, although the number of physicians is adequate, the greater distance from healthcare facilities and fewer paramedical staff have increased the Health Service Index (HSI) value, indicating greater vulnerability. Improving the HSI would reduce the CVI of the block. Remedial actions in this regard could include increasing the number of paramedical staff in the short term and expanding healthcare facilities in the long term. Thus, the CVI and its contributing sub-parameter indices can guide vulnerability reduction in communities in a prioritized manner. Within Kultali, the villages of Nagenabad, Deulbari, Bamon Mollar Chowk, Meriganj, Vinodpur, Keorathali, Dongajora, and Shan ki Jahan have vulnerability scores above 0.9.

3.4.2 Basanti

The researcher carried out respondent surveys and recorded observations in fifteen villages of the Basanti block. Basanti recorded the second-highest CVI (0.898), closely following Kultali. The Parameter Indices for Access to Basic Services, Shelter, and Physical Profile contribute the most to the CVI. Like Kultali, Basanti also exhibits a similar pattern in the sub-parameters constituting access to basic services, with piped water supply being the most significant component of this index. Three out of the fifteen surveyed villages did not have access to safe drinking water. The unavailability of safe drinking water and poor road conditions significantly contribute to the high vulnerability value of this parameter. Here too, the power supply condition is better but does not significantly contribute to reducing vulnerability. The power supply in all the villages does not significantly lower the vulnerability of the Access to Basic Services parameter. The villages in Basanti that require improvement in their drinking water supply to make it safe are Chunakhali Hatkhola, Phul Malancha, and 7 No. Choravidya. The road conditions in Basanti were found to be comparatively better than those in the villages of Kultali.

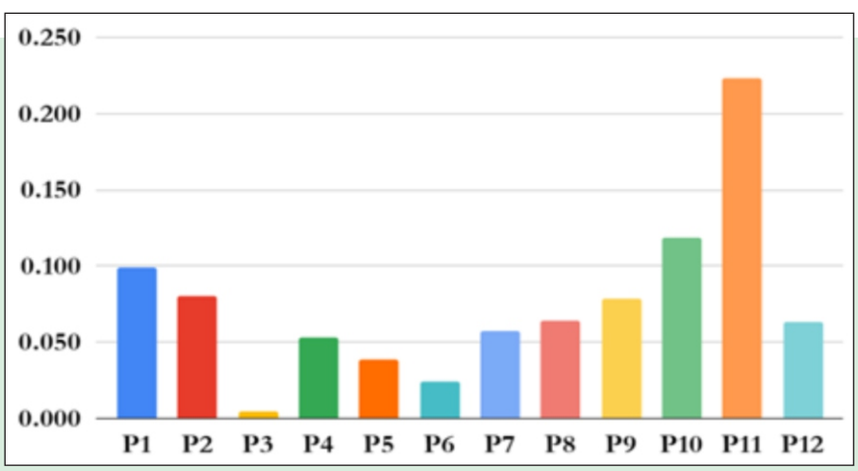

Figure 3.13: Different contributing sub-indices for Basanti

Eleven out of the fifteen villages are highly vulnerable due to the use of temporary materials in dwellings. Residents from four of the fifteen surveyed villages reported below-average conditions of their houses, reflecting their vulnerability to impending disasters. Except for four villages, residents of

all the others have suffered damage from disasters in the past. The livelihoods of all the villages, except for one, rely on a single source of income, rendering them highly vulnerable and significantly increasing the family financial condition index value.

3.4.3 Gosaba

Twenty-six villages were surveyed in Gosaba through respondent surveys and observations. This block yielded a Composite Vulnerability Index (CVI) value of 0.876, making it the third most vulnerable block after Kultali and Basanti. The major contributors to the CVI of Gosaba are the Access to Basic Services Index, the Shelter Index, and the Physical Profile Index.

Twelve out of twenty-six villages in Gosaba (Hetal Bari, Choto Molla Khali, Dakshin Radhanagar, Tara Nagar, Thakur Tola, 2 No. Emli Bari, Rajat Jubilee, Jamespur-Enpur, Kumirmari, Paschim Kumirmari, Chandiron, Amtali) lack a supply of tap water, which is a significant problem in this block as it heavily impacts the Access to Basic Services Index. The villages of Biraj Nagar, Biraj Moni, Kamakhyapur, Palpur, Harishpur, Bottoli, 4 No. Aram Pur, Gosaba, Purba Aram Pur, Hetal Bari, Choto Molla Khali, Thakur Tola, and 2 No. Emli Bari are in urgent need of health centres closer to households, along with a greater requirement for paramedical staff.

In the Shelter Index, the damage to houses has a slightly greater influence on the overall index, closely followed by the impact of building materials. A remarkably high number of villages (20) have suffered damage to their houses from past disaster events, making this the highest contributor to the Shelter Index. The use of temporary construction materials in 14 villages has contributed to the increased vulnerability associated with this sub-parameter across all villages.

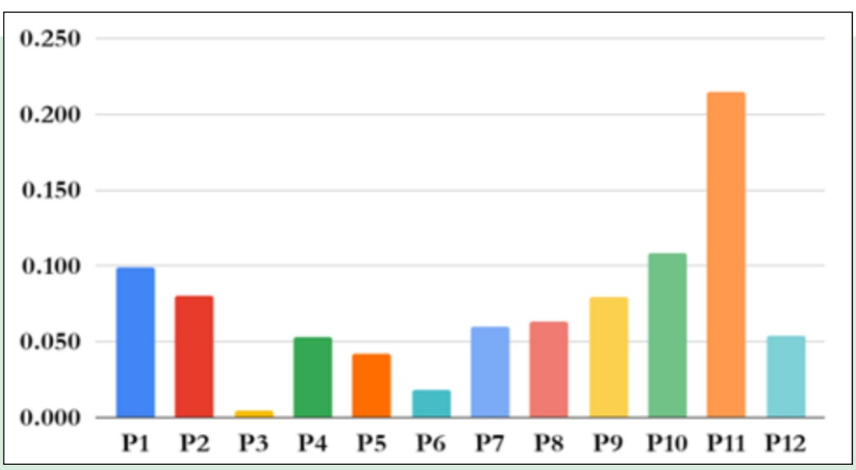

Figure 3.14: Different contributing sub-indices for Gosaba

All villages in Gosaba have access to temporary shelters; however, the distances to these shelters vary, with twelve villages located more than 4 kilometres away. This results in a poor provision of shelters during a disaster, thereby increasing the vulnerability value of this sub-parameter.

All the villages have experienced damage to their houses from past disasters, and except for two villages, none of the others have the capacity to rebuild. Although the respondents face significant dangers from their surroundings, they are keen to remain in their places of residence.

The residents of Gosaba rely on a single source of livelihood and are not members of self-help groups that could supplement their income through diversified sources, which could have reduced their vulnerability.

The condition of the healthcare system in Gosaba varies, with the villages of Gosaba and Purba Arampur needing urgent attention. The availability of doctors in Gosaba is concerning, particularly due to the lower number of doctors present in Biraj Nagar, Biraj Moni, 4 No. Chondipur, Manmath Nagar, Kamakhyapur, Palpur, Bottoli, Nabagopal Tetultoli, 4 No. Aram Pur, Gosaba, Purba Aram Pur, Rangabelia, Jotaram Pur, and Chandiron.

3.4.4 Kakdwip

Kakdwip, with a vulnerability score of 0.822, is the block with the next highest vulnerability. It is heavily influenced by the sub-parameters of access to basic services, shelter, physical profile, and hazard profile. The moderately influencing sub-parameters include employment, disaster risk reduction, health services, and family financial condition. The sub-parameters with low influence are government assistance, education and vocational training, education infrastructure, and household nutrition.

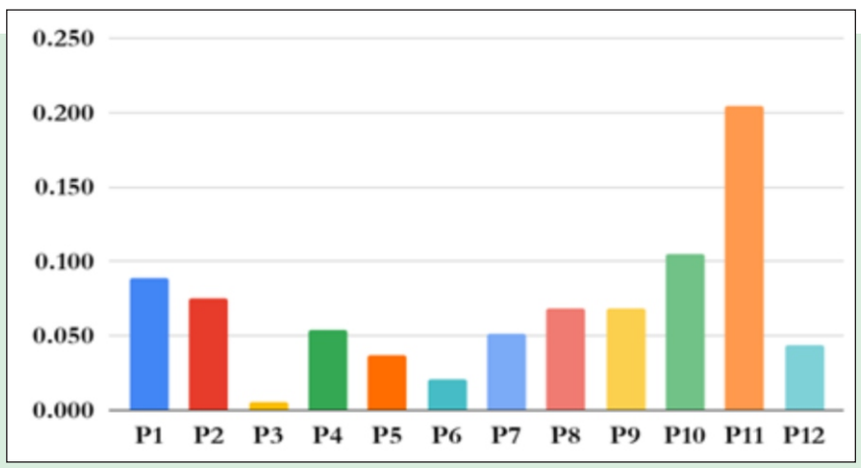

Figure 3.15:Different contributing sub-indices for Kakdwip

While there are temporary shelters in Kakdwip, their provision is not readily available during hazardous events. One reason for this may be the proximity of these shelters to the settlements and households. Most respondents reported that the shelters were located at considerable distances from their villages.

Piped water supply was low in the surveyed villages of Kakdwip, while the power supply is in a better condition compared to safe drinking water and road conditions. Dependence on livelihoods from either agriculture or fisheries makes the respondents highly vulnerable. This vulnerability is somewhat mitigated by self-help group membership, which provides a micro-finance safety net to its members. Residents of Kakdwip reported experiencing moderate damage due to natural hazards and were able to partially rebuild their homes. The value of the "Health Service" parameter in Kakdwip is influenced by the low number of paramedical staff in hospitals and the greater distance of hospitals from the dwellings.

3.4.5 Pathar Pratima

Although Pathar Pratima ranks last among the vulnerable blocks, it still has a relatively high vulnerability score of 0.771. The highest contributors to its vulnerability are Government Assistance, followed by Physical Profile and Shelter. Moderate influencers of vulnerability in this block include hazard profile, disaster risk reduction actions, and family financial conditions. Access to basic services, health services, education and vocational training, and employment are the next significant influencers of vulnerability in Pathar Pratima. Education infrastructure and household nutrition are the least contributing factors to the block's vulnerability.

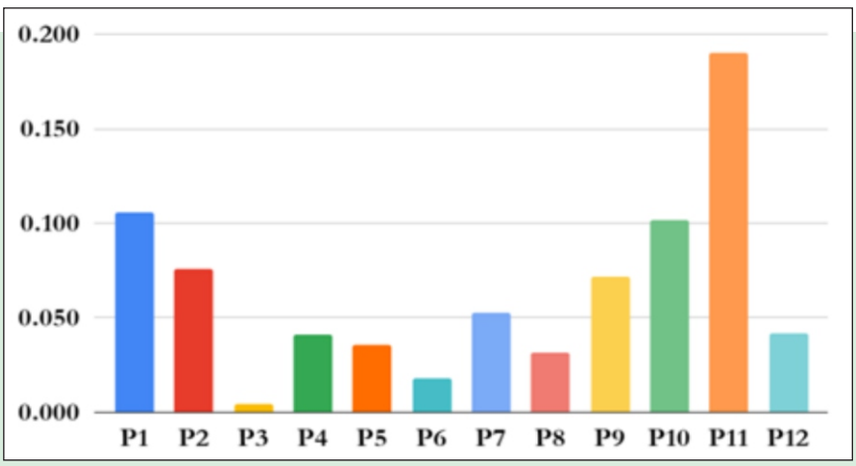

Figure 3.16: Different contributing sub-indices for Pathar Pratima

The use of temporary construction materials by residents of Pathar Pratima has significantly increased the vulnerability value of the shelter index, leading to damage in their dwelling units from past disaster events and leaving their houses in a moderate condition. The extent of the damages has been too severe for residents of Shridhar Nagar, Shree Bor Nagar, South Gangadharpur, Digambarpur, and Kritadaspur to rebuild their homes. Nevertheless, they choose to remain on their ancestral land despite the risk of these disasters. All villages in this block, except Gada Mathura, lack access to safe drinking water. The average condition of roads and better power supply have helped to lessen the block's overall vulnerability. The healthcare system is considered moderate by beneficiaries, with a good availability of doctors; however, Shridhar Nagar and Shree Bor Nagar report a lower quality of healthcare services. Vulnerability in the block has been exacerbated by the very low availability of paramedical staff in hospitals.

It is evident that all the blocks studied exhibit high levels of vulnerability, with the Composite Vulnerability Index (CVI) ranging from 0.772 (least vulnerable) in Pathar Pratima to 0.904 (most vulnerable) in Kultali, where the CVI scale ranges from 0 (indicating least vulnerability) to 1 (indicating highest vulnerability).

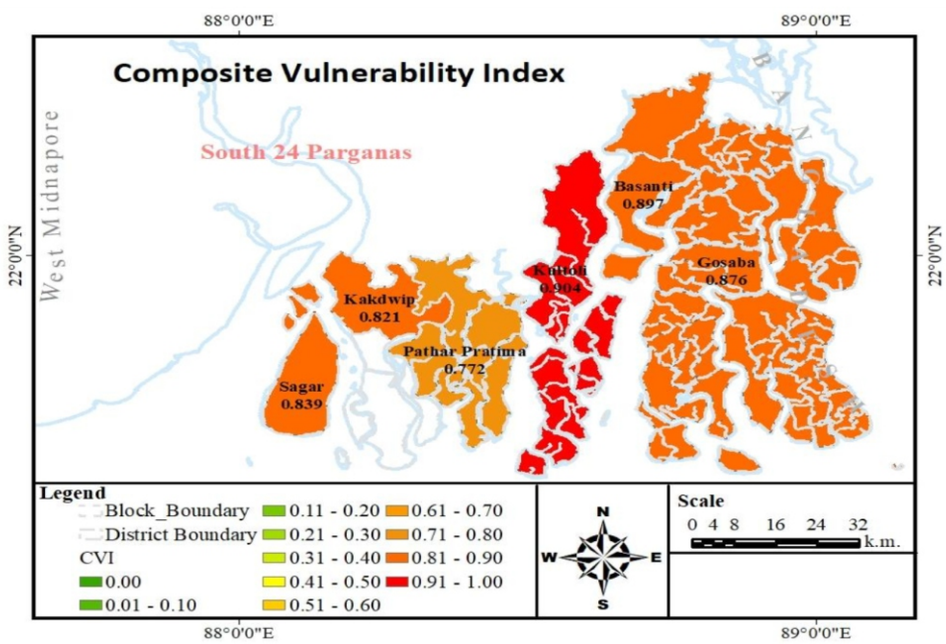

Figure 3.17: Composite Vulberability Index

3.5 Conclusion

The vulnerability of South 24-Parganas, particularly in the coastal blocks constituting the study area, is well recognized. In recent years, this region has experienced several damaging cyclones, resulting in significant losses to infrastructure and livelihoods. Disasters comprise three components: hazards, vulnerabilities, and capacities. Vulnerability assessment has emerged as a crucial domain in disaster studies, rooted in the mitigation and risk reduction paradigm that recognizes vulnerability reduction as a critical component of overall risk reduction. The vulnerabilities faced by communities residing in hazard-prone areas stem from various inherent systemic weaknesses, while capacities are grounded in the systemic strengths of these communities. Community strengths and weaknesses can be intrinsic or extrinsic, varying across socio-cultural contexts.

The authors identified twelve broad parameters from questionnaire surveys and literature reviews to develop the Composite Vulnerability Index (CVI) at both the village and block levels. The overall conceptual framework is based on the premise that a Composite Vulnerability Index is a function of a community's hazard exposure, vulnerability, and capacities. Each Parameter Index (PI) contributes to the CVI, and each Sub-parameter Index (SPI) contributes to its corresponding PI. In some villages, it was observed that the Access to Basic Services Index (ABSI) and the Shelter Index (SI) significantly elevated the CVI and the vulnerability of the communities. A further examination revealed that two SPIs under the ABSI-lack of safe potable water and poor road conditions-contributed to this vulnerability. Addressing road repairs and maintenance would serve as an actionable item for short-term vulnerability reduction. Tackling the issue of safe drinking water can have short-, medium-, and long-term implications, involving the repair of damaged pipes (short- to medium-term) and the installation of new pipes where there is currently no piped water supply.

While studies have evaluated vulnerability at the district level, South 24-Parganas has not been identified as a vulnerable district, highlighting the importance of constructing revised indices. Observing coastal communities based on equivalent parameters has led to the development of other composite socio-economic vulnerability indexes that do not explicitly consider capacities. To assess capacity building within the exposed community, questions were posed regarding available warning methods, the proximity and type of temporary shelters, and the convenience and quality of health facilities and infrastructure. Capacities have been grouped under three broad dimensions: housing and infrastructure, intrinsic capacities, and extrinsic capacities. Certain livelihoods in the Indian Sundarbans area expose people to hazards and increase their vulnerability, necessitating an enhancement of their intrinsic capacities through government employment-generating schemes.

The CVI developed in this study represents a modest step toward quantifying vulnerability in an accessible manner, using heuristic tools without resorting to complex mathematical techniques. This rationale is likely to be comprehensible to policymakers and block and district-level officials. The study's output can easily be communicated in a one-page document, which can be utilized by non-technical survey personnel to collect village-level data for calculating CVIs. This approach can serve as a beneficial foundation for interventions, providing a reasonably robust evidence-based rationale that eliminates conjecture and guesswork from decision-making and intervention strategies.

Statements and declarations

No other journal is considering publishing the content, nor has it been published and according to the writers, there isn't a conflict of interest.

3.6 Summary of Chapter

This chapter explores the vulnerability of South 24-Parganas, particularly focusing on its coastal blocks, which have been significantly impacted by recent cyclones that have caused substantial damage to infrastructure and livelihoods. It discusses the three components of disasters: hazards, vulnerabilities, and capacities, emphasizing the importance of vulnerability assessment in disaster studies. The chapter establishes that vulnerability reduction is crucial for effective risk mitigation and outlines the systemic weaknesses and strengths that contribute to community vulnerabilities.

The authors identified twelve broad parameters through questionnaire surveys and literature reviews to develop the Composite Vulnerability Index (CVI) at both village and block levels. The framework posits that the CVI is influenced by a community's hazard exposure, vulnerabilities, and capacities. Key findings indicate that the Access to Basic Services Index (ABSI) and the Shelter Index (SI) significantly contribute to the CVI, with specific SPIs-such as the lack of safe drinking water and poor road conditions-identified as major factors increasing vulnerability. The chapter suggests that addressing infrastructure issues, particularly in road repair and water supply, could provide immediate and long-term benefits in reducing vulnerability.

Furthermore, it highlights the absence of South 24-Parganas in existing district-level vulnerability studies, underscoring the need for updated indices that consider community capacities. The chapter emphasizes the necessity of assessing capacity-building measures within the community, which include the availability of warning systems, proximity to shelters, and access to healthcare facilities. It categorizes capacities into intrinsic and extrinsic factors, noting that specific livelihoods increase vulnerability and necessitate government interventions.

The CVI presented in this study serves as a user-friendly tool for quantifying vulnerability without complex mathematical methods, making it accessible to policymakers and local officials. It concludes that the study's findings can be effectively communicated in concise documents, providing a solid evidence-based foundation for decision-making and intervention strategies aimed at reducing vulnerability in South 24-Parganas.

Here are the key findings of the chapter:

1. **High Vulnerability of Coastal Blocks:** South 24-Parganas, especially its coastal blocks, exhibits significant vulnerability, having faced numerous damaging cyclones that impact infrastructure and livelihoods.
2. **Components of Disasters:** The chapter identifies three critical components of disasters: hazards, vulnerabilities, and capacities, with a particular emphasis on vulnerability assessment as essential for effective disaster risk reduction.
3. **Composite Vulnerability Index (CVI):** The authors developed a CVI using twelve broad parameters identified through surveys and literature review. The CVI is influenced by a community's hazard exposure, vulnerabilities, and capacities.
4. **Influence of Sub-parameters:** Access to Basic Services Index (ABSI) and Shelter Index (SI) significantly contribute to the CVI. Specific sub-parameters, such as lack of safe drinking water and poor road conditions, were identified as major contributors to increased vulnerability.
5. **Actionable Recommendations:** Addressing infrastructure issues, particularly road repairs and ensuring safe drinking water supply, can provide both short-term and long-term benefits in reducing community vulnerability.

6. **Need for Updated Indices:** The chapter highlights the absence of South 24-Parganas in previous district-level vulnerability studies, reinforcing the need for revised indices that incorporate community capacities.
7. **Capacity Building:** The assessment of community capacities included factors like warning systems, access to temporary shelters, and healthcare facilities. These capacities are categorized into intrinsic and extrinsic factors that influence community resilience.
8. **User-Friendly CVI:** The CVI developed in this study offers a straightforward method for quantifying vulnerability without complex mathematical techniques, making it accessible for policymakers and local officials.
9. **Communication and Decision-Making:** The study's findings can be effectively summarized in concise documents for non-technical personnel, facilitating data collection for CVI calculations and providing a strong evidence base for interventions aimed at reducing vulnerability.

These key findings collectively underscore the urgent need for targeted interventions and strategic planning to enhance community resilience in South 24-Parganas.

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4 Geo Spatial Analysis of Human-Tiger Conflict in Indian Sundarban

Rupayan Sardar, Santanu Ghosh and Tuhin Bhadra

Abstract

The Indian Sundarbans, the world's largest halophytic delta, is home to a diverse community of flora and fauna. This unique landscape hosts more than 80 species of flora and 1,300 species of fauna, including the Royal Bengal Tiger (Panthera tigris), the only tiger species supported by a mangrove ecosystem. The region provides numerous socio-economic essentials such as fuelwood, honey, wax, timber, tannin, and vascular species, which are vital for the livelihood of marginal or fringe dwellers. However, the rich resources and high yield of the mangrove ecosystem also result in widespread carnivore-based conflicts, particularly for forest-fringe communities, who face unavoidable attacks when venturing into the forest.

Inadequate freshwater availability, increasing salinity, and harsh climatic conditions have been observed to adversely affect the tiger population. These prolonged challenges and the limited availability of prey drive tigers to frequently move between forest compartments, increasing the likelihood of human-tiger encounters. At the same time, the economic incentives of honey collection, fishing, and crab hunting, coupled with a lack of alternative livelihoods, compel local communities to enter the forest repeatedly, exacerbating the conflict.

Additionally, it has been observed that after devastating cyclones and during pandemic situations, the rate of tiger attacks rises significantly. To mitigate this prolonged conflict, the people of this ecologically sensitive region require alternative livelihood opportunities and robust community development programs.

Keywords: *Human-Wildlife Conflict, Sundarban Tiger Reserve, Tiger Attack Hotspots, Livelihood and Conservation, Conflict Mitigation Strategies*

4.1 Introduction

Human-tiger conflict is an integral aspect of the livelihoods in the Indian Sundarbans region. Situated at the confluence of the Ganges, Brahmaputra, and Meghna rivers on the Bay of Bengal, the Indian Sundarbans mangrove forest is the largest mangrove ecosystem in the world, primarily consisting of halophytic plants. This ecosystem supports over 80 species of flora and 1,300 species of fauna and serves as a nursery habitat for commercially valuable fish and crustaceans (Karim, 1994). In addition to acting as a sediment-trapping pool, mangroves contribute to nutrient cycling, protect shorelines from erosion, and provide socio-economically essential products such as firewood, honey, wax, timber, and tannin (FAO; Kathiresan & Alikunhi, 2010).

The Indian Sundarbans is a complex network of tidal waterways, mudflats, and small islands covered with salt-tolerant mangroves (UNESCO, 2023). These forests play a vital role in protecting human societies from natural calamities like cyclones, tsunamis, and tidal surges (Biswas & Biswas, 2019). The region has long been inhabited by the Royal Bengal Tiger (Panthera tigris), along with other large carnivores and diverse wildlife species. However, the proximity of human settlements to the core and buffer zones of the forest has led to escalating conflicts, particularly between humans and the Royal Bengal Tiger (Chatterjee, 2023).

Covering approximately 10,000 square kilometres, the Indian Sundarbans is one of the world's most prominent hotspots for human-tiger conflict, with a population of over nine million people and more than 200 tigers (Chatterjee et al., 2022). Over the past two centuries, the forest has suffered severe

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degradation as human encroachment has extended to the interior southern islands of the Indian Sundarbans (Das, 2017). During the 19th century, the British East India Company's reclamation of the Indian Sundarbans introduced a new hazard—human-tiger conflict. As unskilled and unprotected workers ventured into the forest to clear land, they were attacked by tigers, earning the Royal Bengal Tiger the reputation of being a "man-eater" (Bacon, 1937). The panic caused by these attacks temporarily halted land reclamation efforts, allowing many cleared lands to revert to mangroves.

The boundaries of the Indian Sundarbans are defined by the Ichamati-Raimangal River to the east, the Hugli River to the west, the Bay of Bengal to the south, and the Dampier-Hodges line drawn in 1829–1830 to the north (Danda et al., 2011). The Indian Sundarbans was designated a Reserve Forest under the jurisdiction of the state forest department in 1878 and was later classified as a "Protected Forest" under the Forest Act of 1865. By 1943, the forest was reclassified as a "Protected Forest" to safeguard it from further reclamation, eventually earning its status as a "Reserved Forest" due to its unique ecosystem (Chatterjee, 2018).

The eco-specific physical environment of the Indian Sundarbans deeply influences the socio-cultural fabric of its communities, particularly the families of tiger attack victims (Chowdhury, 2014). Environmental challenges such as low rainfall, increasing salinity, and intensified cyclones exacerbate the vulnerability of the Indian Sundarbans for both human and tiger populations. Cyclonic hazards erode landforms, fragment habitat zones, and force tigers to move closer to human settlements in search of food.

The traditional worship of the forest goddess Bonbibi before entering the forest reflects the cultural practices of honey collectors and fishermen, known locally as "forest workers." These individuals have historically relied on the forest for their livelihoods, armed only with the sacred blessing of Bonbibi. However, the lack of alternative employment opportunities for marginal villagers, coupled with the lucrative nature of crab and fish hunting and honey collection, compels many to venture into the dense forest and narrow creeks. This, in turn, increases the likelihood of tiger attacks (Chatterjee et al., 2022).

This study aims to identify the tiger attack-prone forest blocks of the Sundarban Tiger Reserve and analyze the trends in tiger attacks over the past 12 years. It provides a comprehensive perspective on human-tiger conflict in the Indian Sundarbans and highlights the adaptive measures required to mitigate these conflicts effectively.

4.2 Study Area

4.2.1 Brief Description

The Indian Sundarbans Tiger Reserve, located primarily within the South 24-Parganas district and extending partially into the North 24-Parganas district of West Bengal, India, constitutes a significant portion of the Indian Sundarbans region. Situated just below the Tropic of Cancer, the reserve spans latitudes 21° 31' to 22° 31' North and longitudes 88° 10' to 89° 51' East. Established on December 23, 1973, the reserve covers an area of 2,585 km^2 out of the total 4,263 km^2 of the Indian Sundarbans (UNESCO, 1987).

In 1984, 1,330.12 km^2 of the reserve was designated as the Indian Sundarbans National Park, which was recognized as a UNESCO World Heritage Site in 1985 (UNESCO, 1987). An additional 362.33 km^2 outside the National Park was declared as the Sajnekhali Wildlife Sanctuary in 1976 and became part of the Global Network of Biosphere Reserves in 2001 (Chowdhury & Sharma, 2021).

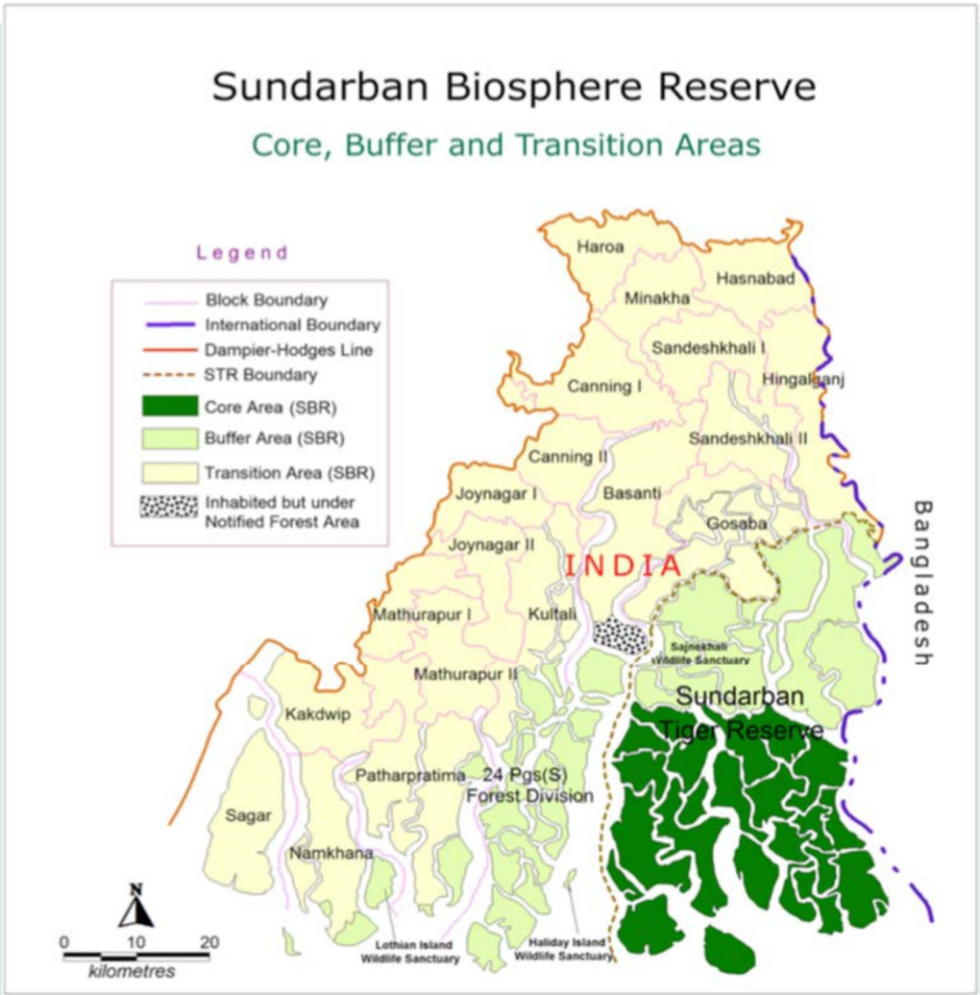

Figure 4.1: Surdanban Tiger Reserve (Ghosh et. al., 2021)

The reserve is bordered by Bangladesh to the east, the South 24 Parganas Forest Division to the west, fringe villages to the north, and the Bay of Bengal to the south. The landscape features a network of rivers, streams, and creeks, with approximately 65% landmass and 35% water bodies (WWF India, 2020). The buffer zone serves as a transitional area between the core protected zone and human settlements, regulating human activities to minimize conflicts between local communities and wildlife (Chowdhury & Sharma, 2021).

Dominated by Sundari trees *(Heritiera fomes)*, the forest provides dense cover with broad leaves and an extensive canopy, offering camouflage and shade for tigers. These forests also sustain vital prey species such as deer and wild boar, which are essential for tiger survival (WWF India, 2020).

4.2.2 Problems of the study area

The Indian Sundarbans, a vast mangrove forest located at the delta of the Ganges, Brahmaputra, and Meghna rivers, is a critical habitat for the Bengal tiger. Despite the risks posed by wildlife, particularly tigers, local communities rely on the forest for their livelihoods due to a lack of alternative employment opportunities. Residents engage in essential activities such as fishing, crab collection, honey gathering, firewood collection, and harvesting non-timber forest products like medicinal plants and fruits. Many individuals also collect shrimp and prawn seeds for the aquaculture industry, while others graze their livestock in the forest.

Although these activities provide subsistence and income in an economically marginalized region, they expose individuals to significant risks, including tiger attacks. The forest remains indispensable for the survival of these communities, underscoring the socio-economic challenges they face. This research aims to identify the vulnerable zones within the Indian Sundarbans Tiger Reserve where human-tiger conflict is most prevalent, focusing on areas with the highest rates of conflict.

4.3 Methodology

In this research, authentic datasets were collected from multiple sources. First, interviews were conducted with locals from several villages, including Parashmanipur, Satjelia, Rajatjubli, Amlamethi, Chargheri, Kumirmari, Luxbagan, Dayapur, Bali, and Rangabelia. These villages were selected because their residents frequently enter the forest for fishing and hunting to sustain their livelihoods. Engaging with the affected communities in these areas of the Indian Sundarbans provided valuable first-hand accounts of human-tiger conflicts (Chowdhury & Sharma, 2021).

Next, data were obtained from NGOs operating in the region. These organizations systematically record each tiger attack incident with detailed descriptions, making their documentation a reliable and essential source for this research. Lastly, data were collected from the Indian Sundarbans Forest Department, which was cross verified with the NGO records to ensure accuracy and consistency.

Using the primary and secondary data collected, a hotspot zonation map was prepared to identify areas with a high frequency of human-tiger conflicts. A statistical analysis of the last 12 years (2010–2022) was conducted to examine the month-wise pattern of tiger attacks in the Indian Sundarbans Tiger Reserve (STR). These insights were used to identify trends and inform mitigation strategies (WWF India, 2020).

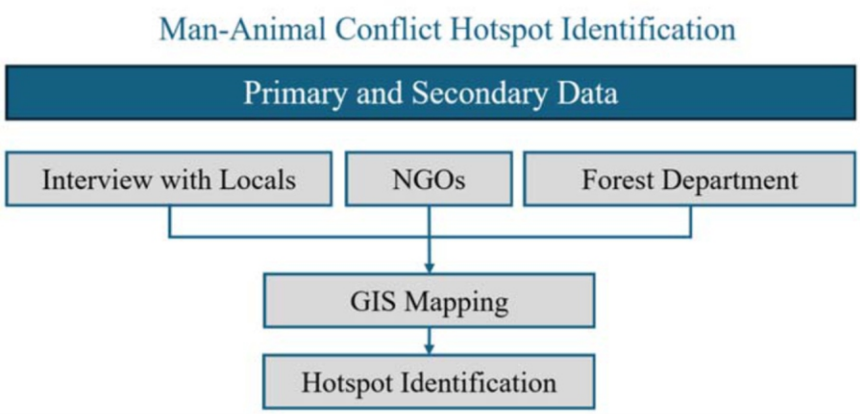

Figure 4.2: Methodology Adopted

4.4 Findings and Discussion

Data on human-tiger conflicts in the Indian Sundarbans Tiger Reserve (STR) has been collected for the period from 2010 to 2022, detailing the number of incidents in each block. Most blocks reported fewer than five conflicts over the 12-year period. However, Pirkhali and Jhila blocks each recorded more than ten incidents. The high number of conflicts in Jhila can be attributed to its location in the buffer zone, which lies adjacent to the core tiger reserve. Despite restrictions, this area has a relatively high tiger density, increasing the likelihood of encounters, particularly for individuals who rely on the forest for resources.

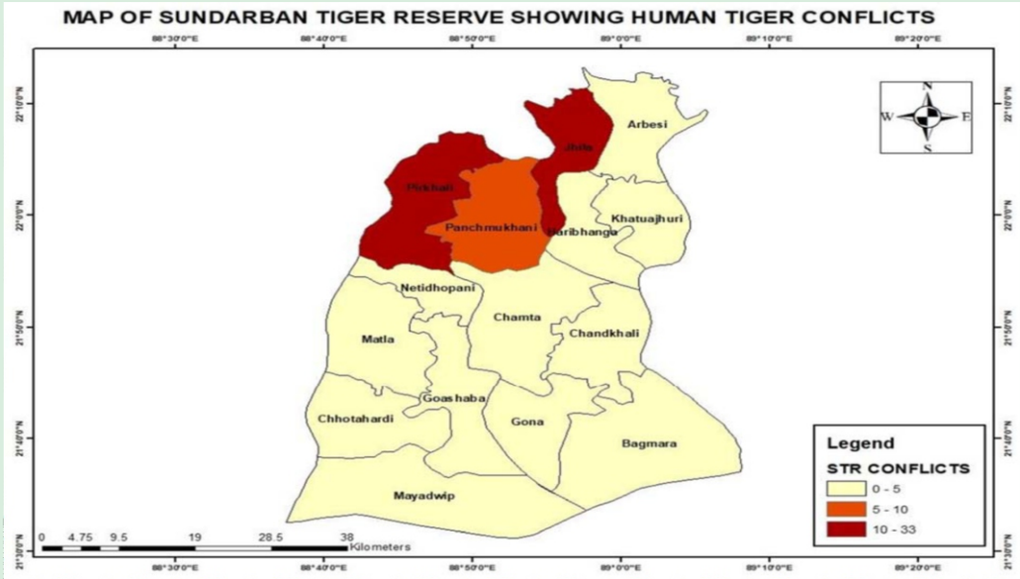

Figure 4.3: Surdarban Tiger Reserve showing Human-Tiger Conflicts

The buffer zone, including Jhila and Pirkhali, continues to experience frequent tiger activity, as tigers often venture into these areas despite existing restrictions. Seasonal scarcity of prey within the core reserve is likely a driving factor, prompting tigers to move into buffer zones such as Jhila in search of food. This movement increases the probability of human-tiger interactions, heightening the risk of conflic

4.4.1 Trends of human tiger conflict of last twelve years from 2010 to 2022

A detailed month-wise analysis of tiger attack patterns in the Indian Sundarbans is presented using a bar diagram (Table 4.1 and Figure 4.4). The data reveals that tiger attacks are not homogeneous throughout the year. Although the monsoon season experiences fewer incidents, attacks occur in almost every other month. During the post-monsoon period, favourable climatic conditions encourage more forest dwellers to enter the forest, leading to a higher frequency of attacks.

Table 4.1: Month-wise trends of human tiger conflict of last twelve years from 2010 to 2022

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
2010	0	0	1	1	1	6	4	1	0	0	0	0	14
2011	0	0	0	4	0	2	2	2	0	2	0	0	12
2012	0	2	0	2	2	0	0	2	1	1	0	1	11
2013	0	1	2	1	2	0	1	0	2	2	1	5	17
2014	1	4	0	1	0	1	1	2	0	2	2	2	16
2015	1	0	0	2	0	0	1	2	0	1	1	2	10
2016	0	2	0	0	0	1	2	0	0	4	1	0	10
2017	0	2	0	0	0	1	2	0	0	4	1	0	10
2018	0	2	0	0	0	1	2	0	0	4	1	0	10
2019	0	2	0	0	0	1	2	0	0	4	1	0	10
2020	3	1	1	4	0	5	5	2	4	3	0	5	33
2021	1	2	1	2	0	4	2	2	2	3	8	2	29
2022	6	4	2	4	4	4	0	4	4	0	2	0	34
Total	12	22	7	21	9	26	24	17	13	30	18	17	216
Average	0.9	1.7	0.5	1.6	0.7	2.0	1.8	1.3	1.0	2.3	1.4	1.3	16.6

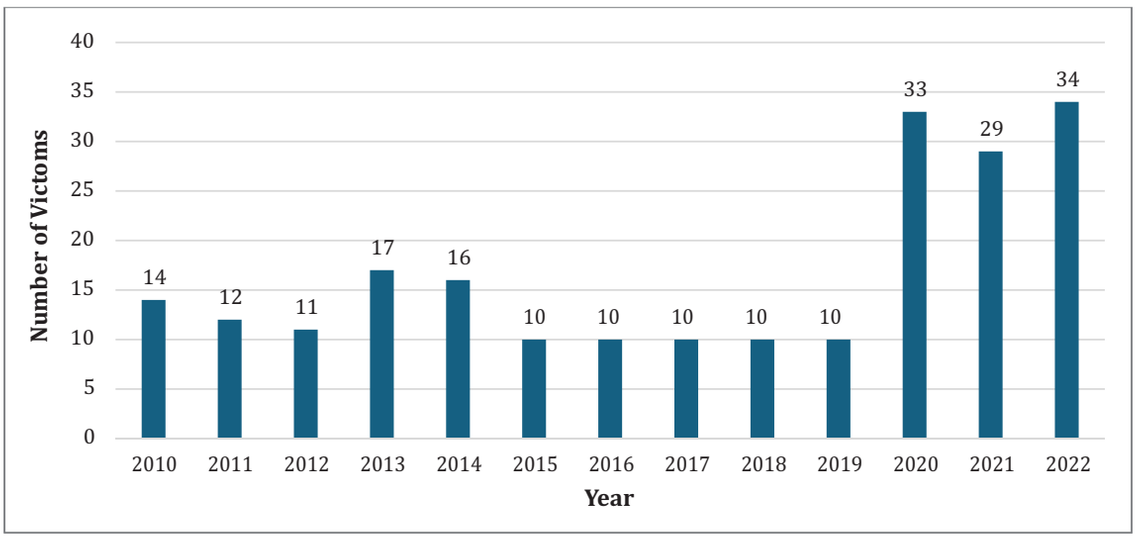

Figure 4.4: Bar diagram shows trends of human tiger conflict of last twelve years from 2010 to 2022

Year-wise data highlights a significant shift in tiger attack rates during the last three years, particularly during the COVID-19 pandemic. The pandemic's economic impact forced marginalized communities and migrant workers to depend heavily on forest resources for their survival. Many individuals, driven by unemployment and lack of income opportunities, were compelled to enter the forest for fishing, honey collection, and wood gathering, increasing the risk of tiger encounters.

The adverse conditions along forest fringes, combined with the pandemic, contributed to the spike in tiger attacks during this period. These incidents significantly impact local livelihoods, mobility, and even migration patterns. Some families, unable to cope with the risks, have been forced to migrate from the Indian Sundarbans to safer areas.

4.4.2 Major Findings

The economic impact of the pandemic forced many people to depend more heavily on forest resources for their livelihoods. As more individuals entered the forest for fishing, honey collection, and wood gathering, the likelihood of encountering tigers increased. The pandemic also disrupted regular patrolling and conservation activities due to lockdowns and restrictions. With reduced monitoring, both humans and tigers moved more freely, resulting in more conflicts. Additionally, as communities faced economic hardships, some ventured into deeper and more dangerous parts of the forest that they previously avoided, further increasing the chances of tiger encounters.

Cyclones cause extensive damage to the forest, including the destruction of mangroves and other habitats. This displacement forces tigers out of their usual territories in search of food and shelter, increasing the likelihood of encounters with humans. The natural prey of tigers is also affected by cyclones; with their habitats destroyed or disrupted, prey species become scarce, pushing tigers closer to human settlements in search of food. After a cyclone, local communities often enter the forest more frequently to gather resources such as firewood, building materials, and food to rebuild and sustain their livelihoods. This increased human activity in tiger territories raises the chances of conflict. Cyclones disrupt regular patrolling and conservation activities due to damaged infrastructure and the diversion of resources to disaster relief. This reduction in monitoring allows both humans and tigers to move more freely, leading to more conflicts. Additionally, cyclones often lead to increased salinity in the water, affecting the availability of fresh water and prey for tigers, which can force them to move closer to human habitation.

4.5 Conclusion

The conclusion of the chapter "Geo-Spatial Analysis of Human-Tiger Conflict in the Indian Sundarbans" underscores the persistent and complex nature of human-tiger conflicts in the region. The study reveals that the high dependency of local communities on forest resources, combined with environmental challenges like cyclones and habitat degradation, increases the frequency of tiger encounters. Specific areas, especially in buffer zones such as Jhila and Pirkhali, emerge as conflict hotspots due to their location near core tiger habitats.

Environmental stressors, such as rising salinity and frequent cyclones, drive tigers closer to human settlements, further intensifying these conflicts. Additionally, economic pressures and limited livelihood options compel residents to venture into the forest for resources, exposing them to greater risk. The COVID-19 pandemic exacerbated this situation by forcing more individuals to rely on the forest due to economic hardship and reduced monitoring.

The chapter concludes that while tiger conservation is essential, there must also be a focus on creating sustainable livelihoods and enhancing safety measures for local communities. Developing alternative income sources, implementing better monitoring, and educating communities on safe practices could help reduce conflicts. Ultimately, a balanced approach that prioritizes both wildlife conservation and community welfare is crucial for fostering long-term coexistence in the Indian Sundarbans.

Statements and declarations

No other journal is considering publishing the content, nor has it been published and according to the writers, there isn't a conflict of interest.

4.6 Summary of Chapter

The chapter titled "Geo-Spatial Analysis of Human-Tiger Conflict in the Indian Sundarbans" investigates the ongoing conflict between humans and Bengal tigers in the Indian Sundarbans mangrove region. The chapter identifies key factors contributing to these conflicts, such as the limited livelihood options for residents, which compel them to enter tiger habitats for resources like fish, crabs, and honey. Despite the high risks, the forest remains essential for their economic survival.

The study highlights that specific forest blocks, particularly in buffer zones like Jhila and Pirkhali, experience a higher rate of tiger attacks. Seasonal changes, the COVID-19 pandemic, and environmental events like cyclones have intensified these conflicts. Cyclones, for instance, destroy habitats and reduce prey availability, forcing tigers to move closer to human settlements.

Through geo-spatial analysis and community interviews, the study identifies tiger attack hotspots and tracks conflict trends from 2010 to 2022. Findings suggest that post-monsoon periods see an uptick in attacks due to increased forest activity by locals. The study emphasizes the need for alternative livelihoods and improved monitoring to mitigate conflicts and promote safer coexistence between humans and tigers in this unique ecosystem.

Here are the key findings of the chapter:

1. **High-Risk Forest Blocks:** Certain forest blocks in the Indian Sundarbans, particularly Jhila and Pirkhali in the buffer zones, are identified as high-risk areas for human-tiger conflicts. These blocks experience a higher rate of tiger attacks due to their proximity to core tiger habitats and the high density of tigers in these areas.
2. **Impact of Environmental Factors:** Cyclones and increased salinity disrupt tiger habitats, leading tigers to move closer to human settlements in search of food. Habitat destruction and reduced prey availability following cyclones contribute significantly to human-tiger encounters.

3. **Economic Pressures and Limited Livelihoods:** Economic necessity drives residents to enter tiger habitats to gather resources like fish, crabs, and honey. This dependency, coupled with limited local job opportunities, increases the likelihood of encounters with tigers.
4. **Seasonal and Pandemic Influence on Conflict Rates:** The frequency of tiger attacks tends to rise during post-monsoon periods when more villagers enter the forest. Additionally, the COVID-19 pandemic intensified conflicts as economic hardships forced more people to rely on forest resources, while lockdowns reduced forest monitoring.
5. **Need for Alternative Livelihoods and Conflict Mitigation:** The chapter underscores the importance of providing alternative livelihood options and enhancing community development programs to reduce dependency on forest resources. Increased monitoring, patrolling, and safety measures are recommended to mitigate human-tiger conflicts and promote safer coexistence.

These findings highlight the complex socio-economic and environmental dynamics contributing to human-tiger conflicts in the Indian Sundarbans, suggesting that holistic approaches are essential to effectively address these issues.

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5 Mangrove Degradation: Escalating Disasters and Climate Risks in the Indian Sundarbans

Garima Aggarwal, Shreyash Dwivedi, Krishnakali Ghosh, Ranit Chatterjee and Shivani Shukla

Abstract

The Indian Sundarbans are a UNESCO World Heritage Site facing increasing vulnerabilities due to climate change, disasters, and degrading mangroves. In the face of climate change and disasters, the Indian Sundarbans play an important role in protecting coastal communities and ecosystems. Various natural and anthropogenic factors threaten mangroves, despite their ecological and socioeconomic importance. Several factors, including deforestation, pollution, rising sea levels, and cyclone intensification drive mangrove degradation. The study identifies root causes and interconnections among contributing factors by analysing data and literature available through secondary sources. According to the findings, mangrove loss increases disaster vulnerability, disrupts ecosystem services, and reduces climate resilience. To mitigate these impacts and safeguard Indian Sundarbans mangrove ecosystems, sustainable conservation practices, community involvement, and policy interventions are recommended.

Keywords: *Mangrove Degradation, Climate Change, Cyclones, Indian Sundarbans ecosystem, Coastal resilience*

5.1 Introduction

The Indian Sundarbans, located at the confluence of the Ganga, Brahmaputra, and Meghna rivers, represents the largest contiguous mangrove forest globally and one of the most biodiverse ecosystems on Earth. As a natural shield against coastal hazards such as cyclones and storm surges, this UNESCO World Heritage Site spans over 10,000 square kilometers across India and Bangladesh (UNESCO, 1987). As well as endemic species such as the Royal Bengal Tiger (Panthera tigris), estuarine crocodiles (Crocodylus porosus), and Heritiera fomes, the Indian Sundarbans also harbors iconic species like the Royal Bengal Tiger (Panthera tigris) (Mukherjee et al., 2014). It also preserves ecological balance, sequesters carbon, and ensures coastal resilience, in addition to its biodiversity.

In spite of the Sundarbans' global importance, they face increasing threats from both biological and anthropogenic causes. As a result of climate change, sea level is rising, cyclones are occurring more frequently and intensely, and salinity is invading the mangrove ecosystem (DasGupta & Shaw, 2013). Moreover, the degradation of mangrove swamps exacerbates this degradation through deforestation, pollution, and the conversion of mangrove swamps to agriculture and aquaculture, further threatening the region's ecological integrity and the livelihoods of millions of people (Gopal & Chauhan, 2006; Mukherjee et al., 2014).

Mangrove degradation undermines biodiversity, increases disaster risks, and weakens climate resilience in the region. As natural buffers, mangroves absorb the energy of storm surges, reducing coastal erosion, and providing ecosystem services such as fisheries, water purification, and carbon storage (Donato et al., 2011). Nevertheless, the loss of mangroves has increased coastal communities' vulnerability to natural disasters as well as reduced the sundarbans' ability to function as a carbon sink, thus accelerating climate change (Spalding et al., 2014).

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The objective of this chapter is to examine the multidimensional threats to the Indian Sundarbans mangroves from an ecological, socio-economic, and climate perspective. Hence, it is urgently necessary to conserve and manage this valuable ecosystem to ensure its long-term preservation.

5.2 Study Area

The Indian Sundarbans, located in the Ganga-Brahmaputra delta in West Bengal, India, encompass approximately 4,263 square kilometres of mangrove forests. This district is part of the South 24 Parganas and North 24 Parganas districts of West Bengal. In this region between 21°31′N and 22°31′N and 88°10′E and 89°51′E, a complex network of tidal waterways, mudflats, and mangrove islands give way to diverse flora and fauna, including the Royal Bengal Tiger. Among the most important species are Avicennia spp., Sonneratia spp., Heritiera fames, and Rhizophora spp., which create dense canopy cover that is home to a variety of fauna and flora. Although mangroves play an important role in ecosystem services, environmental and human factors are putting increasing pressure on them. A fragile ecosystem in the Indian Sundarbans is increasingly threatened by rising sea levels, cyclones, and human activities.

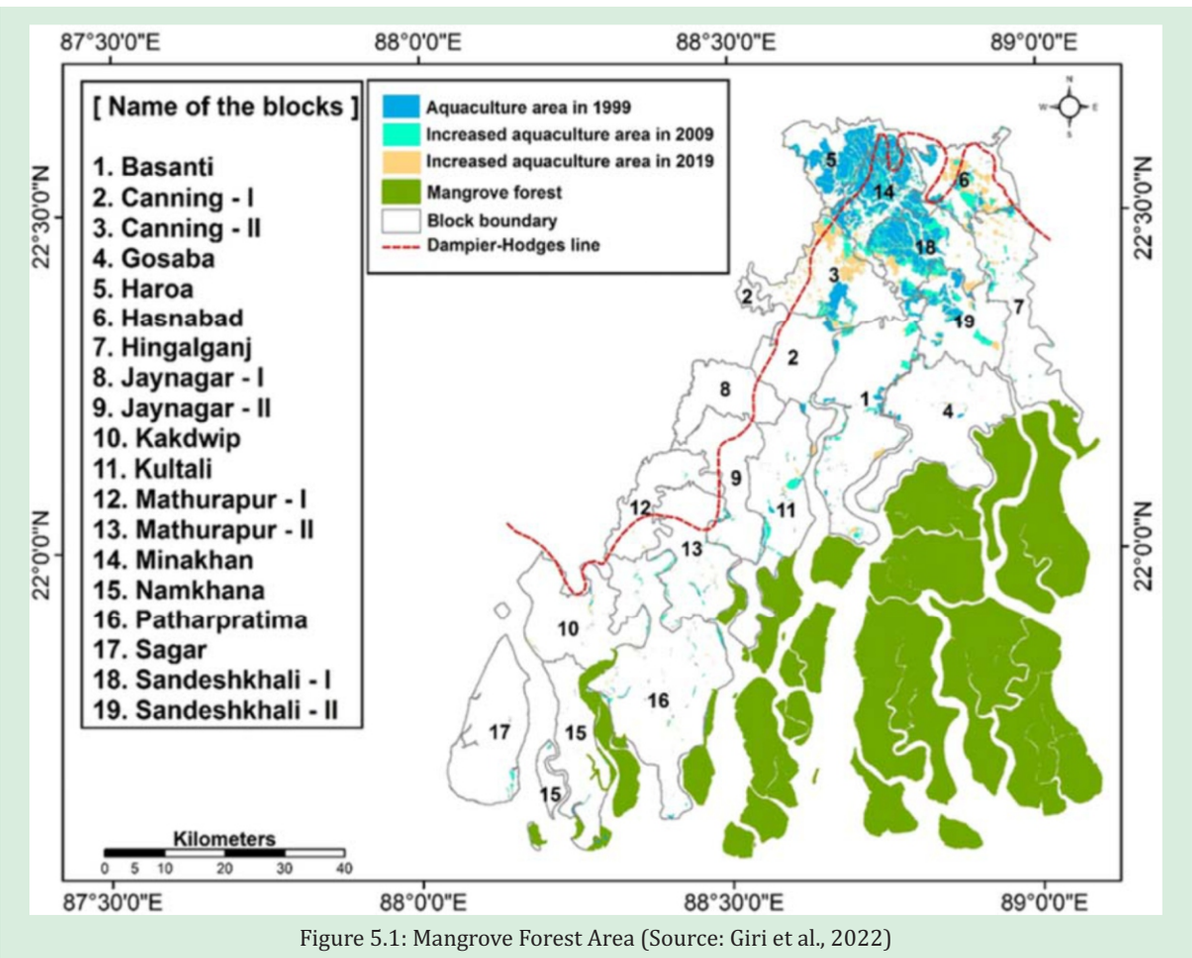

Figure 5.1: Mangrove Forest Area (Source: Giri et al., 2022)

A major component of the Indian Sundarbans is its large tidal holophytic mangrove blocks, which provide critical ecosystem services critical to biodiversity conservation and disaster risk reduction. There are several dominant mangrove species, including Herritiera fames, Rhizophora spp., Bruguiera spp., Ceriops decandra, Sonneratia spp., and Avicennia spp., while Nypa fruticans is commonly seen along waterways. A number of these species play an important role in sediment trapping, shoreline stabilization, and providing habitat for marine and terrestrial organisms.

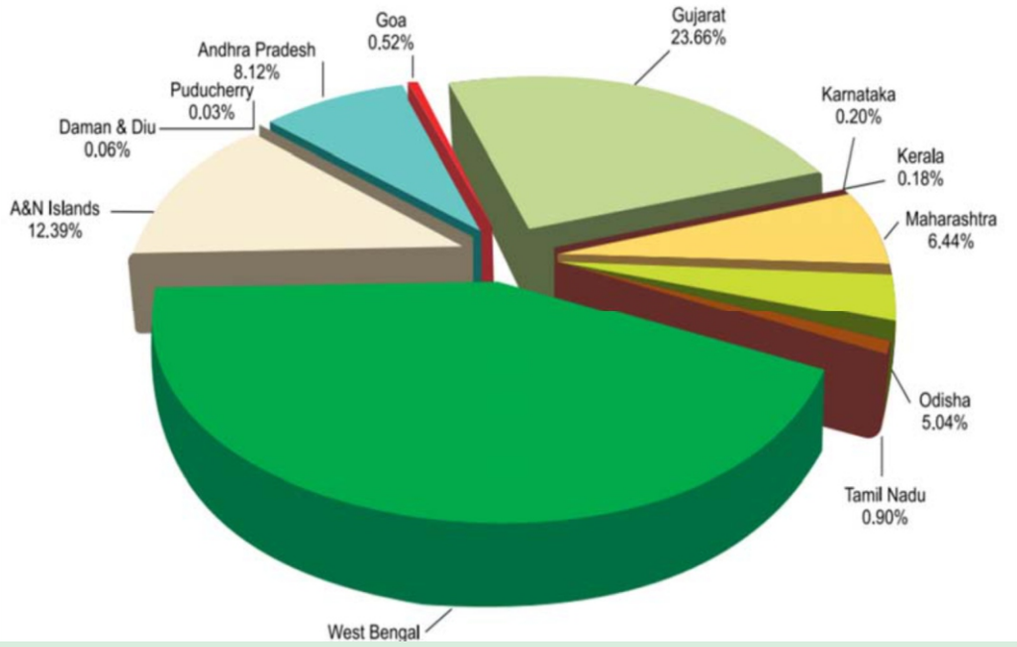

Figure 5.2: Mangrove Cover (Source: Forest Survey of India, 2019)

Furthermore, mangrove swamps provide an important habitat for iconic wildlife, such as the Royal Bengal Tiger (Panthera tigris) and estuarine crocodiles (Crocodylus porosus), emphasizing their importance for biodiversity conservation. In addition to protecting coastlines against erosion, mangrove roots also act as natural buffers, preventing tidal waves and storm surges that would otherwise cause damage to the coastline (Spalding et al., 2014). Furthermore, they provide nutrient cycling and carbon sequestration by storing substantial quantities of atmospheric carbon dioxide (Donato et al., 2011).

5.3 History of Disasters in the Indian Sundarbans

The Indian Sundarbans have been plagued by a number of natural disasters (Table 5.1) that have caused extensive destruction. There has been a significant loss of life, property, and biodiversity due to these disasters in the past. During cyclones, embankments are breached, allowing salt water to enter, disrupting agriculture and livelihoods (DasGupta & Shaw, 2013).

Table 5.1: History of Disasters in Sundarban Region

Disaster	Affected Blocks Affected	People Died	Affected Cropping Fields
Depression, Cyclone & Flood in 1950	Haroa, Hingalganj, Hasnabad, Inakhan, Sandeshkhali I & II, Kakdwip, Sagar, Patharpratima	6000 people died	2006.70 ha Paddy and 668.90 ha other Crops
Cyclone of 1953	Hasnabad, Sandeshkhali		1337.80 ha Paddy 133.78 ha other crops
Embankment Failure 1953	Haroa, Hasnabad, Canning, Kakdwip, Sagar, Mathurapur		6689.02 hectare in Haroa block 200.67 hectare of paddy in Hasnabad block 1337.80 hectare in Canning block

Disaster	Affected Blocks Affected	People Died	Affected Cropping Fields
Cyclone in 1956	Diamond Harbour, Canning, Mathurapur, Kakdwip, Sagar, Patharpratima		136 bighas of paddy fields
Storm and Cyclone of 1959	30 Mouzas of Sadar, Baduria, and Haroa block.	8 people killed & more than 100 affected	2, 00,000 bigh as
Cyclone of 1960	Sandeshkhali block	232 families became homeless	1000 bighas of land was affected by submergence into saline water. Inundation of 11 villages and 9000 bighas of agricultural lands
High Tide and Embankment Erosion of 1962	Canning block		5500 acres of land was inundated by saline water
Embankment Failure 1964	Hasnabad Block		15000-hectare agricultural land was affected.
Cyclone of 1964	Kakdwip block	Two villagers were reportedly killed and three injured by the storm	Saline water had fl ooded 40,000 hectares of agricultural field
Kalbaishakhi 1964	Sundarban coastal areas	400 houses were destroyed and four people were seriously injured	15,000 hectares of agricultural fields were submerged.
Flood of 1968	In South 24 Parganas (Canning and Gosaba) In North 24 Parganas (Barasat subdivision)	10 killed 225 injured 20,000 homeless	
Storm & High Tide in 1969	Kakdwip, Sagar, Namkhana, Patharpratima	2500 villagers homeless	
Flood of 1970	Kolkata city & Surroundings of Both 24 Parganas	Nearly 17 lakhs 42 killed	400 ha. Cropland affected
High Tide of 1970	Fraserganj, Lakshmipur, South Durganagar	1,000 people get affected	
Flood of 1971	Sundarban & Contai block of Medinipore	60000 people affected	25000 damaged houses 8 crores worth of crops get damaged
Flood of 1973	Lower Gangetic plain including the Sundarban region	3 lakhs homeless, 6 persons killed	5 lakh acres and 10,000 houses damaged

Disaster	Affected Blocks Affected	People Died	Affected Cropping Fields
Cyclone of 1974	Canning, Sandeshkhali, Basanti, Minakhan, Sagar, Namkhana Patharpratima	19 people killed	200 houses were damaged, and 4 Sq. Miles of land was inundated
Cyclone of 1976	Canning, Patharpratima, Some islands of Sundarban, Haldia Port	95,000 people were affected & 19 Killed	4 Crores worth of agricultural loss and 15 lakhs worth of other economic l oss
Cyclone of 1977	Coastal block of Sundarban, Kanthi block	17 persons died and 50 people were seriously injured.	Approximately 1000 houses were destroyed.
Flood of 1978	Basanti, Jaynagar I, Canning I & II, Gosaba, Basirhat I & II, Haroa, Minakhan, Hasn abad, Hingalganj, Sandeshkhali I & II	15.40 lakhs affected 63 killed	17,5,580 house damaged and INR 11,299,800 worth of loss
Cyclone of 1979	Kakdwip block		7000 people lost their houses
Cyclone and Flood of 1981	S 24 Parganas, N 24 Parganas,	397 people and 651 cattle were killed.	11,54,391 hectares of cropland costing Rs.8, 73, 86,100,
Cyclonic Storm of 1982	Canning Block	2 people died	300 families lost their houses
Flood of 1984	N 24 Pargana and S 24 Pargana	4425 cattle were killed	57288 ha farmland w as affected
Flood of 1986	South 24 Parganas, North 24 Parganas	9 persons reported dead	In North 24 Parganas, the affected agricultural the land was 67286 hectares, and the number of damaged houses was 40645. In South 24 Pargana, the total affected area, and the total damage agricultural lands were 2248.60 sq. km and 105411 hectares respectively
Cyclone of 1987	Haroa, Hasnabad, Hingalganj, Sandeshkhali I & II, and Minakhan block	585 people lost their lives.	10.63 lakh the population was affected, and 269 p eople lost their life in N 24 Pargana. In S 24 Pargana, 8.96 lakh population was affected and the loss of human life was 316, and that of cattle was 16,210
Cyclone of 1989	13 blocks of the Sundarban		1.86 lakh people were adversely affected.
Flood of 1990	N 24 Pargana, S 24 Pargana	41 people died and 3,870 cattle were lost.	0.035 million hectares of agricultural land were inundated, 4,454 houses damaged, and 1.6 million population was affected in North 24 Parganas. In South 24 Pargana, 0.16 million people and 0.041 million hectares of farmland

Disaster	Affected Blocks Affected	People Died	Affected Cropping Fields
Flood of 1993	South 24 Pargana	3 people died	damaged houses were 10,410, and 12,089 hectares of cropland worth Rs. 81, 75,000 lakh was destroyed.
Cyclone of 1994	Basanti, Gosaba and Canning blocks of South 24 Pargana & North 24 Parganas,	7 people died	
Embankment Loss & Flood (1996)	Sandeshkhali I & II, Hasnabad of North 24 Parganas		2,192 houses collapsed, 0.341197 million population affected, and 0.18066 million hectares of farmlands were destroyed
Flood of 1999	seven municipalities, including Sundarban was affected in the district of South 24 Parganas	7 people died	3, 13,000 people were affected, and 6,847 houses collapsed in South 24 Pargana. North 24 Parganas, 1075 sq.km of the area was inundated resulting in the collapse of 22367 houses
Flood of 2000	22 blocks of North 24 Parganas.	17 people lost their life.	The total number of damaged houses by the flood were 1, 74,580. In addition to it, 15, 5,600 hectares of cropped fields were destroyed, and about 8.16 lakhs people became homeless
Flood of 2001	Haroa, Sandeshkhali I & II, Hasnabad and Hingalganj	38400 population was affected	collapsed houses were 1331, and public infrastructure worth values Rs. 0.1722 crores were destroyed
Flood of 2004	N 24 Par gana, S 24 Pargana	6,20,958 people were affected and 14 people were reported dead	6,667.5 hectares crops worth Rs. 25, 45, 72,000 were damaged
Flood of 2005	Kultali, Mathurapur, Basanti, Gosaba, Namkhana, Kakdwip, and Patharpratima and 15 blocks of North 24 Pargana	16 people died and nearly 7 lakh people get affected.	1,11,519 hectares of agricultural land were damaged causing 16,858 lakhs worth of economic loss.
Cyclone of 2006	Mathurapur block	10 people killed	5000 kuccha houses collapsed.
Flood of 200 7	North 24 Parganas, South 24 Parganas	24,70,212 were affected and 27 people killed	1,11,136 hectares of crop were damaged.
Cyclone Aila – May 2009	North 24 Parganas, South 24 Parganas	139 people killed	affecting about 2.2 million people in the state
Flood of 2014	Sagar, Namkhana, Sandeshkhali I & II and Hingalganj.		22.90 sq km area get inundated

Disaster	Affected Blocks Affected	People Died	Affected Cropping Fields
Cyclone 'Komen' of 2015		125 people were killed and 22,716 livestock killed	12,92,372 ha crop damaged,
Cyclone Bulbul 2019	North and South 24 Parganas and e ast Medinipur	North 24 Parganas -6, South 24 Parganas -3,	No. of people affected: 4,65,000 House damaged: 60,000 No. Extensive damage to Mangrove Forest in Sundarban Delta, cultivation of flowers, vegetables, paddy crops, and pan fields in the affected districts.
Cyclone 2020 Amphan	North and South 24 Parganas	98 persons lost their lives in West Bengal	
Cyclone 2021 Yaas	North and South 24 Parganas	3 lakh houses were damaged in West Bengal	3.2 lakh people were evacuated from South 24 pargana and 1.5 lakh f rom North 24 Pargana Rs 20,000 crore worth of loss due to the cyclone.

(Source- compiled through various published sources)

5.4 Mangrove ecosystem

The mangrove ecosystem provides a wide range of ecosystem services crucial to maintaining ecological balance and supporting human livelihoods. The following are among them:

- Mangroves act as natural buffers, reducing the impact of storm surges, cyclones, and tidal waves on coastlines. The dense root systems of these plants prevent soil erosion and stabilize coastlines in the event of extreme weather events (Spalding et al., 2014).
- Mangroves are highly effective carbon sinks, storing nearly four times as much carbon per hectare as tropical rainforests. As a result of their ability to sequester carbon dioxide, they play a crucial role in combating climate change (Donato et al., 2011).
- The Indian Sundarbans mangrove ecosystem sustains a wide array of biodiversity, including the endangered Royal Bengal Tiger, estuarine crocodiles, and a wide variety of fish, crabs, and birds. Several marine species of commercial and ecological importance breed and nurse in these ecosystems (Kathiresan & Bingham, 2001).
- In addition to filtering water, mangroves also act as a natural nutrient and contaminant trap, maintaining water quality and protecting neighboring marine ecosystems such as coral reefs and seagrass beds (Alongi, 2002).
- Mangroves provide essential resources, including fuelwood, honey, and medicinal plants. Local communities benefit from fisheries and aquaculture, which sustain their livelihoods (Mukherjee et al., 2014).
- Local communities revere Bonbibi, the forest goddess, as the protector of forest workers, and mangroves hold cultural and aesthetic importance for local communities. Moreover, eco-tourism contributes to the local economy in the Indian Sundarbans due to its scenic beauty.

Despite their immense value, mangrove forests are at risk due to unsustainable exploitation and climate change. To ensure that the Indian Sundarbans continue to provide services and to enhance their resilience against climate change and disasters, it is essential to protect these ecosystems.

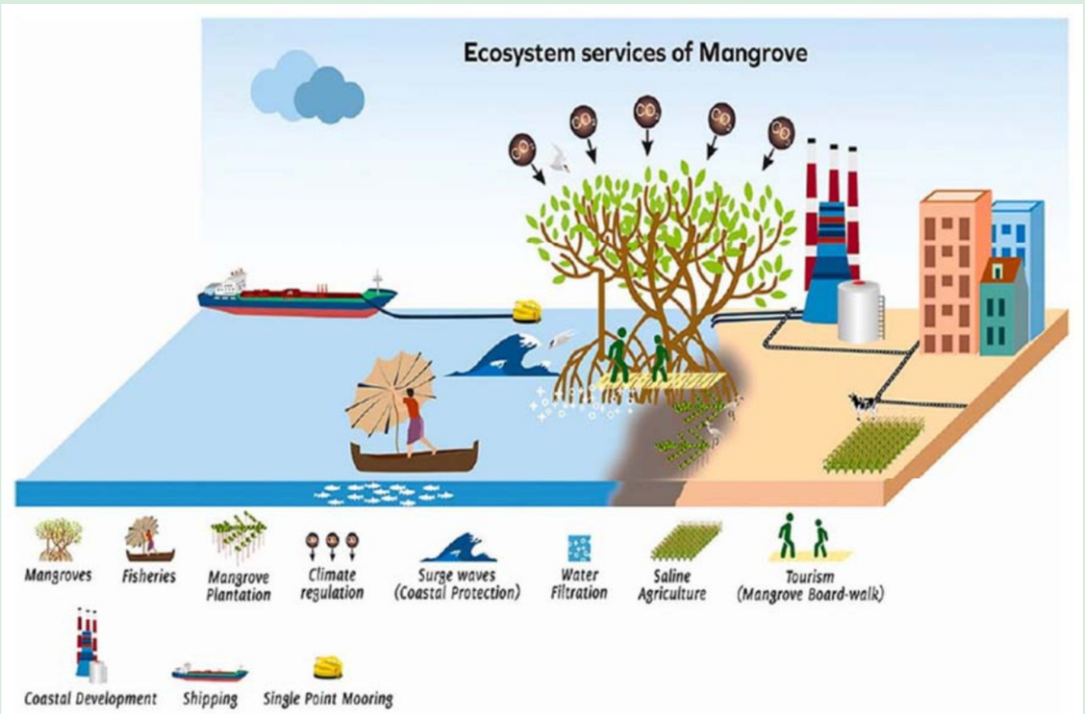

Figure 5.3: Ecosystem Services of Mangroves (Sandilyan & Kathiresan, 2012)

5.5 Mangrove Habitat

Deltaic Mangrove Habitat

Along the east coast of India, deltaic mangroves are commonly found in fertile deltas formed by rivers such as the Ganges, Brahmaputra, Mahanadi, and others. Moreover, these regions have fine-grained, loosely bonded mud flats that are nutrient-rich, making them ideal for the growth of mangroves. Nevertheless, marine ecosystems such as deltaic mangroves are highly dynamic and susceptible to natural disturbances, which include oceanic currents, tsunamis, and cyclones, which cause subsidence and erosion (Gopal & Chauhan, 2006). This type of habitat is exemplified in the Indian Sundarbans, which are a part of the Ganges-Brahmaputra delta and support extensive mangrove forests that are crucial to coastal protection and preserving biodiversity.

Marshy Backwater, Estuarine, and Coastal Mangrove Habitat

Coastal regions along the west coast of India are more likely to have mangroves in marshy backwaters, estuaries, and coastal regions. There is minimal delta formation in estuaries like those associated with the Indus, Narmada, and Tapti, which are funnel-shaped. These ecosystems do not thrive in large lakes, but rather in smaller lakes and creeks, such as Pulicat Lake, Chilka Lake, and Vembanad Lake in Kerala (Mukherjee et al., 2014). There are nutrient-rich sediments and relatively stable coastal conditions in these areas that provide a conducive environment for mangrove growth, though human activities and salinity intrusion pose threats.

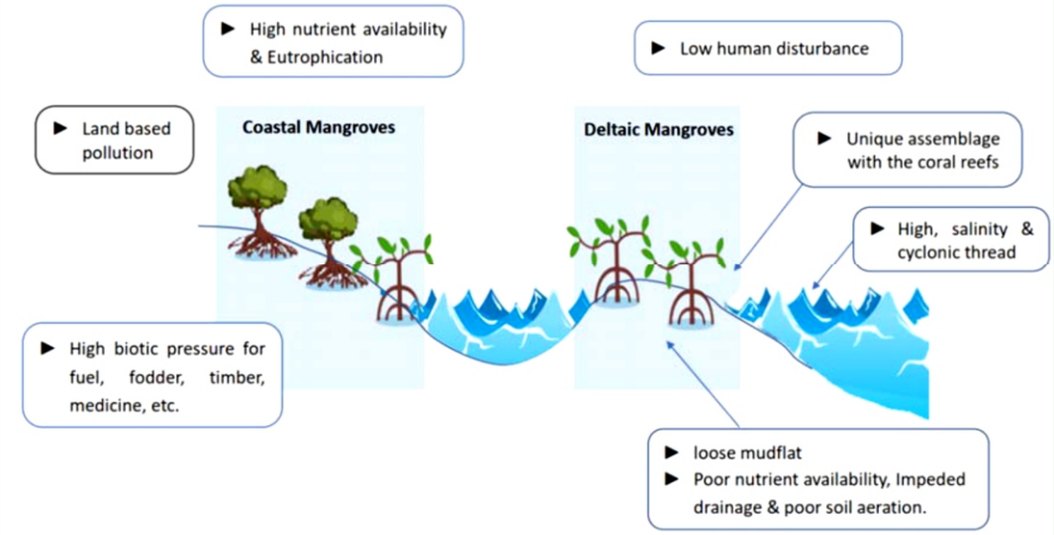

Figure 5.4: Mangrove Habitat

5.6 Threat to Mangroves

- The Indian Sundarbans is warming faster than the global average, increasing by 0.5°C per decade (SAPCC, 2017). As a result of climate change, frequency and intensity of cyclones has increased which further exacerbated the loss of mangrove cover in the region. (Gopal & Chauhan, 2006; DasGupta & Shaw, 2013).
- There has been a significant decline in mangrove cover due to deforestation for agriculture, aquaculture, and urbanization (Gopal & Chauhan, 2006).
- A major factor in the degradation of mangrove habitats is the discharge of industrial and municipal wastes. This affects both flora and fauna in the mangroves (Kathiresan & Bingham, 2001).
- Mangrove resources are exploited unregulated due to institutional gaps, weak governance, and insufficient enforcement of conservation policies (Mukherjee et al., 2014).

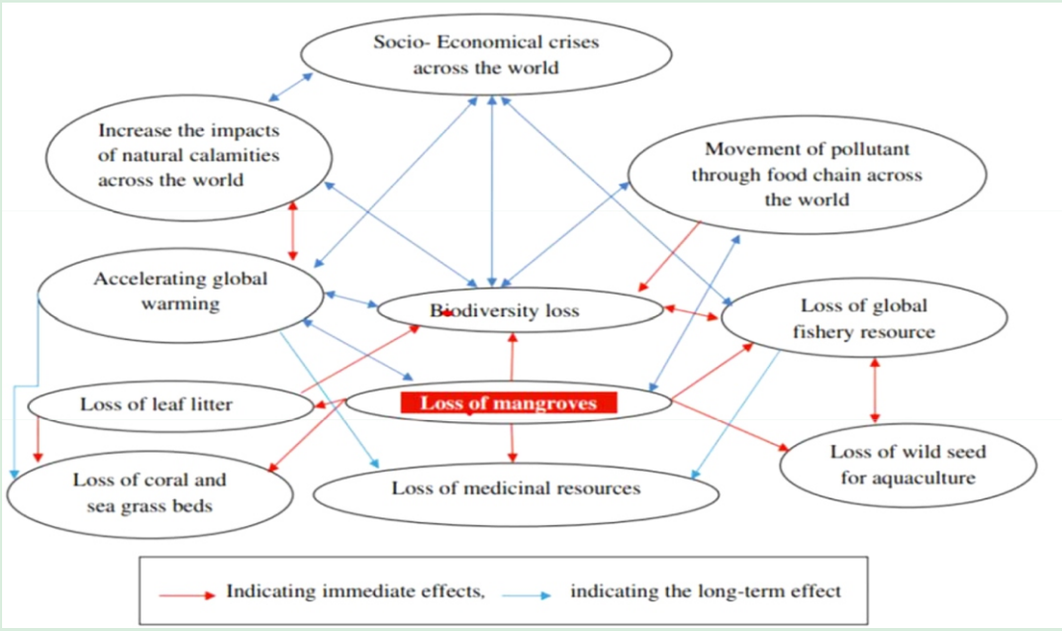

Figure 5.5: Loss of Mangroves (Sandilyan & Kathiresan, 2012)

5.7 Mangrove Degradation

In the Indian Sundarbans, mangrove swamps are being removed more frequently to make way for agriculture. As a result of deforestation, habitat fragmentation is increasing, reducing resources for wildlife, including the Royal Bengal Tiger and estuarine crocodiles. Furthermore, the destruction of mangroves increases coastal communities' vulnerability to cyclones and floods by decreasing their ability to act as natural shields against tidal surges.

5.8 Impact of Mangrove Degradation

The loss of mangroves increases disaster vulnerability by reducing the natural buffer against cyclones and storm surges. The exploitation of wood, honey, and fisheries undermines the livelihoods of local communities. Moreover, declining mangrove health exacerbates climate change by decreasing their carbon sequestration capacity (Donato et al., 2011).

Mangroves have been degraded by deforestation, aquaculture expansion, and pollution, reducing their resilience to natural disasters. It is estimated that approximately 4.3% of global mangrove cover was lost between 1985 and 2020, with similar trends also being observed in the Indian Sundarbans (Giri et al., 2022).

According to the analysis, the major drivers are natural factors, anthropogenic activities, institutional challenges, and socio-economic pressures. The following are some key observations:

5.8.1 Drivers of Mangrove Degradation

- Mangroves were extensively damaged by cyclones such as Aila (2009) and Amphan (2020).
- There have been significant deforestation and habitat fragmentation due to the expansion of agriculture and aquaculture.
- Unsustainable exploitation of mangrove resources was a result of weak policy enforcement.

5.8.2 Impacts on Disaster and Climate Risk

- The loss of mangroves has exacerbated the vulnerability of coastal communities to flooding and cyclones.
- The loss of habitat has led to the extinction of species like the Royal Bengal Tiger and reduction of fish populations in local communities, affecting local livelihoods.
- The degrading of mangroves contributes to global warming by releasing less carbon into the atmosphere.

5.8.3 Statistical Analysis of Mangrove Cover

An analysis of satellite data showed that the area of mangroves declined by 5% from 2000 to 2020. The highest deforestation rates were observed in areas nearby human settlements and agricultural zones.

5.8.4 Rising Sea Levels and Coastal Erosion

Indian Sundarbans sea levels are rising twice as fast as the global average, causing mangrove habitats to be submerged at a faster rate than in other parts of the world. As a result, critical sediment has become less accessible, affecting mangrove regeneration (Pitchaikani, 2020).

5.8.5 Cyclone Impacts

The increased temperature of the oceans has resulted in more intense cyclones such as Amphan and Aila, which have caused significant damage to agricultural lands and mangroves. As a result of cyclonic surges breaching embankments, agricultural productivity was reduced by over 20% in affected areas due to prolonged saline water logging (State Level Action Plan on Climate Change, 2017-2020).

5.8.6 Pollution and Habitat Degradation

Degradation of mangrove habitats has been exacerbated by untreated industrial and municipal wastes discharged into rivers. The effects of high salinity and pollution on key mangrove species have led to their decline in growth and regenerative capacities (Sandilyan & Kathiresan, 2012).

5.9 Conclusion and Key Findings

- Mangroves in the Indian Sundarbans form a critical ecological and socio-economic buffer, providing coastal protection, biodiversity, carbon storage and livelihood security for the local communities. However, their spatial extent and ecological health is declining. The degradation of mangroves is primarily driven by anthropogenic factors such as expansion of agriculture & aquaculture, over extraction of resources and pollution.
- Climate related factors such as rising temperatures, sea-level rise, increased coastal erosion and growing frequency & intensity of cyclones are accelerating mangrove degradation and making the ecosystem more fragile to disasters. Major cyclones such as Aila, Amphan and Yaas, have caused repeated damage to embankments, increased salinity and reduced both mangroves health and agricultural productivity.
- The decline of mangroves directly exposes coastal communities to storm surges, tidal flooding and livelihood disruption, particularly in vulnerable communities with limited adaptive c.
- For achieving long-term coastal resilience requires restoration of native mangrove species, promote alternate livelihoods & socio-economic rehabilitation measures and improved water & salinity management practices. The use of geospatial tools for regular monitoring of degradation trends and integration of disaster preparedness plans along with enhanced institutional coordination, is also essential to support sustained resilience and informed decision making.

Statements and declarations

No other journal is considering publishing the content, nor has it been published and according to the writers, there isn't a conflict of interest.

5.10 Chapter Summary

This chapter examines the degradation of Indian Sundarbans region resulting from combined factor such as decline of mangroves, global warming, climate change and increasing disaster vulnerability. Recurrent cyclones such as Aila, Amphan and Yaas, have compounded ecosystem stress due to various reasons such as damage of embankments, salinity ingress and disruption of livelihoods, there by affecting their local communities and overall coastal resilience.

The chapter underscores the need for appropriate conservation policies, restoration of mangrove ecosystem, strengthened institutional mechanisms and adoption of sustainable ecosystem management practices to safeguard both the environment and the communities in the region.

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6 Disaster-Induced Migration in the Indian Sundarban Islands

Mohan Kumar Bera

Abstract

This chapter examines disaster-induced migration in the Indian Sundarban Islands, where frequent natural hazards, particularly saline water floods and cyclones, compel residents to adopt migration as a critical survival strategy. The analysis delves into migration patterns, socio-economic and cultural drivers, and the consequences of migration on local resilience and community structure. By exploring socio-economic transitions and the role of remittances in disaster recovery, this study highlights the progression of migration from a seasonal coping mechanism to a long-term adaptive strategy in response to worsening environmental and climatic conditions. The chapter concludes by emphasizing the urgent need for sustainable development initiatives and resilience-building strategies to address the chronic vulnerabilities faced by the Indian Sundarbans' communities.

Keywords: *Disaster induced migration, Environmental adaptation, Socio-economic resilience, Sundarban Vulnerability, Livelihood diversification*

6.1 Introduction

Migration is recognized as one of the potential responses of communities living with environmentally sensitive livelihoods (McLeman & Hunter, 2010). There is a close relationship between natural hazards and migration, as understanding this interplay helps reveal a community's coping capacity and ability to deal with increasing vulnerability. Post-disaster migration has been established as a livelihood diversification strategy and an adaptive response to disasters (Black et al., 2011; Warner & Afifi, 2014; Adger et al., 2015). Migrants have been reframed as adaptive agents contributing to resilience-building strategies (Ransan-Cooper et al., 2015; Rigg & Oven, 2015).

In the Sundarban islands, land productivity is lower than in mainland areas, and agricultural activity is highly seasonal. Many residents migrate temporarily and return during the monsoon to be with their families. These migrants are often landless or small landholders. The ability of people to cope with livelihood crises has diminished due to frequent saline water floods, making migration a last resort for survival. Studies show that agricultural production in the region decreases by approximately 20% in the years following saline floods (CSE, 2012). Research indicates that migration patterns in the Indian Sundarbans have changed significantly after 2009 (Mukhopadhyay, 2016; Ghosh, 2017). What was once primarily seasonal migration has evolved into permanent migration for many. However, not all natural hazards lead to migration; the socio-economic and cultural context, along with the timing of the disaster, plays a crucial role (Paul, 2005).

Residents of disaster-affected villages often understand that government measures to mitigate natural hazards, provide relief, or offer compensation are inadequate. Consequently, many migrate in search of livelihoods, though some prefer to stay and rely on locally available opportunities, expecting continued government support. This study examines the changing nature of migration before and after disaster events, exploring its socio-economic and cultural determinants. It also seeks to understand whether migration has increased or decreased vulnerability and investigates the socio-economic changes induced by mass migration in the Sundarban islands.

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6.1.1 Understanding migration in the context of disasters

Migration can be viewed as a failure to adapt to changes in one's physical environment (Tacoli, 2009). While many people endure harsh climatic conditions or disasters, only some choose to migrate as a coping mechanism. The decision to migrate depends on various factors, including the socio-economic and cultural conditions of individuals and the timing of the disaster (Paul, 2005). To assess the impacts of migration, it is essential to examine the characteristics of migration flows, such as duration, destination, and composition.

The drivers of migration are complex and multifaceted. At the place of origin, migration may be driven by political instability, conflict, lack of livelihood opportunities, overpopulation, and limited access to resources. At the destination, factors such as employment opportunities, higher wages, labour demand, and political stability play significant roles (Massey et al., 1993). Other factors that facilitate or restrict migration include communication networks, government policies, economic ties, and socio-cultural exchanges (Deshingkar, 2006). These drivers are often overlapping, highlighting the multi-causality of migration (Boyle et al., 1998).

Chronic disasters affect all people, but their impacts vary significantly. Financially stable, well-educated, and socially well-connected households are less affected by disasters (Tacoli, 2009). Households that own physical assets such as land or property are also less likely to migrate compared to landless or small landholding households. Poor households, however, often lack the capacity to migrate due to their dependence on local income sources. For rural households, migration is a strategy to diversify income and recover from agricultural losses and other damages caused by disasters (Deshingkar, 2006).

Studies in countries like Mexico, Nepal, and Mali have demonstrated that remittances reduce poverty and enhance resilience to disasters (Lopez-Cordova, 2005; Lokshin & Bontch-Osmolovski, 2010; Gubert et al., 2010). Similarly, research in Ghana and Burkina Faso has shown that households receiving remittances are more resilient to disasters (Mohapatra et al., 2009). Migration, therefore, serves as both an adaptive strategy and a source of income for rural households.

The increasing frequency of disasters has led to a rise in migration over recent decades. This trend often results in increased remittance transfers to households following disasters, facilitating recovery and reconstruction (Mohapatra et al., 2009). Studies from El Salvador, earthquake-affected Pakistan, and tsunami-affected Aceh in Indonesia reveal that remittances have positive impacts on consumption, housing, and human capital accumulation. Migration, particularly temporary and seasonal, significantly contributes to rural economies (McLeman & Smit, 2006).

While migration is often a response to environmental changes, political, economic, and social conditions also play vital roles in influencing migration outcomes (Piguet, 2013). The Sundarban islands, part of the Ganga-Brahmaputra delta, are highly vulnerable to environmental degradation. Frequent breaches in mud embankments result in saline water floods, causing significant damage to livelihoods, especially agriculture. For example, the village of Baliara on Mousuni Island has been experiencing recurring floods and saline water intrusion since Cyclone Aila in 2009, forcing many residents to migrate (Samanta et al., 2017; Basu & Bhattacharya, 2017).

In such contexts, migration becomes a critical coping strategy. However, there is a lack of research on the long-term impacts of disaster-induced migration in the Indian Sundarbans. This study aims to assess the impacts of migration on vulnerability and recovery, examine changes in migration patterns, and analyse the socio-economic consequences of mass migration in disaster-affected villages.

6.2 Study Area

The Indian Sundarbans, situated in the Ganga-Brahmaputra delta in West Bengal, India, are among the most environmentally vulnerable regions in the world. Much of the area lies below mean sea level, necessitating the construction of extensive embankments to protect against tidal surges and floods. However, these embankments are frequently breached, leading to recurrent saline water flooding. This environmental degradation has severe consequences for agriculture, the primary livelihood of the region, and causes significant disruption to local communities (CSE, 2012; Samanta et al., 2017).

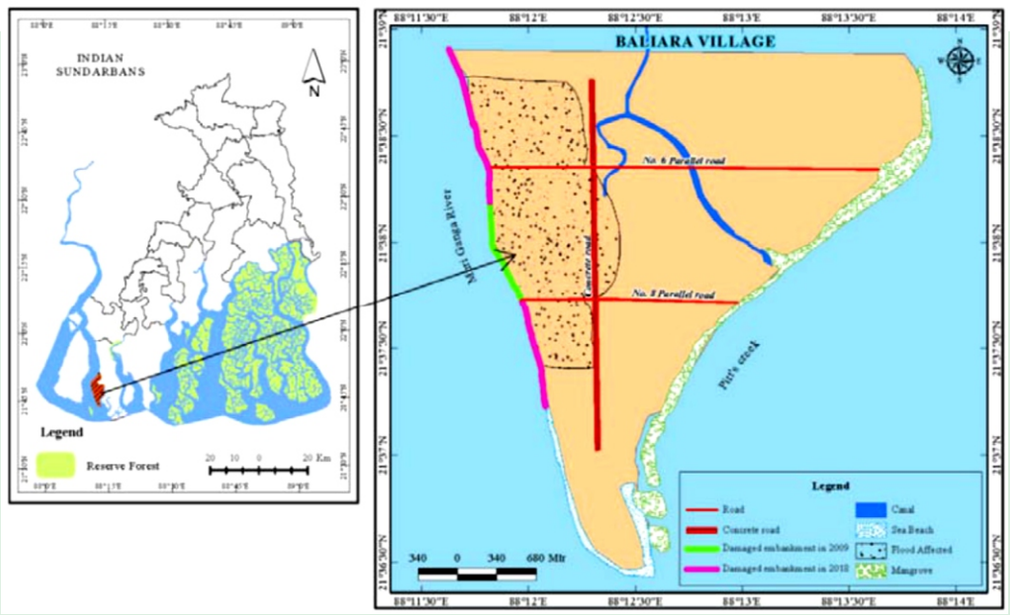

Figure 6.1: Study Area Baliara Village

The village of Baliara on Mousuni Island serves as a focal point for this study due to its acute vulnerability to flooding. Since Cyclone Aila in 2009, the village has experienced consistent saline water intrusion, devastating agricultural lands and other livelihood sources. Most of the inhabitants in Baliara live below the poverty line and depend on seasonal migration to cope with the lack of sustainable local livelihood opportunities (Basu & Bhattacharya, 2017).

A case study was conducted in the western part of Baliara village, where a significant proportion of household heads, predominantly male members, migrate in search of jobs as a coping mechanism for disasters. The most affected hamlet lies between the No. 6 and No. 8 parallel roads in the western part of Baliara village (Samanta et al., 2017). This area faces heightened vulnerability due to its location and socio-economic conditions (Mukhopadhyay, 2016).

6.3 Methodology

A case study method was employed to explore a phenomenon within a bounded system, as described by Yin (2009) and Merriam (2014). A bounded system refers to a unit of analysis constrained by a defined place and time (Stake, 2013). The single case study approach is especially suitable for examining unique events within a specific environment (Stake, 2013).

The study focuses on a Muslim hamlet in Baliara village, where most households rely on remittances. While a few individuals migrated before Cyclone Aila in 2009, the majority began migrating after the disaster. Some residents stopped migrating and shifted their focus to village-based livelihood activities.

Respondents for the study were categorized into three groups: (1) migrants before Cyclone Aila, (2) migrants after Cyclone Aila, and (3) return migrants and non-migrants. As the research was conducted during June and July 2018, most migrant labourers were away, as they typically return to the village during the monsoon season.

Out of 35 respondents, 25 (71%) began migrating after Cyclone Aila, 4 (11%) had migrated before Aila, 4 (11%) were return migrants, and 2 (6%) were non-migrants. All respondents were male and aged between 14 and 55 years. Data collection involved interviews, field observations, and a review of published and unpublished reports (Stake, 2013). Each in-depth interview lasted approximately 45 minutes, addressing key topics categorized according to the respondents' migration status:

Migration After Cyclone Aila (Ages 14–35)

- Previous experiences
- Driving factors
- Job opportunities at migration destinations
- Strategies to find jobs at the destination
- Managing travel expenses for job searches
- Duration of migration
- Individual versus family migration
- Remittance management strategies
- Socio-economic changes in the village after mass migration
- Future migration plans

Non-Migrants/Return Migrants (Ages 35–45)

- Current economic activities
- Reasons for not migrating or ceasing migration
- Adequacy of local livelihood opportunities
- Coping strategies for livelihood crises

Migration Before Cyclone Aila (Ages 45–55)

- Migration destinations and duration
- Job opportunities in the village and outside
- Nature of migration (seasonal, cyclical, or regular)
- Differences in migration trends and impacts before and after Aila

Data analysis followed an inductive approach to synthesize information from the interviews. Transcribed data were coded using a keyword coding scheme (Saldaña, 2014), and themes and sub-themes were generated to connect research questions with respondents' answers. Key themes included:

- Floods and River Encroachment: Landlessness, homelessness, living at risk, residential mobility, reduced reliance on traditional livelihoods.
- Seasonal Migration: Income for development, wage labour, income diversification.
- Post-Flood Migration: Migration to neighbouring states, managing livelihood crises, remittances, development, education, and health.

- Non-Migrants: Community respect, family obligations, shortage of skilled labour, self-dependency.
- Local Government: Adequate humanitarian support, sustainable livelihoods, self-help groups, and protection of migrant labourers.

6.3.1 Migration in Search of Jobs

In the Indian Sundarban islands, farming is the primary source of income for most residents (Bera, 2019). In addition to fishing to diversify their livelihoods, many individuals engage in fishing to supplement their incomes, but fishing interests are declining because of the low price of fish, the lack of fishing spots, and the lack of fishing skills. While many people have lost their agricultural livelihoods, fishing has not gained popularity as an alternative activity (Bera, 2019). Due to the economic crisis, many villagers have turned to wage labor and migration in search of work as their main sources of income. Since migration requires little monetary investment and is a stable source of income (Bera, 2019), it has become a strategy for generating income.

Table 6.1: Relationship between landholding and nature of migration

Land holding	Before saline water flood			After saline water flood	
	Primary source of livelihood	Secondary source of livelihood	Nature of migration	Primary source of livelihood	Nature of migration
>10 Bigha	Only agriculture	Govt. or private job	No migration	NA (Wait for recovering the land)	No migration
5-10 Bigha	Agriculture	Small scale trading	No migration	Dependency on small scale trading	No migration
5-10 Bigha	Agriculture	Betel leaf plantation	No migration	Wage labour work	Long term Migration
3-5 Bigha	Agriculture	Fishing	Seasonal migration	Fishing	Seasonal migration
3-5 Bigha	Agriculture	Saline water pisciculture	Seasonal migration	Saline water pisciculture	Long term migration
1-3 Bigha	Agriculture	Wage labour work	Seasonal migration	Wage labour work	Long term migration
<1 Bigha	Wage labour work	Agriculture	Long term migration	Wage labour work	Long term migration

(1 Bigha = 0.62 Acre)

As can be seen from Table 6-1, migration is not a new strategy of livelihood in these villages. In flood-prone areas, people migrate seasonally for wage work, mainly at farms, brick kilns, and rice mills. It is common for fishermen to migrate at the end of February or in early March and return during the Eid celebrations. A majority of villagers who rely on agriculture migrate after monsoons and after harvest. Although there are jobs in villages, the wages are inadequate to handle a family's daily expenses. For short periods of time, villager migrants have been migrating to nearby cities in search of employment. The migrants are mostly unskilled labourers aged thirteen to sixty (Bera, 2019). Most villagers migrate

to places where their friends or neighbours work, so they can travel safely, find jobs easily, and find shared homes and places of worship. Initially, travel is irregular, but later becomes regular. Workers move from place to place depending on employment opportunities, the nature of those jobs, and the wage rates.

A villager explained, "My first job was as a well builder. After a few years, I started experiencing health problems. Currently, I work as a construction labourer (Primary Survey, 2018)". The majority of migrants work in construction, agriculture, gardening, and small-scale manufacturing. Additionally, they may work as domestic helpers or security guards. There are times when they change jobs in search of higher wages and lighter workloads. Goldsmithing is also a popular career path for young male population. During the training period, these unskilled boys receive pocket money, free food, and shelter. As soon as they gain the necessary expertise, they decide to move to the Gulf countries or Singapore.

Several migrant laborers who trained in Kolkata moved to Kerala because of the higher wages, good weather, diverse and flexible job opportunities, the favorable sociopolitical environment, and the existence of cultural ties. The majority of migrants are school dropouts who began working at a very young age. For safety reasons, labour contractors do not employ these underage workers. In most cases, underage workers procure work in private homes through individual networks. A number of young migrants have begun to migrate for wage work in recent years after graduating from high school. However, those who are educated may also work at small-scale industries, hotels and restaurants.

The employment of migrant workers was initially supervised by labour contractors, since it was easier to get a job through them. Laborers are often unable to get paid on time, so many try to escape the supervision of their contractors and look for jobs on their own. In a long-term stay, they establish personal relationships with the local people and expand their network by socializing at local places of worship. They find it easier to live their lives if they learn the local language. In order to find a job, skilled migrants often advertise at the local market. As one respondent shared, "I have worked as a wage worker in the past. The number of new migrants is much higher than that of old migrants since the latter cannot devote themselves to highly demanding income-generating activities for an extended period of time. Migrants either stop migrating or engage in lighter work after the age of 45.

The duration of migration varies according to age, marital status, type of work, and season. Initially, migrant workers spend two to three months at their new location, but eventually they stay for months or even years. The present study shows that around 75% of migrant labourers return to their villages during the monsoon season due to flooding crises. In general, migration duration depends on the type of job one holds. During the monsoon season, workers who construct roads return home and resume their work. Hotel and restaurant workers, on the other hand, are more likely to be employed regularly. While migrants often travel frequently, they often seek stability through jobs in their home villages. The uncertainty associated with chronic disasters makes this kind of stability difficult to achieve.

Villagers who live in flood-prone hamlets stay home during flood season (July to October). It is also during this period that workers who migrated in search of work tend to return home. Some migrant workers do not return, however, because they do not want to lose their wages. It is common for neighbouring families to stop losses and destruction from occurring during emergencies by helping each other.

In the aftermath of a flood, remittances play an important role in helping the villagers recover. Visiting migrant laborers send money home through money orders, bank transfers, or to another villager's bank account. The earnings of migrant workers are traditionally brought home with them after returning

home. During their travel, they are vulnerable to pickpockets and thieves. The postal service is no longer preferred by migrants due to delays in the service. In recent years, it has become more common for people to send money directly to another villagers' bank accounts. It can be a friend, a relative or someone close to you who holds the account. Deposit slips are kept as proof of transfer by the sender. Food and travel are included in the fee, which is equivalent to the local daily wage. The Pradhan Mantri Jan Dhan Yojana of the Government of India has enabled many labourers to open their own bank accounts. It has made it easier for them to send money home.

Even though most villagers are affected by frequent flooding, not all of them choose to migrate. In addition to the nature of income-generating activities, the structure of the family determines the tendency to migrate. Nuclear families are less likely to migrate than joint families. The majority of individuals with prior migration experience move to look for jobs immediately after a flood. In order to meet their daily needs, other members of the family seek alternative livelihood opportunities. One earning member of a family, however, does not wait long to migrate after a disaster. The present study indicates that around 95% of migrants are males looking for work: leaving women, elderly people, people with disabilities, and children behind. Also, some women migrate with their husbands, but they don't stay long. The present study did not find any independent female migrants. The majority of young men migrate from flood-affected hamlets, so local families rarely have young men at home during times of emergency. It is difficult for joint families to cope with all the challenges the hamlet faces during a disaster, despite having male members.

After the abolition of the landlord system in 1977, hardly any big landholding families remain in the village. In the present generation, landholdings have dwindled because of the encroachment of the river and the practice of sharecropping. The small tracts of agricultural land owned by poor families have similarly diminished. Due to the increasing population and the reduced availability of land in riverside hamlets, villagers can no longer rely on local sources of income, and they turn to migration practices. Migration from flood-affected villages can be explained based on certain characteristics. It can be long-term temporary (rural–urban), long-term permanent (rural–rural), long-term return, seasonal (fishing, wage labour), or circular (Table 6.2).

Table 6.2: Migration Flow from Baliara Village in Indian Sundarbans

Type of migration	Type of migrants	Destination	Push factors	Pull Factors	Impacts
Long-term temporary (rural – urban/rural)	All age groups, male	Kerala, Kolkata, Delhi, Gujarat	Flood, river erosion, damage to houses, loss of crops, lack of jobs, crisis of food	Availability of jobs, high wage rates	Dependency on remittances, disaster recovery, injury
Long-term permanent (rural –rural)	Entire family	Nearest safe villages	River erosion and displacement	Living without risk	Avoiding disasters permanently, loss of social network, disruption of traditional income-generating activities, living with poverty
Long-term international	Young, male	Gulf countries	High ambition	Attraction of high wages	Improved economic condition

Type of migration	Type of migrants	Destination	Push factors	Pull Factors	Impacts
Long term Return	Middle - aged, male	Affected village	Inability to cope with weather, sickness, long absence from family	Alternative livelihood opportunities, family bonding, rebuilding of embankment, self-respect	Coping with disaster by resorting to alternative sources of livelihood, job diversification
Seasonal fishing	Young, male	Neare st fishing harbours	Lack of job opportunities, small landholdings	Availability of jobs (deep-sea fishing)	Reducing economic vulnerability
Seasonal wage labour work	Young, male	Cold storage (nearest districts), brick kilns	Lack of job opportunities, small landholdings	Availability of jobs	Reducing economic vulnerability
Seasonal during floods (mainly July to October)	Entire family (mainly children, elderly people and the sick)	Elevated roadside, homes of relatives or friends, schools, temples or mosques, clubs	Floods during monsoon	Living safely	Crisis of food and safe drinking water, waterborne diseases, lack of security, debt incurred during shifting
Circular (rural–urban)	Young, male	Garment and hotel industry (Kolkata)	Lack of job opportunities, small landholdings, lack of interest in farming and fishing, social status	Availability of jobs, attraction of urban life	Dependency on remittances, reduced savings after floods

In the villages of the Indian Sundarbans, migration is a continuous phenomenon, as it is practiced reducing economic vulnerability (Bera, 2019). The non-productivity of land after a flood severely threatens livelihood activities. The practice of regular out-migration has given way to the practice of long-term mass migration after a flood. Mass migration in search of jobs has become the only viable strategy to recover from the adverse effects of a disaster.

As stated previously, most of these migrants are male members of all age groups. However, many middle-aged people have stopped engaging in out-migration and prefer to participate in income-generating activities based in the village. Residents living near the embankment are most vulnerable to floods. They move to safe places during a flood and return once the situation becomes normal. These households rely completely on individual savings, social networks and various forms of aid during their temporary stay. River erosion also causes the permanent displacement of many households living near the embankment. These households shift to safer areas in neighbouring villages, other islands or even the mainland. Due to their migration, they often lose access to their social networks and traditional sources of income.

As per the findings of the survey, women have become responsible for all family decisions due to the prolonged absence of their husbands. In fact, they are overburdened with responsibilities during floods if the male members are unable to return home. These women are highly vulnerable due to their limited access to socio-economic resources. Mass migration causes a shortage of labour in the village. In response, women engage in wage labour.

The Swarna Jayanti Swarojgar Yojana is a government scheme that helps the women to unite and form labour groups *(khata)* in the village. Their main purpose is to search for work, engage in income-generating activities and bargain for wages collectively. Often, the labour groups of the women are criticised by male labourers, but the local government i.e., gram panchayat encourages them and provides them with multiple job opportunities. However, the involvement of the women in the labour force burdens them with the task of financially supporting their families in addition to the household work they already perform. Some women who do not like to work as daily wage labourers move to the city to provide domestic help services.

6.3.2 Factors of Migration from Baliara

The major driving factors of migration from Baliara village are availability of work at the village, floods, reduced earnings and irregular payments, maintaining social status, building a house at a safe place, lack of fishing activity and attraction of urban life.

(a) *Availability of work at the village:* Migration depends on the availability of work opportunities at the village. Reconstruction work at the embankment is another factor that influences migration decisions because daily wage labourers prefer to work within the village. Migrant labourers either return or stop going out during the reconstruction phase of disaster in the village. The reconstruction process does not start immediately after a flood as it takes time for the necessary funds to be sanctioned. The migrant labourer therefore continues to leave the village and work at other locations until the reconstruction begins. Post-disaster reconstruction activity is done through the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), which aims to enhance livelihood security in rural areas by providing at least 100 days of wage employment in a year to every household. Although this can be a potential source of income, many young villagers do not like to take up MGNREGA work due to the delay in payments. Thus, while elderly villagers and women work under the MGNREGA scheme, young men decide to leave the village and engage in other earning activities.

(b) *Flood season:* Whether an affected person decides to migrate depends on the season during which floods occur. The late monsoon season (late August to October) is most prone to the breaching of embankments, which in turn causes floods. This season is also considered to be a period of crisis in the village because of the lack of sufficient stocks of food grains. As a result, many villagers are compelled to go out to work.

(c) *Reduced earnings and irregular payments:* The large number of available agricultural labourers and the lack of adequate work opportunities in the village after a flood inevitably bring about a drastic reduction of wage rates. Although the irrigation department pays a good amount of money, the delay in making payments results in a lot of hardship for the villagers who are largely dependent on daily wages. As a result, they prefer to move to places where they can access work opportunities and get paid on time.

(d) *Maintaining social status:* Landholding families are totally dependent on agriculture. The agricultural produce of the kharif and rabi crop seasons and the available fish and vegetables are enough to meet their needs. A family's wealth and status are based on agricultural production, and so the loss of land mass and the consequent decrease in productivity after a flood can

undermine that status. Traditionally wealthy families hire labourers to perform agricultural work. Their consciousness of their social position makes them reluctant to work with the labourers to earn money during a crisis. Migration therefore becomes the only option for them to sustain their income and recover from their losses after a disaster. However, the phenomenon of mass migration leads to a shortage of young men equipped to undertake disaster-management measures during emergencies. As one respondent reacted, "If everybody goes out, then how will disaster be managed?"

(e) *Building house at a safe place:* There is a growing trend among the young boys and girls of the village to get married to people settled in safer areas. However, the families of potential brides often do not want to establish relationships with people from affected villages and therefore reject marriage proposals. As a result, many young men have been trying to buy land in safe places before getting married. Migration in search of jobs becomes an alternative source of income, and the money is used to buy a small plot at a suitable location.

(f) *Lack of fishing activity:* Although fishing is an important source of livelihood, many villagers do not have access to suitable fishing sites, particularly in shallow-water fishing areas. The contract necessary for deep-sea fishing must also be obtained prior to the fishing season. Thus, if a flood occurs during the monsoon, the villagers do not get the opportunity to work in fishing boats. Even though the supply of mixed-water fish increases after a flood, landowners usually do not allow others to catch the fish. The villagers therefore have no choice but to resort to migration.

(g) *Attraction of urban life:* Young men prefer to migrate in search of jobs rather than engage in fishing and farming. Their parents give them permission to go out because it reduces the family's expenditure on food. Usually, the young villagers do not work while they are at home. However, once they leave the village, they start working overtime to earn more money. The migration of young villagers therefore not only reduces family expenses but also increases the family's income. Many stay permanently at the place of migration due to the attractions of an urban environment. Some migrants also engage in vending and pulling rickshaws in the city instead of working as daily wage labourers.

6.3.3 Returning Home

Initially, unskilled or semi-skilled migrant labourers face many difficulties in getting jobs. Even if their social networks enable them to procure employment, their situation is uncertain due to poor work environments and lack of adequate monetary benefits (Perch-Nielsen *et al.,* 2008). However, in general, the perception of migration is positive because many migrant labourers successfully engage in trading (CSE, 2012). Some choose not to return when agricultural activities in their village are restored to normal operations. Migrant labourers return during the reconstruction phase depending on the relative monetary benefits from jobs available in and outside the village; types of work available in and outside the village; structure of the family (joint family and nuclear family); age of the migrant labourers; marital status of the migrants; the types of work they are engaged in and their areas of expertise; types of resource holdings in the village; the migrants' social status in the village; and financial deposits. Very often, contractors misbehave with migrant labourers and do not pay their wages; therefore, many labourers move to places close to home. This lets them earn money and look after their family at the same time. However, young people who are influenced by the success stories of migration in the village follow their neighbours to distant places in search of jobs (CSE, 2012).

Some landless villagers migrate entire families but, sometimes, the education of children suffers. Usually, the women stay home and participate in alternative livelihood activities such as catching *meen* (baby tiger prawns), doing *zari* work (traditional embroidery), and making fishing nets. Their income enables them to support their children's education.

There are households who do not migrate because of the physical inability of their members to engage in wage labour. There are villagers who resort to begging in neighbouring villages where nobody knows them. Others choose to stop migrating and focus on alternative sources of income in the village. Villagers stop migrating because they cannot adjust to the food, language, or weather at the place of migration, or they cannot cope with the physical demands of the job, or they are too attached to their children and elderly parents to move. These villagers manage their livelihood by limiting their expenditure. Non-migrant labourers engage with local sources of livelihood and self-employment activities. These labourers are also involved in various social activities and attached to religious and local institutions. Although these community practices do not generate income, they provide social respect and recognition.

Flood water helps to increase the production of brackish-water fish, and this becomes a source of income for the villagers. Fish traders can continue their business to fulfil their needs. Villagers who have agricultural machines work in neighbouring villages to diversify their income without resorting to migration. Villagers also create new sources of livelihood such as pisciculture (both, individual and collective, the latter in collaboration with a self-help group).

6.4 Findings and Discussion

The decision to migrate is a complex process involving numerous interrelated factors, including environmental conditions, availability of resources, wage rates, distance from migration destinations, social networks, work opportunities, age, gender, training, and skills. "Pull and push" factors provide a valuable framework for understanding the specific elements influencing migration behaviours (Lee, 1966). These drivers can be classified into political, social, economic, environmental, and demographic categories (Kartiki, 2011) (Table 6.3).

Table 6.3: Factors of Migration in Villages

Type	Pull factors	Push factors
Environmental factors	• Fertile land • Productivity of commercial crops (betel vine) and vegetables	• High frequency of floods and cyclones • Rapid river erosion, landlessness and displacement • Breaching of embankments and risk of disasters • Crisis of fresh water and food • Salinization of agricultural l and • Damage to houses and local infrastructure
Social factors	• Emotional attachments with close relatives and other inhabitants of the village • Social networks and kinship ties	• Isolation from the mainland • High dependency on natural resources • Living without risk • Poor infrastructure and services • Living at risk • Maintaining social status
Economic factors	• Low cost of living; • Wage work for managing embankments	• High wage rates • Availability of jobs • Small holdings • High health expenses • Crisis of alternative livelihoods • Loss of fishing • Delayed payments through MGNREGA

Type	Pull factors	Push factors
Political	• Active participation in local self-government	• Lack of proper management and reconstruction of embankments • Inadequate relief and rehabilitation programmes • Political violence
Demographic factors	• Old age • Joint family • Families with school going children	• Young married • Nuclear family • Families with small kids

Migration, while not always a suitable strategy for coping with disasters (Kartiki, 2011), has become increasingly necessary for residents of Mousuni Island due to chronic floods since 2009, which have left few viable income options. Although the migration of young men cannot entirely meet their families' needs, it significantly alleviates food insecurity and unemployment in the village. Government policies, such as subsidized rice distribution at Rs. 2/kg through the Public Distribution System, provide additional support.

Contrary to Kartiki's (2011) findings, this study demonstrates that migration enhances resilience, enabling families to invest in higher education, better healthcare, and improved living conditions. Many villagers have purchased land in safer locations and invested in betel vines, agricultural machinery, and engine-driven rickshaws. Those who migrate to Gulf countries or Malaysia often build well-constructed houses. However, frequent natural hazards, including floods, have limited the long-term positive impacts of migration on the community.

Chronic floods since 2009 have devastated livelihoods based on locally available natural resources. While remittances provide partial relief, they cannot entirely offset the economic losses incurred. For instance, while remittances reduce school dropout rates after a flood, they often fail to support higher education. Young men prioritize saving money to purchase land and construct homes in safer areas. Although migration is a temporary coping strategy (Kartiki, 2011), it has proven effective in enhancing resilience and reducing disaster risks. Studies have shown that migration diversifies livelihood activities (Table 6.4), but the present research reveals a shift away from natural resource-based livelihoods.

Table 6.4: Changing Livelihood Activities

Livelihood activities before the floods	Livelihood activities one year after the floods	Livelihood activities five years after the floods
• Agriculture (rice, betel leaf and seasonal vegetables) • Commercial aquaculture • Fishing (deep-sea fishing and brackish-water fishing) • Wage labour • Rickshaw pulling • Seasonal migration (brick kilns, cold storage, wage labour) • Temporary/seasonal trading (fish, vegetables and rice)	• Deep-sea fishing • Long-term migration • Wage labour	• Sharecropping far away from the affected village or in non-affected villages • Deep-sea fishing • Commercial aquaculture • Circular migration • Trading (dry fish) • Wage labour • E-rickshaw pulling

Migration patterns and the distance from affected areas are closely related. Affected households often prefer to migrate shorter distances, which may be geographically, linguistically, or socially defined. Researchers such as Turton and Turton (1984) emphasize that the availability of livelihood opportunities is the most critical factor in selecting a migration destination. The findings of this study highlight that the unavailability of job opportunities within the same socio-cultural boundaries forces residents of the Indian Sundarbans to migrate farther afield. This contrasts with the findings of Kayastha and Yadava (1985), Smith and McCarty (1996), and Gibbons and Nicholls (2006), which suggest a stronger preference for closer migration destinations. Nonetheless, decisions about the timing and location of migration are typically individual rather than collective.

Despite prolonged absences from home, male migrants effectively manage family expenditures, provide adequate food, and ensure their children's access to higher education. One respondent shared, "We could not produce paddy for nine years, but there is no hunger in the village." Remarkably, despite the persistent risk of floods, the local market has flourished. Families have been able to build durable homes, acquire property, and deposit money in banks. Awareness of the importance of higher education has also increased among villagers. Migrant labourers allocate significant resources to the education of younger family members, enabling them to pursue government jobs or opportunities abroad. Middle-aged migrants are also establishing connections to facilitate their children's migration to foreign countries. Young educated migrants, upon returning home, save money to cover travel expenses and begin applying for passports.

Migration distance is influenced by various socio-economic and environmental factors. Residents of the Indian Sundarbans often migrate far from their homes due to limited local job opportunities. While closer destinations are preferred, when possible, this is not always feasible given the socio-economic constraints of the region. Young migrants frequently explore distant urban areas, motivated by better wage prospects and diverse employment opportunities.

Although migration has its challenges, it has enabled the community to recover partially from disaster-induced hardships. Remittances have allowed families to improve their standard of living, invest in assets, and secure their future. However, the benefits of migration are moderated by frequent floods and other environmental stressors, which continue to affect the community's overall resilience.

6.5 Conclusion

While migration is often necessary after disasters, support from the government is essential for the proper management of risks and effects. Such support may be provided through social protection, the development of public infrastructure, and the promotion of sustainable livelihood practices. Conventional disaster relief measures adopted by the government have failed to stop migration (Parasuraman and Unnikrishnan, 2000). People living in the islands are aware of the limitations of these measures in pre-empting the breaching of embankments and the repeated occurrence of saline water floods. While they continue to expect government support, they prefer to migrate to ensure the recovery and well-being of their family and community. Increasing impacts of frequent natural hazards created a space for remittance dependency recovery. Remittances are not only used for reconstruction and rebuilding but spent for human resource development and health. Remittance has also positive impacts on the well-being of the communities. Therefore, migration has enhanced the resilience of people to cope with disasters. Since the seasonal migration transformed into long term migration, security and protection well-being of migrant labourers are urgently required.

Statements and declarations

No other journal is considering publishing the content, nor has it been published and according to the writers, there isn't a conflict of interest.

6.6 Summary of Chapter

This chapter, titled "Disaster-Induced Migration in the Indian Sundarban Islands," examines the phenomenon of migration as a response to recurring natural hazards, particularly flooding, in the Sundarban region of India. It explores how environmental changes, exacerbated by climate impacts, drive residents to migrate, either temporarily or permanently, in search of livelihood opportunities. The chapter analyses migration patterns before and after major disasters, such as Cyclone Aila in 2009, and considers socio-economic and cultural factors influencing migration decisions.

Key findings reveal that frequent saline water floods have significantly reduced agricultural productivity and forced many residents, primarily male members, to seek employment elsewhere to support their families. Migration has transformed from seasonal to long-term, reflecting an adaptive strategy aimed at mitigating the economic vulnerabilities posed by natural disasters. The study categorizes migrants into different groups based on their migration timing and motivations, ranging from young temporary workers to families who have permanently relocated.

The chapter also discusses the impacts of migration on community dynamics, such as the role of remittances in local economic resilience and the emergence of women in local labour markets due to the absence of male family members. Migration's benefits, including income diversification and economic support through remittances, are offset by challenges, such as loss of social networks, family separations, and continued reliance on government support for disaster recovery. The chapter concludes that while migration provides short-term economic relief, it highlights the need for sustainable livelihood options and robust disaster resilience strategies within the Indian Sundarbans to address long-term vulnerabilities.

Here are the key findings of the chapter:

1. **Migration as an Adaptive Response:** Due to frequent natural hazards, particularly saline water flooding and cyclones, migration has become an essential adaptation strategy for residents of the Indian Sundarbans. Over time, migration patterns have shifted from seasonal to more long-term as environmental conditions have worsened.
2. **Economic Pressures Drive Migration:** Frequent flooding has significantly reduced agricultural productivity, making it difficult for residents to sustain their livelihoods locally. As a result, many, especially male household members, migrate to urban areas for employment, sending remittances back to support their families.
3. **Socio-Economic and Cultural Impacts on Communities:** The prolonged absence of male migrants has led to shifts in family roles, with women taking on greater economic responsibilities within the village. This has led to the formation of labour groups and new socio-economic dynamics, though it also increases women's vulnerability.
4. **Dependence on Remittances for Local Resilience:** Remittances play a critical role in household income, enabling families to recover from disaster impacts, support education, and improve living conditions. However, this dependence on remittances underscores the economic vulnerability of communities lacking local income opportunities.
5. **Need for Sustainable Livelihoods and Disaster Resilience:** While migration helps households cope with economic pressures, it highlights a need for sustainable livelihood options and robust

disaster resilience measures within the Indian Sundarbans. Improving local infrastructure, offering livelihood alternatives, and strengthening disaster preparedness would reduce dependence on migration and enhance community resilience.

This chapter emphasizes that, while migration is a crucial coping mechanism, long-term resilience in the Indian Sundarbans will require integrated strategies to address both environmental and socio-economic vulnerabilities.

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7 Social Capital and Disaster Risk Reduction: A Case Study of Gosaba Block of Indian Sundarbans, India

Shiladitya Chakraborty

Abstract

A disaster not only harms the economy and infrastructure but also has complex social impacts. Researchers worldwide have recognized that community participation and social networks play a crucial role in dealing with both man-made and natural disaster risks. Thus, 'Social Capital' can be defined as the network of various social relationships that significantly influence how a community responds to a disaster. This study investigates how bridging, bonding, and linking social capital contribute to disaster management and recovery. The study was conducted one month after the landfall of the severe tropical cyclone, Bulbul, which struck the Indian state of West Bengal on November 9, 2019. This qualitative research is based on field surveys. Data was gathered through semi-structured interviews with cyclone survivors from Rangabelia Gram Panchayat (GP) and Gosaba Gram Panchayat (GP), as well as focal persons such as the Gram Panchayat Pradhans and Upa-Pradhans. Additionally, to extend the investigation, the research included a pair of focus group discussions (FGDs) with members of the disaster-affected communities in the two Gram Panchayats. The study shows that the communities in the Indian Sundarbans, affected by the tropical cyclone, heavily relied on their social capital to cope with the crisis. The paper, therefore, discusses the role of different types of social capital at various stages of the crisis management cycle in the context of Cyclone Bulbul. The article concludes by highlighting factors such as poverty, migration, politicization of the local community, and corruption, which ultimately reduce the efficacy of social networks in dealing with crises. The study suggests that disaster management policies should create more opportunities for leveraging social capital to recover from disasters and promote community resilience in the aftermath of such events.

Keywords: *Social Capital, Disaster Management, Disaster Risk Reduction, Community Resilience, Cyclone*

7.1 Introduction

A disaster is defined as a catastrophic situation in which the normal pattern of life or ecosystem has been disrupted and extraordinary emergency interventions are required to save and preserve lives and/or the environment (MHA, 2011). In India, disasters are a frequent occurrence, and the country is extremely susceptible to various types of disasters, both natural and man-made. The unique geo-climatic conditions of India, combined with socio-economic vulnerabilities, make it one of the most disaster-prone nations in the world (MHA, 2011). Disasters not only disrupt societal functioning but also result in widespread loss of human lives, property, and environmental devastation.

Despite repeated experiences with disasters, disaster management in India has largely remained institutional and top-down in its approach (Orga et al., 2021). Policymakers often fail to acknowledge that most disasters originate at the local level and require mitigation approaches that are locally grounded and community driven. Social capital within local communities can play a significant role in post-disaster recovery and in building community resilience (Pandey et al., 2021). Effective disaster reduction strategies must incorporate bottom-up approaches that recognize and leverage the strengths of local factors and community networks.

Among the various disaster risks, tropical cyclones pose a significant and recurring threat to India. With a long coastline spanning approximately 7,516 km, about 5,700 km of which is vulnerable to tropical cyclones and tsunamis, India's eastern coastline is particularly at risk (MHA, 2011). Cyclones originating in the Bay of Bengal frequently affect the eastern coast, displacing millions and causing

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extensive damage. One such example is Cyclone Bulbul, which struck the coasts of India and Bangladesh on November 9, 2019. The cyclone wreaked havoc in the Indian state of West Bengal, causing significant destruction.

Cyclone Bulbul resulted in the loss of 14 lives and affected approximately 3.5 million people in West Bengal. The storm damaged 5,17,535 houses and impacted 14,89,924 hectares of agricultural land, leading to an economic loss estimated at ₹238.11 billion. The cyclone also disrupted infrastructure, snapping cable lines and causing a ₹5.97 billion loss to the power department alone (India Today, 2019). Such incidents highlight the urgent need for improved disaster preparedness and community-based resilience strategies to mitigate the adverse effects of tropical cyclones and other hazards.

7.2 Literature Review

7.2.1 Understanding the Key Concept: Social Capital

The concept of social capital is a multifaceted construct that can be traced back to the writings of Alexis de Tocqueville, who highlighted the significance of social networks in fostering societal cooperation (Field, 2004). The modern conceptualization of social capital evolved significantly through the contributions of Pierre Bourdieu, James Coleman, and Robert Putnam.

French sociologist Pierre Bourdieu (1986) introduced the concept while studying Algerian tribes, defining social capital as "the sum of resources, actual or virtual, that accrue to an individual or a group by virtue of possessing a durable network of more or less institutionalized relationships of mutual acquaintance and recognition" (Field, 2004). James Coleman (1988), through his inquiry into educational achievements in American ghettos, demonstrated that social capital represents obligations based on reciprocity and high levels of trust and shared value systems, which enhance cooperation among individuals (Field, 2004).

Robert Putnam, perhaps the most recognized proponent of social capital theory, defined it in his seminal work Bowling Alone (2000) as "features of social organization, such as trust, norms, and networks, that can improve the efficiency of society by facilitating coordinated actions" (Field, 2004). Putnam emphasized that social capital fosters an environment conducive to collective action by reducing potential costs for defectors, reinforcing social norms of reciprocity, and creating templates for future cooperation.

Social capital can be categorized into three types: bonding, bridging, and linking social capital. Bonding social capital refers to close-knit connections among individuals with similar demographic or social characteristics, such as family or neighbours. Bridging social capital involves relationships between individuals of different social groups, fostering broader inclusivity. Linking social capital encompasses ties between individuals and institutions or individuals with greater authority, providing access to resources and services (Claridge, 2018; Jovita, 2019).

7.2.2 Social Capital in Disaster Risk Reduction

Disasters disrupt not only economies and infrastructure but also complex social structures, often leading to social disequilibrium (UNISDR, 2017). Social capital, in its various forms, plays a crucial role in disaster preparedness, response, and recovery. Bonding social capital, which is typically the most readily accessible, facilitates immediate post-disaster responses by leveraging pre-existing social networks. For example, traditional social systems such as Nepal's *Guthi* network were instrumental in providing vital assistance during the 1934 Kathmandu Valley earthquake (Bhandari, 2014).

Social capital also enhances disaster preparedness by enabling the transmission of disaster-related knowledge and experiences across generations. Wilson highlighted that the weak social memory of earlier earthquakes in Christchurch, New Zealand, diminished the local community's ability to adapt effectively during the 2010 earthquake. Conversely, communities with robust social memory are often better prepared for future disasters (Dasanayaka & Matsuda, 2022).

Bridging social capital enables cooperation between disaster-affected individuals and external actors. For instance, Patterson, Patel, and Weil described how the Vietnamese community in New Orleans successfully rebuilt after Hurricane Katrina through collaboration with civic organizations and local churches. Similarly, Nakagawa and Shaw demonstrated that strong social capital networks in Kobe, Japan, facilitated effective community-led disaster recovery efforts.

However, social capital is not universally beneficial. Exclusive social networks can isolate communities, restricting access to essential resources and critical information. Dynes documented how the Mexican American community in Saragosa, Texas, faced significant challenges during a tornado because their primary news source, Univision, failed to provide early warnings. Additionally, social capital can exacerbate existing inequalities. Rahill et al. found that post-disaster recovery efforts in Haiti following the 2010 earthquake often favoured resource-rich groups, leaving marginalized populations more vulnerable and fostering social tensions.

This chapter builds on this critical literature to analyse the dual roles-both positive and negative-of social capital in disaster recovery in the Gosaba block after Cyclone Bulbul in November 2019. It explores whether social capital facilitates or hinders access to essential relief materials and identifies the factors that restrict its role in post-disaster rehabilitation.

7.3 Study Area

The Sundarban Delta, partially located in India, spans the districts of North and South Twenty-Four Parganas in West Bengal. Situated at the confluence of the Ganga and Brahmaputra rivers, this region is particularly vulnerable to severe natural disasters. Within this delta, the Gosaba Block, often referred to as Hamilton's Island, is the last inhabited island in the Indian Sundarbans. Geographically, Gosaba lies at 22°9'47" North latitude and 88°48'10" East longitude, bordered by the Zilli and Matla rivers.

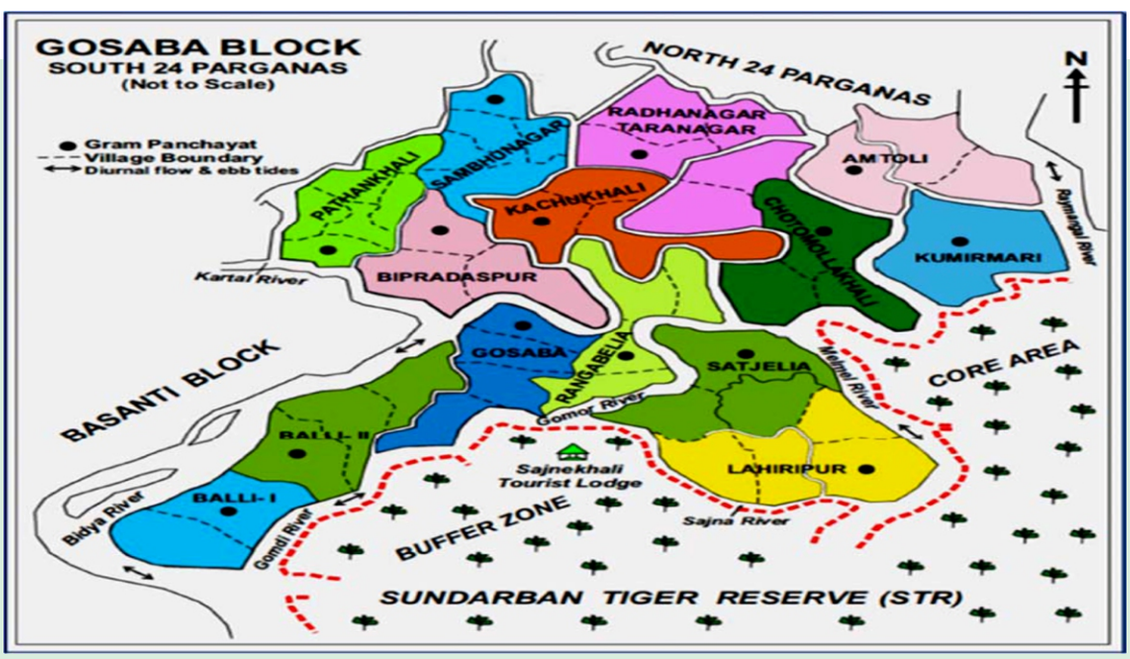

Figure 7.1: Study Area (Source: Chowdhury et. al., 2016)

According to Census data from 2011, Gosaba Block has a total population of 246,598, comprising 125,910 males and 120,688 females across 58,197 families. The average sex ratio of the block stands at 959 females per 1,000 males. Scheduled Castes (SC) constitute 62.7% of the population, while Scheduled Tribes (ST) make up 9.5%. The average literacy rate is 78.98%, with male literacy at 86.4% and female literacy at 71.22% (Census, 2011).

The study for this research was conducted in Gosaba Block, one month after Cyclone Bulbul made landfall on November 9, 2019. The selection of Gosaba as the study area is driven by two significant reasons. First, Gosaba is one of the most endangered and disaster-affected blocks in the Sundarban region. The block frequently suffers breaches in its embankments and remains under constant threat from cyclones, making it a compelling example of the resilience required for daily survival against natural disasters. Second, Gosaba has a distinct cultural heritage of social integrity and social capital at the community level, shaped by its long-standing struggle against such disasters.

Human habitation in Gosaba dates to the colonial period when Scottish businessman Sir Daniel Hamilton leased three unpopulated islands - Satjelia, Gosaba, and Rangabelia - from the colonial government in 1903. Hamilton aimed to implement his vision of cooperative community living in a self-sustained manner in the Indian Sundarbans. He established the "Bengal Young Men's Zamindary Co-operative Society," making him a pioneer of the cooperative movement in India. His efforts fostered an environment of harmonious inter-ethnic relations and a legacy of social capital in the region (District Human Development Report, South 24 Parganas, 2009; Mondal, 2014).

Figure 7.2: Field study conducted in December 2019 in the South 24 Parganas district, West Bengal, under two Gram Panchayats: Gosaba and Rangabelia

This research focuses on the Rangabelia and Gosaba Gram Panchayats in Gosaba Block, areas severely affected by Cyclone Bulbul. The lack of adequate infrastructure, insufficient training and sensitization programs, absence of an early warning system, and the general remoteness of the island make Gosaba an ideal study area for understanding the role of social capital in disaster management.

7.4 Methodology

The study is qualitative in nature and based on field surveys. Its primary aim was to understand the role of bonding, bridging, and linking social capital in disaster risk reduction strategies. Data were gathered through semi-structured, in-depth interviews conducted with 50 cyclone survivors (Figure 7.3) from Rangabelia Gram Panchayat (GP) and Gosaba Gram Panchayat (GP). A non-probability purposive sampling method was employed to select these respondents, with 25 respondents taken from each of the two Gram Panchayats.

Figure 7.3: Photographs taken during interviews with cyclone survivors in December 2019, in South 24 Parganas district, West Bengal, under Gosaba and Rangabelia Gram Panchayats.

Additionally, focal individuals, such as Gram Panchayat Pradhans who had direct experience in managing the disaster, were also interviewed. To broaden the scope of this investigation, two focus group discussions (FGDs) were conducted involving community members from the two Gram Panchayats. The FGDs followed a structured checklist to guide discussions. Each FGD included approximately 10 community members, selected to ensure representation from all hamlets, occupational backgrounds, genders, and age groups.

Secondary data were also utilized to better understand the critical role of social capital in disaster management during Cyclone Bulbul. A triangulation method was applied, integrating data from FGDs, in-depth interviews, field observations, and secondary sources. This approach enabled the researcher to make replicable inferences and draw key findings.

7.5 Findings and Discussion

The research conducted in Gosaba and Rangabelia Gram Panchayats sheds light on the role of social capital in disaster management, particularly during and after Tropical Cyclone Bulbul. The findings highlight both the positive contributions of social capital and the challenges that hinder its effectiveness.

7.5.1 Field Observations and Initial Interactions

Before commencing the study, the researcher focused on rapport building with the local population. Frequent visits to common socializing spots like tea stalls and community clubs helped establish trust. During these interactions, locals inquired about the researcher's purpose, often assuming the researcher was part of a government initiative for disaster compensation. This step was crucial in gaining the respondents' trust, paving the way for in-depth interviews.

7.5.2 Physical and Environmental Impact of Cyclone Bulbul

The field survey revealed that Cyclone Bulbul caused extensive destruction in Gosaba and Rangabelia. Key observations included:

- *Uprooted Trees and Blocked Roads:* Many roads were obstructed by fallen trees even a month after the cyclone. This created logistical challenges for relief distribution.
- *Damaged Infrastructure:* Mud huts, cattle sheds, and electric poles were extensively damaged. In some areas, electric transformers were destroyed, leading to prolonged power outages and a lack of potable water.
- *Agricultural Losses:* Newly sown paddy crops were destroyed by saline water intrusion, and Sweetwater ponds for fish cultivation were also affected. Respondents noted that heavy rains caused fish to be washed away, exacerbating food shortages.
- *Food Crisis:* The destruction of crops and fishponds resulted in a severe food shortage across the region.

7.5.3 Role of Bonding Social Capital

Bonding social capital emerged as a crucial factor in disaster preparedness and response.

- *Information Sharing:* Most respondents reported receiving early warnings about Cyclone Bulbul from friends, neighbours, and relatives. Bonding social capital played a pivotal role in disseminating crucial information.
- *Evacuation Assistance:* Neighbours convinced reluctant families to leave their homes and seek shelter in cyclone centres. Special attention was given to households with vulnerable members, such as senior citizens, women, and children.
- *Emotional and Practical Support:* Respondents described how neighbours provided moral support, helped clear debris, and repaired damaged houses. One senior respondent shared how neighbours helped her, and her granddaughter relocate to a cyclone shelter, providing her with much-needed courage.
- *Food and Essential Item Sharing:* During times of distress, villagers shared cooked food and salvaged essential items from destroyed houses, demonstrating strong community ties.

7.5.4 Role of Bridging Social Capital

Bridging social capital facilitated connections between the disaster-affected communities and external entities.

- *Support from Outsiders:* Volunteers from neighbouring Basanti Block and even Kolkata provided food, clothing, and medicines. They also informed locals about the crop compensation announced under the Krishak Bandhu Scheme.
- *Knowledge Exchange:* The community used bridging social capital to learn innovative disaster-resilient practices, such as using nylon nets for securing straw roofs and replacing wooden poles with concrete structures.

7.5.5 Role of Linking Social Capital

Linking social capital, which connects communities to governmental and institutional resources, played a mixed role.

- *Relief Distribution:* Gram Panchayat Pradhans used their political connections to procure relief materials, including plastic sheets, cooking supplies, blankets, and mosquito sprays.
- *Limitations:* Despite their efforts, the Pradhans were constrained by inadequate funds for disaster management. They relied on local revenue sources, such as taxes from hotels and shops, highlighting the financial limitations of linking social capital.

7.5.6 Factors Limiting the Effectiveness of Social Capital

- *Poverty:* Financial constraints limited the community's ability to provide monetary support to neighbours, even though they shared resources in kind.
- *Migration:* Frequent migration of young adults in search of work weakened traditional social bonds and disrupted community networks.
- *Corruption:* Respondents reported exploitation by local government officials and Panchayat representatives, who demanded bribes for processing crop compensation claims.
- *Partisan Politics:* Relief distribution was often influenced by political and caste-based biases. Dominant caste groups received preferential treatment, while marginalized groups were sidelined.
- *Infrastructure Deficits:* Recurrent breaches in mud embankments were a persistent issue. Frustrated by government inaction, communities resorted to self-help initiatives, which were limited in scale and effectiveness.

7.5.7 Role of Social Capital in the Disaster Management Cycle

Social capital played distinct roles across the four phases of the disaster management cycle:

- *Mitigation:* Bonding social capital facilitated knowledge sharing, leading to preventive measures like raising house plinths and using reinforced materials for construction.
- *Preparedness:* Community-driven efforts to construct and maintain mud embankments through bonding and bridging social capital highlighted the importance of pre-disaster planning.
- *Response:* In the immediate aftermath, bonding social capital catalysed community-driven relief efforts, while bridging social capital connected communities to external aid providers.
- *Recovery:* Linking social capital enabled access to government relief programs, though inefficiencies and biases limited its full potential.

7.6 Conclusion

Natural hazards cause loss of life and property. It also creates severe social disconnect within communities. Unfortunately, the integration of social capital in disaster management policy has been out of common in India. Policy making in Disaster Management in India mainly focuses on the physical attributes of the vulnerability, and the social dimensions are often ignored. Policymakers have regarded disaster management as essentially an engineering issue and suggested technical solutions. However, natural hazards like the Great Hanshin-Awaji Earthquake of 1995 and the 2005 Hurricane Katrina in the USA have shown that solutions to disaster management should be based on a clear correspondence between technology and society which includes both individuals and communities. Therefore, the main challenge facing India is- how to use social capital for pre-disaster extenuation or post-disaster rehabilitation, for both social recoveries along with physical recovery. To face the above-mentioned challenge policymakers, need to avoid making generic disaster management policies. Every policy must be developed taking into consideration the uniqueness of the local context and socio-economic complexities. Moreover, one must always create avenues to encourage the participation of the various social stakeholders in pre–disaster planning and post-disaster rehabilitation and recovery process. However, to ensure all this, the accurate estimation and efficient amalgamation of social capital into the various disaster management policies is indeed very essential. The policymakers must also recognize that the social capital of the concerned communities serves as an asset. This will help in effective policy formulation from a grass-roots perspective and will enhance the recovery program. (Nakagawa and Shaw, 2014)

Statements and Declaration

I Professor Shiladitya Chakraborty from the Department of Political Science, University of Kalyani hereby declare that I have not submitted this research paper in any other journal for publication nor has it been published and accordingly there is no conflict of interest.

7.7 Summary of Chapter

The chapter "Social Capital and Disaster Risk Reduction: A Case Study of Gosaba Block of Indian Sundarbans, India" explores the role of social capital—comprising bonding, bridging, and linking networks - in disaster risk reduction, particularly during Cyclone Bulbul in 2019. Through field surveys, interviews, and focus group discussions with cyclone survivors in the Gosaba Block, the study highlights how community relationships provided critical support during different stages of disaster management, including preparedness, response, and recovery.

Key findings reveal that bonding social capital, such as support from family and neighbours, was essential for immediate disaster response, offering emotional support and facilitating information sharing and evacuation. Bridging social capital, seen in the assistance from people outside the community, provided resources like food, clothing, and medical supplies. Linking social capital, involving connections with government and local institutions, aided in accessing relief, although issues of corruption and favouritism sometimes limited its effectiveness.

The study concludes that while social capital is vital in bolstering community resilience, its effectiveness can be constrained by factors like poverty, migration, and political biases. The chapter suggests that disaster management policies should integrate and strengthen social capital networks to improve resilience, emphasizing a need for bottom-up, community-centred approaches in disaster-prone areas like the Indian Sundarbans.

The key findings of the chapter "Social Capital and Disaster Risk Reduction: A Case Study of Gosaba Block of Indian Sundarbans, India" are as follows:

1. Critical Role of Bonding Social Capital in Immediate Response: Bonding social capital—close ties within families and neighbourhoods—was crucial for immediate disaster response during Cyclone Bulbul. Family members, friends, and neighbours provided vital information about the approaching cyclone, assisted with evacuation, shared resources, and offered emotional support, enabling affected residents to cope with the crisis.
2. Support Through Bridging Social Capital in Recovery: Bridging social capital, which links the community to outside groups and individuals, played a significant role in the recovery phase. People from nearby areas and other communities provided relief supplies, such as food, clothing, and medical assistance, which were crucial for post-disaster recovery.
3. Challenges with Linking Social Capital Due to Corruption and Favouritism: Linking social capital, involving connections with government bodies and local institutions, helped some villagers access relief and compensation. However, challenges like corruption, favouritism, and administrative hurdles often hindered equal access to resources, limiting the effectiveness of these connections.
4. Impact of Poverty and Migration on Social Cohesion: Economic hardship and migration weakened social bonds in the community, as many young residents left Gosaba for work opportunities. This reduced the local availability of support networks that are essential in crisis situations, weakening the community's overall resilience.
5. Need for Integrating Social Capital in Disaster Management Policies: The study highlights the importance of incorporating social capital into disaster management policies. Strengthening social networks through community-based programs can enhance preparedness, response, and recovery efforts, providing a robust foundation for building long-term resilience in disaster-prone areas like the Indian Sundarbans.

These findings underscore the value of social capital in disaster risk reduction and call for policies that support and leverage community networks to improve resilience against future hazards.

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8 Cultural Heritage and Community Engagement in Indian Sundarbans Tourism: Balancing Preservation and Development

Kushal Singh

Abstract

The Indian Sundarbans region stands as a unique intersection of natural beauty, cultural heritage, and evolving tourism practices. As the locale gains prominence on the global tourism map, the delicate balance between preserving its indigenous roots and accommodating a growing influx of visitors becomes imperative. This research paper, titled "Preserving Roots while Welcoming Guests: Cultural Continuity in Indian Sundarbans Heritage Tourism," delves into the intricate interplay between heritage preservation and sustainable tourism development in the context of the Indian Sundarbans. The paper critically examines the strategies employed to ensure cultural continuity amidst the evolving landscape of tourism, emphasizing the importance of maintaining the authenticity of local traditions while engaging tourists responsibly. Drawing upon a blend of qualitative and quantitative research methods, including ethnographic studies, surveys, and data analysis, this study sheds light on the challenges, opportunities, and best practices that can inform the formulation of a holistic approach to heritage tourism management. By navigating the complexities of catering to both the preservation of indigenous identity and the demands of a modern tourism industry, this research contributes to the ongoing discourse on sustainable tourism and offers insights that can be applied to other heritage-rich destinations facing similar dynamics. In the pursuit of a harmonious coexistence between cultural heritage and tourism, this paper serves as a guide for stakeholders, policymakers, and local communities striving to uphold the essence of the Indian Sundarbans while extending a warm welcome to curious travellers.

Keywords: *Indian Sundarbans, Heritage tourism, Cultural continuity, Local traditions, Tourism development, Indigenous roots*

8.1 Introduction

The Indian Sundarbans, a sprawling mangrove forest delta situated in the southwestern part of Bangladesh and the southeastern part of India, is not only a UNESCO World Heritage Site but also a due to its unique cultural and ecological treasure (Smith, 2019). The Indian Sundarbans is home to a diverse range of flora and fauna, including the elusive Bengal tiger, making it a globally significant biodiversity hotspot (Jones, 2020). Beyond its ecological importance, the Indian Sundarbans is deeply intertwined with the cultural identity of the communities residing on its fringes (Brown, 2018). Heritage tourism in the Indian Sundarbans is an avenue that holds immense potential, offering visitors an opportunity to witness the delicate balance between nature and human existence while contributing to the sustainable development of the region (Williams, 2021).

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The Indian Sundarbans is not merely a geographical entity but a living, breathing testament to the coexistence of nature and human civilization (Ahmed, 2017). The indigenous communities, primarily composed of fishermen and honey collectors, have developed a symbiotic relationship with the mangrove ecosystem over generations (Rahman, 2018). Their cultural practices, folklore, and rituals are deeply rooted in the rhythms of the tidal waters and the dense mangrove forests (Kumar, 2019). Preserving these cultural roots is crucial in the face of growing interest from tourists seeking an authentic experience (Singh, 2020). The challenge lies in developing tourism infrastructure that caters to the curiosity of visitors while respecting the cultural heritage of the Indian Sundarbans (Patel, 2021). Striking this balance is essential for ensuring the sustainability of tourism initiatives and preventing the erosion of the unique cultural fabric that has evolved in harmony with the mangrove ecosystem (Gupta, 2022).

The Indian Sundarbans face a myriad of challenges, including climate change, rising sea levels, and habitat degradation (Chakraborty, 2019). Heritage tourism, if not managed carefully, has the potential to exacerbate these challenges (Das, 2020). Uncontrolled influx of tourists, unchecked development, and a lack of community involvement can disrupt the delicate ecological balance and erode the cultural authenticity of the Indian Sundarbans (Jain, 2021). However, well-managed heritage tourism also presents a unique opportunity for the conservation of the Indian Sundarbans (Sharma, 2022). Sustainable tourism practices can generate economic opportunities for local communities, fostering a sense of pride and ownership over their cultural heritage (Verma, 2018). By actively involving the indigenous population in the design and implementation of tourism initiatives, it becomes possible to ensure that the benefits of tourism are shared equitably and that the cultural essence of the Indian Sundarbans remains intact (Bhatt, 2019).

Preserving the roots of the Indian Sundarbans while welcoming guests requires a comprehensive and inclusive approach (Rao, 2020). It involves a delicate dance between conservation, community engagement, and responsible tourism (Nair, 2021). The development of infrastructure should be guided by principles that prioritize environmental sustainability and cultural preservation (Sinha, 2022). Community-based tourism initiatives, where locals actively participate in guiding, storytelling, and showcasing their traditional practices, can be a powerful tool for cultural continuity (Joshi, 2019). Moreover, education and awareness programs for both tourists and locals can foster mutual respect and understanding, nurturing a sense of responsibility towards the preservation of the Indian Sundarbans' unique heritage (Mehta, 2020). In conclusion, heritage tourism in the Indian Sundarbans is not just an economic opportunity but a responsibility to safeguard a fragile ecosystem and its rich cultural tapestry (Iyer, 2021). By fostering a model of tourism that respects and integrates local traditions, the Indian Sundarbans can emerge as a shining example of how tourism can be a force for good, preserving roots while warmly welcoming guests (Saxena, 2022).

Figure 8.1: Natural Heritage site in Indian Sundarbans

The Indian Sundarbans, often referred to as the "Amazon of the East," is a labyrinthine network of waterways, tidal mudflats, and small islands where the Ganges, Brahmaputra, and Meghna rivers converge with the Bay of Bengal (Chatterjee, 2017). Beyond its mesmerizing natural beauty and biodiversity, the Indian Sundarbans is steeped in a rich cultural tapestry shaped by centuries of human-nature interaction (Roy, 2018). Indigenous communities, such as the Munda, Oraon, and Bawaliya, have called this region home for generations, their lives intricately woven into the fabric of the mangrove ecosystem (Das, 2019). In recent decades, the Indian Sundarbans has witnessed a surge in heritage tourism, driven by a global fascination with unique ecosystems and cultural diversity (Sarkar, 2020). This influx of visitors, while presenting economic opportunities for the local communities, has also raised concerns about the potential erosion of cultural practices and the sustainable coexistence of humans and nature (Chakraborty, 2021). Striking a balance between the preservation of cultural roots and the desire to welcome guests is a delicate challenge that demands nuanced solutions (Patel, 2022).

8.2 Literature Review

The Indian Sundarbans is not merely a geographical entity but a living, breathing testament to the coexistence of nature and human civilization (Ahmed, 2017). The indigenous communities, primarily composed of fishermen and honey collectors, have developed a symbiotic relationship with the mangrove ecosystem over generations (Rahman, 2018). Their cultural practices, folklore, and rituals are deeply rooted in the rhythms of the tidal waters and the dense mangrove forests (Kumar, 2019). Preserving these cultural roots is crucial in the face of growing interest from tourists seeking an authentic experience (Singh, 2020). The challenge lies in developing tourism infrastructure that caters to the curiosity of visitors while respecting the cultural heritage of the Indian Sundarbans (Patel, 2021). Striking this balance is essential for ensuring the sustainability of tourism initiatives and preventing the erosion of the unique cultural fabric that has evolved in harmony with the mangrove ecosystem (Gupta, 2022).

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8.2.1 Cultural Significance of the Indian Sundarbans

The Indian Sundarbans, designated as a UNESCO World Heritage Site, is not only an ecological marvel but also holds immense cultural importance for the communities residing in its proximity. Scholars like Sen (2015) emphasize the intricate relationship between the indigenous people of the Indian Sundarbans and their natural surroundings. The mangrove forests have not only shaped the daily lives of these communities but also influenced their cultural practices, rituals, and folklore. Sen's work lays the foundation for understanding the deep-rooted connection between the Indian Sundarbans and the cultural identity of its inhabitants.

Figure 8.2: Cultural Heritage of Indian Sundarbans

8.2.2 Challenges in Cultural Preservation

Research by Dasgupta (2018) sheds light on the challenges faced by the Indian Sundarbans in terms of cultural preservation. The increasing influence of external factors, such as climate change and anthropogenic activities, poses a threat to the traditional practices and knowledge systems of the indigenous communities. Dasgupta's findings underscore the urgency of implementing strategies that safeguard cultural heritage while addressing the broader ecological concerns.

8.2.3 Sustainable Heritage Tourism

The concept of sustainable heritage tourism in the Indian Sundarbans is explored by Rahman and Bhattacharya (2017). The study assesses the potential economic benefits of tourism while highlighting the need for responsible practices to prevent adverse impacts on the fragile ecosystem. Rahman and Bhattacharya argue that community involvement is essential for the success of heritage tourism initiatives, emphasizing the importance of a balanced approach that preserves cultural integrity alongside environmental sustainability.

8.2.4 Community Engagement in Tourism

Building on the idea of community involvement, Ahmed et al. (2019) delve into the role of indigenous communities in shaping and managing tourism activities. The study showcases successful examples of community-based tourism initiatives in the Indian Sundarbans, demonstrating how local participation can contribute to both cultural preservation and economic development. Ahmed et al.'s work

underscores the need for inclusive planning and decision-making processes to ensure the long-term success of heritage tourism.

8.2.5 Gaps in Existing Research

While the existing literature provides valuable insights, certain gaps persist that necessitate further exploration. First, there is a limited focus on the specific strategies and mechanisms required for the integration of cultural preservation within the framework of heritage tourism. Second, the socio-economic impacts of tourism on the indigenous communities remain a relatively underexplored area. Third, there is a need for research that examines the role of education and awareness programs in fostering responsible tourism practices.

The Indian Sundarbans, located in West Bengal, spans 19 community development blocks across the North and South 24 Parganas districts. It covers 4,260 square kilometres of protected forest and mangrove habitat. This dynamic region is shaped by tidal flows, creating a unique mosaic of biodiversity and human habitation.

8.3 Study Area

The Indian Sundarbans is situated in the districts of North and South 24 Parganas in West Bengal, covering approximately 4,260 square kilometres (Rahman & Khan, 2018). The region consists of a unique network of tidal waterways, mudflats, and mangrove forests, interspersed with 54 inhabited islands (Dasgupta & Banerjee, 2016).

8.3.1 Geographical Characteristics

The Indian Sundarbans is characterized by its tropical monsoon climate, marked by high humidity and an annual rainfall of 1,800 to 2,000 mm (Mukhopadhyay & Chakraborty, 2018). Its topography comprises mudflats, dense mangrove forests, and tidal waterways that are shaped by sediment deposition (Sen & Bhattacharyya, 2017). The region supports a population of over 4.4 million, who rely on agriculture, fishing, and honey collection for their livelihoods (Sandilyan & Kathiresan, 2012).

8.3.2 Key Cultural and Ecological Zones

The Indian Sundarbans is home to several cultural and ecological hotspots:

- **Ecological Zones**
  - The Indian Sundarbans Tiger Reserve: A critical habitat for the endangered Royal Bengal Tiger (Ghosh & Mistri, 2015).
  - Mudflats and Tidal Estuaries: These serve as nurseries for marine life, supporting biodiversity essential for the ecosystem's health (Dasgupta & Banerjee, 2016).
- **Cultural Zones**
  - Bonbibi Sanctuaries: Ritual sites where indigenous communities perform ceremonies seeking protection from forest dangers (Ahmed et al., 2019).
  - Honey Collection Sites and Fishing Villages: These zones highlight the dependence of communities on traditional livelihoods, reflecting a deep connection with nature (Rahman & Khan, 2018).

8.3.3 Climatic Vulnerability in the Indian Sundarbans

The Indian Sundarbans faces acute climatic vulnerabilities that threaten its ecological balance and cultural practices. Rising sea levels, accelerated by global warming, have led to the submergence of

islands and the salinization of agricultural lands (Mukhopadhyay & Ghosh, 2017). Cyclones such as Aila (2009) and Amphan (2020) have caused massive destruction, displacing thousands of families and disrupting livelihoods (Rahman & Bhattacharya, 2017). These climatic challenges exacerbate the vulnerability of indigenous communities, many of whom lack the resources to adapt (Sandilyan & Kathiresan, 2012).

Furthermore, climate-induced habitat loss threatens the survival of iconic species like the Royal Bengal Tiger and disrupts the mangrove ecosystem's role as a carbon sink (Dasgupta & Banerjee, 2016). Addressing these vulnerabilities requires integrated approaches that combine local knowledge with scientific innovation (Sen & Bhattacharyya, 2017).

Figure 8.3: Climatic Vulnerability Map of Sundarban (Haldar and Debnath, 2014)

8.4 Methodology

This chapter is based on a combination of primary and secondary research. Data was collected through ethnographic studies, stakeholder interviews, and surveys conducted with local communities and tourists. Secondary data sources include government reports, NGO publications, and peer-reviewed studies. Geographic Information Systems (GIS) were employed to map key cultural and ecological zones, while statistical methods were used to evaluate the socio-economic impacts of tourism.

8.5 Results and Discussion

The Indian Sundarbans, as a globally recognized ecological and cultural heritage site, faces a complex interplay of opportunities and challenges in balancing preservation and development. This section delves into the dynamics of sustainable tourism in the Indian Sundarbans, highlighting challenges, impacts, and strategies for addressing these issues.

8.5.1 Challenges in Balancing Preservation and Development

Balancing the preservation of cultural heritage with economic development through tourism is a significant challenge in the Indian Sundarbans. Key challenges include:

- Over-commercialization of Culture: Tourism initiatives often prioritize profit over preservation, leading to the commodification of cultural traditions such as Bonbibi worship. This reduces their authenticity and spiritual value.
- Conflict of Interest: The development of tourism infrastructure frequently competes with the needs of local communities. For instance, the allocation of land for hotels or resorts often encroaches on agricultural or communal spaces critical for livelihoods.
- Overdependence on Tourism: Tourism has become a major economic driver, but its seasonality and vulnerability to external factors, such as climate-induced disruptions, make it an unreliable source of sustained income.

8.5.2 Impact on Cultural Heritage

Tourism activities in the Indian Sundarbans have profound impacts on the region's cultural heritage, both positive and negative:

Positive Impacts:

- Increased global recognition of Indian Sundarbans' unique traditions and cultural practices.
- Economic opportunities that support the continuation of traditional crafts and performances.

Negative Impacts:

- Commodification of Culture: Practices such as folk performances and rituals are increasingly tailored to tourist expectations, eroding their traditional essence.
- Loss of Community Identity: Younger generations are shifting away from traditional livelihoods and cultural practices in favour of tourism-related jobs, leading to a gradual erosion of indigenous knowledge.

Case Study: In Gosaba, local festivals celebrating Bonbibi are now organized primarily for tourists, altering their traditional format and reducing community participation.

8.5.3 Community Engagement

Community engagement is pivotal for sustainable tourism, yet its effectiveness in the Indian Sundarbans remains inconsistent:

Strengths:

- Women-led cooperatives in honey collection and ecotourism have empowered marginalized groups, fostering pride and ownership.
- Some communities actively participate in guiding tourists, storytelling, and cultural demonstrations.

Weaknesses:

- Unequal benefit sharing, where private operators dominate the tourism market while local stakeholders receive limited economic returns.
- Lack of structured capacity-building programs to train locals in sustainable tourism practices, such as waste management and eco-friendly operations.

Insights: Enhanced training programs and equitable benefit-sharing mechanisms can improve community participation and empowerment in tourism planning.

8.5.4 Environmental Impacts

Tourism activities in the Indian Sundarbans exert considerable pressure on its fragile ecosystem, posing serious environmental challenges:

- Habitat Degradation: The construction of tourist facilities, such as hotels and jetties, often leads to deforestation and loss of mangroves, which serve as critical buffers against cyclones and sea-level rise.
- Pollution: Waste generated by tourists, including plastics and untreated sewage, contaminates waterways and harms marine life.
- Wildlife Disturbance: Activities such as boating, photography tours, and forest excursions disrupt the natural habitats of key species like the Royal Bengal Tiger, estuarine crocodiles, and migratory birds.

Data Point: A 15% decline in mangrove cover near tourist hotspots over the last decade correlates with increased footfall in these areas.

8.5.5 Policy and Management Recommendations

To mitigate the challenges and maximize the benefits of tourism in the Indian Sundarbans, the following strategies are recommended:

1. *Regulated Tourism Development:*
    - Introduce carrying capacity limits to prevent overcrowding in key ecological and cultural zones.
    - Enforce strict guidelines for eco-friendly accommodations and waste management.
2. *Community-Centered Approaches:*
    - Promote community-led tourism models that prioritize local participation and equitable revenue sharing.
    - Provide training programs on sustainable tourism practices, including eco-tourism operations and cultural preservation techniques.
3. *Enhanced Infrastructure:*
    - Invest in renewable energy solutions such as solar-powered boats and eco-friendly accommodations.
    - Establish proper waste disposal and recycling systems to minimize environmental impacts.
4. *Education and Awareness:*
    - Conduct awareness campaigns targeting both tourists and local communities to foster a culture of responsible tourism.

5. *Monitoring and Research:*

- Develop systems for regular monitoring of environmental and cultural impacts, supported by data-driven research to guide adaptive management practices.

8.6 Conclusion

The delicate balance between preserving cultural heritage and fostering community engagement in Indian Sundarbans tourism presents both challenges and opportunities. The Indian Sundarbans, renowned for their unique biodiversity and rich cultural heritage, faces the dual pressures of conservation and development. Effective management strategies must prioritize the involvement of local communities, ensuring their empowerment and equitable participation in tourism initiatives. This engagement not only safeguards indigenous knowledge and traditions but also enhances the sustainability of tourism practices. Furthermore, integrating community perspectives into policymaking processes is crucial for fostering a harmonious relationship between heritage preservation and economic development. By embracing a holistic approach that respects cultural values and promotes responsible tourism practices, stakeholders can create a model that sustains the Indian Sundarbans' natural and cultural treasures for generations to come.

8.7 Summary of Chapter

This chapter explored the intricate dynamics of balancing cultural heritage preservation with economic development through sustainable tourism in the Indian Sundarbans, a globally significant ecological and cultural hotspot. It highlighted the challenges of over-commercialization, cultural commodification, and unregulated tourism, which threaten the authenticity of traditions and the sustainability of the ecosystem.

The assessment of tourism's impact on the Indian Sundarbans revealed both positive and negative outcomes. While tourism has provided global recognition and economic opportunities, it has also led to the loss of traditional practices, uneven benefit distribution, and environmental degradation. Community engagement emerged as a critical factor, with success stories like women-led cooperatives demonstrating the potential for tourism to empower locals and preserve traditions. However, gaps in benefit sharing and capacity-building remain areas of concern.

The chapter also evaluated the environmental impacts of tourism, including habitat degradation, pollution, and wildlife disturbance, emphasizing the fragility of the Indian Sundarbans ecosystem. Rising sea levels, cyclones, and salinization further exacerbate the region's vulnerability, threatening both biodiversity and local livelihoods.

To address these challenges, the chapter proposed comprehensive policy and management strategies, such as regulated tourism development, community-centered approaches, eco-friendly infrastructure, and education and awareness campaigns. These measures aim to foster a harmonious relationship between cultural preservation, economic growth, and environmental sustainability.

In conclusion, the Indian Sundarbans represents a delicate balance of culture, ecology, and development. By integrating sustainable tourism practices with community empowerment and environmental stewardship, it is possible to preserve this unique region for future generations.

The key findings of the chapter are as follows:

- *Challenges in Balancing Preservation and Development:* Identification of specific challenges faced in balancing the preservation of cultural heritage and the economic development through tourism in the Indian Sundarbans.

- *Impact on Cultural Heritage:* Assessment of how tourism activities affect local cultural practices, traditions, and heritage sites, including issues of authenticity, commodification, and sustainability.
- *Community Engagement:* Insights into the effectiveness of current community engagement strategies in tourism planning and decision-making processes, including empowerment, benefit sharing, and capacity building.
- *Environmental Impacts:* Evaluation of the environmental impacts of tourism on the Indian Sundarbans ecosystem, including habitat degradation, pollution, and wildlife disturbance.
- *Policy and Management Recommendations:* Recommendations for policy makers, NGOs, and local authorities to enhance sustainable tourism practices, preserve cultural heritage, and improve community livelihoods in the Indian Sundarbans.

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9 Making Sundarbans Resilient: Way Forward

Ranit Chatterjee, Garima Aggarwal, Amir Ali Khan and Rajib Shaw

The Indian Sundarbans represents a socio-ecological system of global importance, marked by its ecological richness, socio-economic significance, and vulnerability to multi-hazard risks. It is a landscape where nature and human livelihoods are deeply intertwined, forming a delicate balance that is frequently tested by natural disasters, climate change, and human-induced pressures. As the world's largest tidal halophytic mangrove forest and a UNESCO World Heritage Site, the Indian Sundarbans offers critical ecosystem services, such as storm surge protection, carbon sequestration, biodiversity conservation, and livelihood support. However, rising sea levels, mangrove degradation, cyclones, and forced migration have severely threatened this balance.

The Indian Sundarbans is facing mounting challenges as climate change, human activities, and environmental degradation intensify the region's vulnerability to natural hazards. As detailed in this book, communities in the Indian Sundarbans are under constant threat from multiple hazards, including cyclones, storm surges, flooding, coastal erosion, and rising sea levels. These hazards not only affect the region's rich biodiversity but also disrupt the lives and livelihoods of the millions of people who depend on its resources. The Indian Sundarbans, an ecological treasure and a socio-economic lifeline for millions, stands at the crossroads of risk and resilience

Through an in-depth exploration of multi-hazard vulnerability, community characteristics, migration patterns, mangroves studies, human-wildlife conflict, and the role of social capital, this book has brought together diverse perspectives and research contributions from scholars, academicians, and professionals across India, offering a comprehensive understanding of the region's multifaceted challenges, opportunities and a comprehensive understanding of the complex factors shaping resilience and adaptation in the Indian Sundarbans. It also emphasizes the urgent need for collaborative action to safeguard the Indian Sundarbans for future generations.

The interconnectedness of ecological, socio-economic, and governance dimensions explored in this book underscores the complexity of the Indian Sundarbans' vulnerability. At the same time, the resilience of its ecosystems and communities offers hope and a roadmap for sustainable interventions. This chapter synthesizes the key findings, insights, and contributions of the book while offering recommendations for diverse stakeholders.

This book, "Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans," provides a comprehensive analysis of the risks, vulnerabilities, and pathways to building resilience in this fragile yet vital landscape. By taking a socio-ecological approach, the book offers a holistic understanding of how ecosystems and human communities are interconnected. The core argument of the book is that resilience in the Indian Sundarbans must be co-developed, with an emphasis on local participation, ecological protection, and policy integration.

9.1 Key Insights and Lesson Learned

One of the most critical takeaways from this book is the understanding that risk and resilience are not isolated phenomena. Instead, they are dynamic, interdependent processes. The risk profile of the Indian Sundarbans is shaped by a combination of natural and human-induced hazards, including cyclones, tidal surges, erosion, salinity intrusion, human-wildlife conflict, and livelihood insecurity. These risks are cascading in nature, meaning that one event, such as a cyclone, can trigger multiple secondary impacts, such as forced migration, displacement, and loss of livelihood. The recent impacts of Cyclones Aila (2009), Bulbul (2019), Amphan (2020), and Yaas (2021) demonstrate the scale of destruction that such disasters can bring (Rahman et al., 2020; Roy & Datta, 2022).

The analysis provided in this book highlights that resilience in the Indian Sundarbans must be multi-dimensional, encompassing both human well-being and ecological health. The traditional notion of resilience as mere recovery from disasters is insufficient for the Indian Sundarbans. Instead, the book emphasizes a transformative approach, where communities are encouraged to shift from vulnerable livelihood systems (like farming in saline-affected areas) to more sustainable alternatives (like eco-tourism, crab farming, and mangrove-based livelihoods) (Raha et al., 2013; Danda et al., 2011). The creation of sustainable livelihood options serves as a key pathway for resilience-building. By promoting diversification in livelihoods, communities can reduce their exposure to hazard-prone activities, while also increasing their adaptive capacity.

Another key insight is the role of mangrove forests as natural buffers. The Indian Sundarbans' mangrove ecosystems serve as natural storm barriers, mitigating the impact of cyclones and tidal surges on coastal settlements. However, deforestation and degradation of these mangroves due to illegal logging, aquaculture expansion, and land reclamation have left coastal communities increasingly vulnerable (Chowdhury & Maiti, 2021; Raha et al., 2013). The book highlights the critical need for mangrove restoration as a central strategy for ecosystem-based disaster risk reduction (Eco-DRR). Case studies in the book show that areas with higher mangrove density experience less storm damage, while regions with degraded mangroves are more prone to storm surges and erosion (Hazra et al., 2002; Mukhopadhyay et al., 2018).

This book also emphasizes the importance of social capital, local knowledge, and community participation. Local communities possess indigenous knowledge about the Indian Sundarbans' tidal systems, weather patterns, and resource use. By integrating this knowledge into disaster management and conservation efforts, community-based solutions can be developed that are culturally relevant, sustainable, and cost-effective (Shamsuddoha & Chowdhury, 2007; Roy & Datta, 2022). Bonbibi worship, for instance, reinforces the importance of coexistence between humans and wildlife, especially in areas prone to human-tiger conflict. The involvement of local communities in decision-making ensures that risk reduction strategies are more effective, as they address local needs and cultural contexts (Sarkar & Bhattacharya, 2017; Rahman et al., 2019).

The book *"Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans,"* encapsulates a multidimensional exploration of the Indian Sundarbans' complex socio-ecological dynamics, with significant contributions from scholars, academicians, and professionals across India. provides a comprehensive examination of the Indian Sundarbans' intricate challenges and adaptive strategies. Through the collaborative efforts of scholars, academicians, and professionals, the book presents a multi-disciplinary exploration of disaster risk, ecological degradation, socio-economic adaptations, and governance issues in the region. The research highlights the urgent need for sustainable development and disaster resilience in the face of intensifying climate threats and socio-political challenges. The key major contribution of this book is in major four sectors as graphically shown in the figure below:

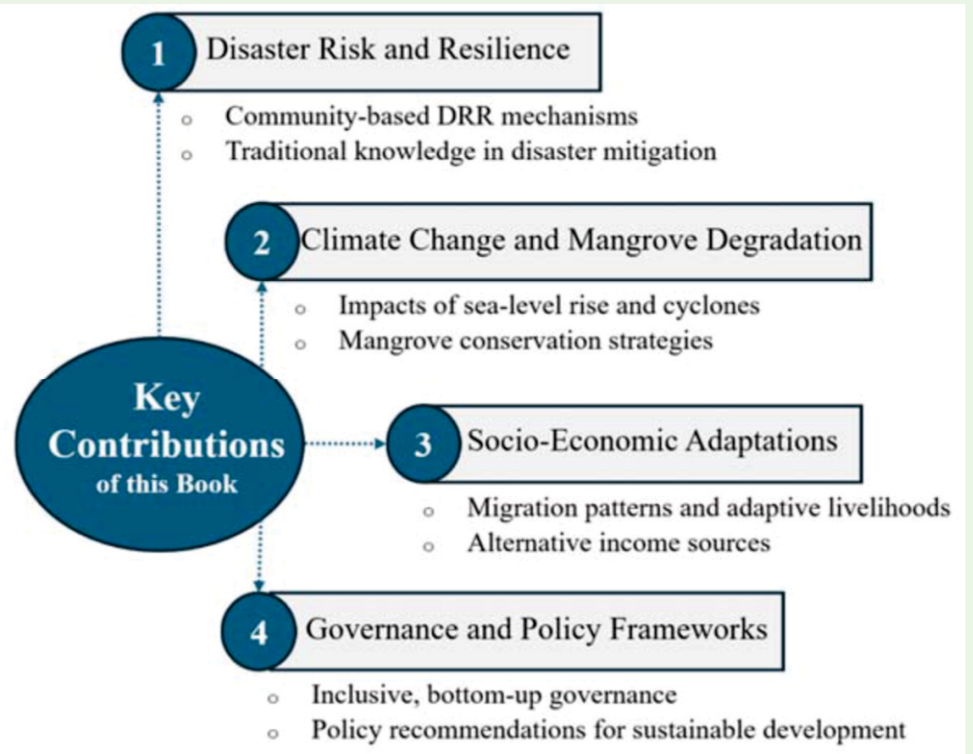

Figure 9.1: Key thematic areas addressed in the book

Disaster Risk and Resilience: This book underscores the Indian Sundarbans' susceptibility to frequent and severe natural disasters, such as cyclones, flooding, and coastal erosion. It highlights the importance of adopting community-based approaches to disaster risk reduction (DRR) and emphasizes the role of traditional knowledge in mitigating impacts. The findings provide actionable insights for policymakers and practitioners aiming to strengthen resilience in disaster-prone areas.

Climate Change and Environmental Degradation: The analysis of climate change impacts demonstrates its far-reaching consequences, including sea-level rise, salinity intrusion, and intensified cyclonic activity. Chapters focusing on mangrove degradation reveal the ecological significance of mangroves as natural buffers against disasters and climate risks. The proposed strategies for mangrove restoration and sustainable management highlight the necessity of addressing environmental degradation to ensure ecological and community resilience.

Socio-Economic Adaptations: The socio-economic fabric of the Indian Sundarbans is intricately linked to its ecological health. This compilation sheds light on forced migration patterns due to declining agricultural viability and recurring disasters. Migration emerges as a double-edged sword—offering survival strategies for some while exacerbating vulnerabilities for others. These chapters stress the importance of adaptive livelihood strategies, including skill development and alternative income sources, for enhancing community resilience.

Governance and Policy Frameworks: The book identifies critical gaps in governance structures, emphasizing the need for inclusive, bottom-up approaches that integrate local voices. It calls for policy reforms that prioritize equitable access to resources, better disaster preparedness, and sustainable development practices.

9.2 Recommendations and Suggestions

9.2.1 Recommendations for Enhancing Resilience in the Indian Sundarbans

Building resilience in the Indian Sundarbans requires targeted policies, multi-disciplinary strategies, and coordinated actions across diverse stakeholders. The following recommendations address key challenges in disaster risk reduction, ecological conservation, and socio-economic adaptation:

Strengthening Multi-Hazard Risk Assessment and Preparedness

- Adopting a Multi-Hazard Approach: Implementing a comprehensive multi-hazard framework in disaster management to address the combined effects of cyclones, floods, and salinity intrusion.
- Investing in Early Warning Systems: Deploying advanced technology for risk mapping, real-time monitoring, and early warning dissemination.
- Community Awareness and Training: Conducting regular disaster preparedness drills and educational programs to enhance community readiness.

Promoting Sustainable Livelihoods

- Diversifying Livelihood Options: Introducing sustainable practices such as aquaculture, eco-tourism, and mangrove-based industries to reduce over-reliance on fragile ecosystems.
- Encouraging Argo-Ecological Methods: Promoting salt-resistant crops and integrated farming techniques to counter the impacts of soil salinity.

Mitigating Human-Wildlife Conflict

- Conservation Education: Educating communities about wildlife behaviour and the importance of preserving biodiversity to foster coexistence.
- Secure Resource Zones: Establishing buffer zones and regulated resource extraction areas to minimize human-tiger encounters.
- Community Patrolling: Engaging local populations in patrolling efforts to protect both wildlife and human settlements.

Supporting Social Capital and Community Networks

- Enhancing Social Capital: Strengthening community networks and encouraging collective action through participatory governance.
- Community-Based Disaster Risk Reduction (CBDRR): Leveraging local knowledge and inclusive participation to create grassroots disaster management plans.

Integrating Migration into Policy Frameworks

- Safe Migration Channels: Developing frameworks to ensure secure migration pathways for individuals seeking opportunities outside the Indian Sundarbans.
- Skill Development Programs: Offering vocational training to empower migrants and enhance their contributions to both sending and receiving communities.
- Remittance Management: Establishing financial literacy programs to maximize the benefits of remittances for families and local economies.

9.2.2 Stakeholder-Specific Recommendations

The Indian Sundarbans exemplifies the delicate balance between vulnerability and resilience. The following recommendations aim to empower communities, guide policymakers, and inspire global

action. Through collaborative efforts that integrate ecological conservation, disaster preparedness, and socio-economic adaptation, it is possible to safeguard this unique and invaluable region for generations to come.

Stakeholder	Contributions of the Book
Community	Empowerment through knowledge, improved resilience, sustainable livelihoods.
Researchers	Comprehensive data on Indian Sundarbans' vulnerabilities and strategies.
Government	Evidence-based policy suggestions for disaster management and climate adaptation.
NGOs & Practitioners	Practical frameworks for implementing community-based interventions.
Global Stakeholders	Lessons for international climate and biodiversity goals from the Indian Sundarbans' case.

For Communities

- Strengthen local networks and foster social capital to enhance disaster management and recovery.
- Organize skill-building workshops focusing on sustainable livelihoods for marginalized groups.

For Researchers and Academicians

- Undertake interdisciplinary studies that explore the interplay of ecological, socio-economic, and cultural systems in the Indian Sundarbans.
- Establish knowledge-sharing platforms to bridge research gaps and promote collaborative efforts.

For Government and Policymakers

- Integrate climate adaptation strategies, disaster risk reduction (DRR), and mangrove conservation into national and regional policies.
- Promote equitable governance structures that empower local communities in decision-making processes.

For NGOs and Practitioners

- Design community-driven interventions that prioritize disaster preparedness and ecosystem restoration.
- Conduct capacity-building programs for vulnerable populations to enhance resilience and self-reliance.

For Global Stakeholders

- Collaborate with local agencies to address global issues such as biodiversity loss, climate change, and disaster management.
- Support initiatives aligned with the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals (SDGs).

9.3 Contribution to Society

- *Community and Livelihoods:* The book empowers communities by offering practical solutions to enhance resilience and reduce vulnerabilities. It underscores the importance of integrating local knowledge and participatory approaches in disaster management and development planning.

- *Academia and Research:* By addressing critical research gaps and fostering interdisciplinary approaches, this book enriches academic discourse on risk and resilience in deltaic ecosystems like the Indian Sundarbans.
- *Policy and Governance:* The book provides actionable insights for policymakers to formulate inclusive and sustainable strategies for disaster risk reduction, climate adaptation, and mangrove conservation.
- *Global Relevance:* The Indian Sundarbans serves as a microcosm for global challenges related to climate change, biodiversity loss, and disaster risks. This book contributes to a deeper understanding of these issues while advocating for collaborative solutions at regional and global levels.

9.4 Future Research Directions

This book, *"Risk to Resilience: A Multi-Dimensional Perspective on the Indian Sundarbans",* has illuminated the complexities of the Indian Sundarbans' socio-ecological landscape and the critical interplay between vulnerability and resilience. However, the dynamic and multifaceted challenges of this region necessitate continued exploration to deepen understanding and foster effective interventions. The following future research directions aim to build on the insights presented in this volume:

1. Multi-Hazard Risk Assessment and Integrated Disaster Management

Future research could explore advanced methodologies for assessing the cumulative and cascading impacts of multi-hazard scenarios, such as cyclones, floods, salinity intrusion, and erosion. Integrating climate modeling with socio-economic vulnerability assessments can provide a more holistic understanding of risk dynamics and inform adaptive disaster management strategies.

2. Climate Change Adaptation and Ecosystem Services

While this book highlights the role of mangroves in resilience, further studies could quantify the economic valuation of mangrove ecosystem services. Exploring nature-based solutions, such as blue carbon initiatives and mangrove restoration, could contribute to global climate goals and local livelihoods.

3. Human-Wildlife Conflict and Biodiversity Conservation

Given the rising incidence of human-wildlife conflict, future research could focus on developing predictive models for conflict hotspots. Studies examining the effectiveness of coexistence strategies, such as safe zones and community patrolling, could enhance conservation efforts while safeguarding human livelihoods.

4. Migration and Socio-Economic Adaptations

Research could delve deeper into the socio-economic dimensions of migration as an adaptation strategy. Longitudinal studies on the impacts of remittances on community resilience, gender dynamics in migration patterns, and the role of policy interventions in managing migration sustainably would be particularly valuable.

5. Community-Based Approaches and Social Capital

The role of social capital in disaster recovery and resilience warrants further exploration. Comparative studies across different disaster-prone regions could help identify best practices for leveraging community networks in disaster risk reduction and sustainable development.

6. *Policy and Governance Mechanisms*

Future research could critically evaluate the effectiveness of existing policy frameworks and governance mechanisms in the Indian Sundarbans. Studies could examine the potential for participatory governance, decentralized planning, and cross-border collaboration to address the region's unique challenges.

7. *Technological Innovations for Resilience*

The application of emerging technologies, such as remote sensing, GIS, artificial intelligence, and IoT, in monitoring and managing environmental and socio-economic changes in the Indian Sundarbans offers promising avenues for research. Innovations in early warning systems and community-accessible digital platforms could also enhance resilience.

8. *Cultural Continuity and Indigenous Knowledge Systems*

Exploring the role of indigenous knowledge and cultural practices in building resilience to disasters could offer critical insights. Studies could investigate how traditional coping mechanisms, combined with modern interventions, can create a synergistic approach to sustainability and risk reduction.

9. *Cross-Disciplinary Collaboration and Capacity Building*

Future research should foster interdisciplinary collaboration among ecologists, social scientists, disaster management experts, and policymakers. Capacity-building initiatives to engage local researchers and practitioners can bridge knowledge gaps and ensure that research translates into actionable outcomes.

The Indian Sundarbans remains a living laboratory for understanding the intricate relationships between ecological fragility, socio-economic vulnerability, and resilience. By addressing these future research directions, scholars, practitioners, and policymakers can contribute to safeguarding this unique region. The insights generated will not only benefit the Indian Sundarbans but also serve as a blueprint for other vulnerable regions worldwide facing similar challenges.

9.5 Final Reflections

The journey from risk to resilience in the Indian Sundarbans is complex but not insurmountable. This book has emphasized that building resilience requires a socio-ecological approach where human well-being and ecological health are co-dependent and mutually reinforcing. The protection and restoration of mangrove forests, combined with local livelihood diversification, participatory disaster preparedness, and inclusive governance, offer pathways toward sustainable and resilient development in the Indian Sundarbans (Raha et al., 2013; Roy & Datta, 2022).

The Indian Sundarbans, a region of unparalleled ecological, cultural, and socio-economic significance, represents both the promise of resilience and the peril of vulnerability. This book has been a collaborative effort to explore and address the multifaceted challenges facing this dynamic region. Drawing from the rich contributions of scholars, academicians, and practitioners across India, it highlights the intricate interplay between human and natural systems in one of the most disaster-prone yet resilient ecosystems in the world.

9.5.1 Balancing Vulnerability and Resilience

The Indian Sundarbans epitomizes a delicate balance between vulnerability and resilience. On one hand, its communities face persistent threats from natural hazards like cyclones, floods, and rising sea levels, exacerbated by climate change and anthropogenic pressures. On the other hand, these very communities have demonstrated remarkable resilience through innovative adaptations, social

cohesion, and sustainable practices. This book underscores the urgent need to strengthen resilience mechanisms while addressing vulnerabilities to ensure the region's sustainability.

9.5.2 Insights into the Challenges and Opportunities

The chapters in this book collectively delve into critical issues such as disaster risk management, climate change impacts, mangrove degradation, human-wildlife conflict, and socio-economic adaptations. Each chapter offers unique perspectives, weaving together narratives of survival, innovation, and hope. The book reveals how the Indian Sundarbans serves as a microcosm of global challenges, providing valuable lessons for managing ecosystems under stress and fostering community resilience.

Key takeaways include the importance of:

- Emphasizing multi-hazard risk assessments to understand the complex interconnections between environmental and socio-economic risks.
- Preserving mangroves as natural barriers against disasters while enhancing their ecosystem services.
- Integrating indigenous knowledge and cultural practices into modern disaster management frameworks.
- Viewing migration not solely as a vulnerability but also as an adaptive strategy requiring policy support.

9.5.3 Contributions to Knowledge and Practice

This book not only contributes to academic knowledge but also provides practical insights for policymakers, NGOs, and global stakeholders. By integrating diverse methodologies—ranging from GIS mapping and community-based participatory research to policy analysis—it bridges gaps between research, practice, and governance. The interdisciplinary and multi-institutional collaboration evident in this book reflects the complexity of the challenges and the need for collective action.

9.5.4 A Call to Action

As the Indian Sundarbans faces increasing pressures from multi-hazard risks and climate change, the need for integrated and inclusive approaches to resilience-building becomes paramount. This book calls upon communities, researchers, governments, NGOs, and international stakeholders to work together to safeguard the Indian Sundarbans' unique ecosystem and the livelihoods it sustains. The lessons learned here are not just relevant locally but resonate globally, offering a blueprint for resilience in the face of adversity.

9.5.5 The Way Forward

While this book provides critical insights, it also highlights the gaps that remain in our understanding of the Indian Sundarbans. Future research and action must focus on long-term sustainability, leveraging technological innovations, strengthening governance mechanisms, and fostering deeper collaboration among stakeholders. The Indian Sundarbans is not just a site of challenges; it is a beacon of resilience, innovation, and hope.

The lessons drawn from the Indian Sundarbans have global relevance for other deltaic and coastal regions that are exposed to climate-induced risks. By shifting from reactive disaster management to proactive resilience-building, the Indian Sundarbans can serve as a global model for integrating ecosystem-based disaster risk reduction (Eco-DRR) and sustainable development goals (SDGs). As communities become more adaptive, innovative, and self-reliant, they contribute to a larger goal of

socio-ecological sustainability. This book calls for continued research, policy innovation, and community participation to ensure that the Indian Sundarbans remains a global model of resilience and sustainability.

In closing, *"Risk to Resilience: A Socio-Ecological Perspective on the Indian Sundarbans,"* is more than a compilation of research—it is a testament to the enduring spirit of the Indian Sundarbans and its people. It invites readers to engage with the complexity of this unique region and to contribute to its preservation and prosperity. As we confront a future marked by uncertainty, the lessons from the Indian Sundarbans remind us of the power of resilience and the importance of collective action in shaping a sustainable world.

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