

Deltas of the World

Chiranjit Singha
Satiprasad Sahoo
Ajit Govind *Editors*

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Livelihood Challenges and Governance Dynamics in the Indian Sundarbans Delta

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Swagata Patra and Monirul Haque

Abstract

The Indian Sundarbans Delta (ISD), situated within the ecologically rich and geopolitically sensitive Ganges-Brahmaputra-Meghna basin, is home to nearly five million people whose lives are deeply entwined with a dynamic but increasingly fragile ecosystem. This region, known for its dense mangrove forests and complex tidal networks, faces mounting threats from climate change, including rising sea levels, frequent and severe cyclones, and increasing soil and water salinity. These environmental stressors have severely impacted traditional livelihoods, *viz.*, agriculture, artisanal fishing, and forest-based activities, forcing many communities into economic precarity. Vulnerability is especially acute in southwestern islands such as Sagar, Mousani, and Ghoramara, where land erosion, saline intrusion, and flooding are recurrent, and infrastructure and institutional support remain weak. While local communities have shown remarkable resilience through adaptive strategies like seasonal migration, crop diversification, and self-help groups, these responses often emerge without robust governance and long-term support. Fragmented institutional frameworks, inadequate coordination across agencies, and a lack of participatory governance have left many of the region's most vulnerable populations without adequate protection or opportunity for recovery. Despite growing recognition of these challenges, there remains a research gap

S. Patra

Department of Agricultural Extension, Palli-Siksha Bhavana (Institute of Agriculture),
Visva-Bharati, Sriniketan 731236, West Bengal, India

M. Haque (✉)

Department of Biological Sciences (Agriculture), Midnapore City College, Midnapore 721129,
West Bengal, India

e-mail: monirulhaque@mcconline.org.in

in understanding how integrated governance and community-driven approaches can be systematically implemented to enhance adaptive capacity. This chapter examines the intersecting challenges of climate vulnerability, livelihood insecurity, and governance inefficiency in the ISD. It also explores the potential for inclusive policy reforms such as decentralised planning, improved inter-agency collaboration, and ecosystem-based adaptation to support sustainable, community-driven development. In doing so, it advocates for a shift from reactive relief to proactive resilience, grounded in the lived experiences and agency of the people who call the Sundarbans home.

Nomenclature and Acronyms

AI	Artificial intelligence
BOB	Bay of Bengal
C.D.	Community development
CBMM	Community Based Co-management
CBOs	Community Based Organization
CRZ	Coastal regulation zone
FRA	The forest right act
GADF	Generic adoption decision framework
ICZM	Integrated Coastal Zone Management
IFS	Integrated farming system
IPCC	Intergovernmental panel on climate change
ISD	Indian Sundarbans Delta
ITKs	Indigenous technical knowledge
JFM	Joint Forest Management
JMM	Joint Mangrove Management
JMMCs	Joint Mangrove Management Committees
LVI	Livelihood vulnerability index
NBS	Nature-based solutions
NGOs	Non-Governmental Organizations
ppt	Parts per thousands
RBT	Royal Bengal Tiger
SHGs	Self help groups
SST	Sea surface temperatures
UNESCO	United Nations Educational, Scientific and Cultural Organization

5.1 Introduction

ISD is recognised as a UNESCO World Heritage Site and one of the world's most critical biodiversity hotspots, forming an integral socio-ecological region at the confluence of the lower Ganges-Brahmaputra-Meghna basin. This deltaic landscape, marked by a complex network of tidal rivers, estuaries, and dense mangrove forests, supports the livelihoods of approximately five million people. Most of this population inhabits low-lying islands and relies heavily on climate-sensitive economic activities such as agriculture, artisanal fishing, and forest-based resource collection.

ISD stands out as particularly vulnerable among the various segments of the larger Sundarbans region. Several studies, including those by Hajra et al. (2021), have employed composite indices to assess coastal vulnerability across blocks within the ISD, assigning vulnerability ranks based on exposure to environmental hazards. These assessments underscore the acute risks posed by soil salinisation, riverbank erosion, and loss of natural ecosystem factors that have repeatedly disrupted local livelihood structures and exacerbated food insecurity (Hajra and Ghosh 2018).

Study from a similar standpoint depicts that integrating scientific knowledge with indigenous and local practices significantly enhances climate resilience in wetland regions, particularly in South Asia's deltaic areas such as the Sundarbans (Haque et al. 2022). From a global perspective, ecosystem-based adaptation combined with local livelihood strategies is crucial to improve food security and reduce poverty under the pressures of climate change (Munang et al. 2014). Governance frameworks that promote community participation and empower local groups align conservation goals with livelihood needs, fostering transparency and inclusive decision-making, as demonstrated in coastal wetland management worldwide (Berkes 2017). The increasing impacts of sea-level rise and intensifying storms place immense pressure on deltaic wetlands, emphasising the need for governance reforms that ensure equitable resource access and bolster disaster preparedness (Reid et al. 2019). In the Ganges Delta, decentralised and community-driven resource management has enhanced institutional capacity and resilience, illustrating the critical role of local engagement in sustaining ecosystem services (Paul et al. 2021).

The challenges have intensified over recent decades, driven largely by climatic and anthropogenic pressures. Recurrent tropical cyclones, rising sea levels, saline water intrusion, and ongoing riverbank erosion have significantly undermined the agrarian and aquatic production systems that sustain the region. Particularly severe events such as Cyclones Sidr (2007) and Aila (2009) impacted around 2.3 million people in the ISD (Hazra et al. 2014). More recently, Super Cyclone Amphan caused widespread livelihood disruption across the region (Basu 2020; Pramanik et al. 2021; Mondal et al. 2022).

The southwestern islands of Sagar, Mousani, and Ghoramara have emerged as focal points of concern due to their high population densities and elevated levels of vulnerability (Hajra et al., 2021). These islands exhibit a complex geomorphological setup shaped by a dynamic tidal drainage system and the continuous processes of erosion and accretion.

The area is particularly susceptible to flooding and saline intrusion, situated on a flat alluvial plain with ground elevations ranging from 2.10 to 2.75 meters above mean sea level (Purkait 2008).

Climate change-induced phenomena such as rising sea levels, altered precipitation patterns, and the increasing frequency and intensity of extreme weather events have significantly impacted the socio-economic stability of island communities (Mullick et al. 2019). Cyclonic storm surges have frequently breached embankments, allowing saline water to inundate agricultural lands, leading to widespread crop failures and deepening rural poverty (Chand et al. 2012; Hajra and Ghosh 2018). In Ghoramara, land loss due to submergence has become a particularly severe threat, with significant tracts of agricultural land disappearing, compelling local populations to abandon traditional livelihoods and migrate (Mondal et al. 2022). These intersecting climatic and socio-economic stressors disproportionately affect economically marginalised groups, increasing their vulnerability to immediate disasters and long-term socio-ecological transformations (Jamal et al. 2022).

Compounding these environmental challenges are structural governance issues. The institutional framework managing the ISD is highly fragmented, with overlapping jurisdictions and poor inter-agency coordination. This fragmented governance structure often lacks adaptive capacity and participatory mechanisms, leading to insufficient support for sustainable livelihoods and local resilience. Critical gaps remain in disaster preparedness, climate-resilient agricultural extension, land-use planning, and natural resource management. Consequently, local communities remain exposed to various socio-ecological risks without adequate institutional support.

ISD presents notable strengths and challenges that shape livelihood and governance dynamics in the region. Substantial financial support from international sources and government initiatives such as the two trillion Indian rupee investment during India's twelfth five-year plan is crucial in advancing climate adaptation and sustainable development efforts (Mahadevia and Vikas 2012). Improved connectivity through affordable river transport and enhanced road networks facilitate access and communication, which is vital for local livelihoods and effective governance (Padhy et al. 2021). Furthermore, the region's rich biodiversity, including endangered species like the Royal Bengal tiger and saltwater crocodile, forms an ecological and cultural foundation that influences community practices and risk mitigation strategies (Jamal et al. 2022). However, the delta also faces significant vulnerabilities. Frequent cyclones and flash floods result in salinisation of land, displacement of residents, and damage to agriculture and ecosystems, while sudden onset of disasters limits effective relief operations (Jamal et al. 2022). Additionally, improper fertiliser use contributes to soil degradation and increased greenhouse gas emissions, threatening agricultural sustainability (Padhy et al. 2021). The overexploitation of prawn seeds disrupts aquatic biodiversity and compromises local food security (Chandra and Sagar 2003). Weak enforcement of environmental regulations and fragmented policy frameworks further hinder mangrove conservation and restoration, exacerbating the region's ecological fragility (Akram et al. 2023). Addressing these intertwined strengths

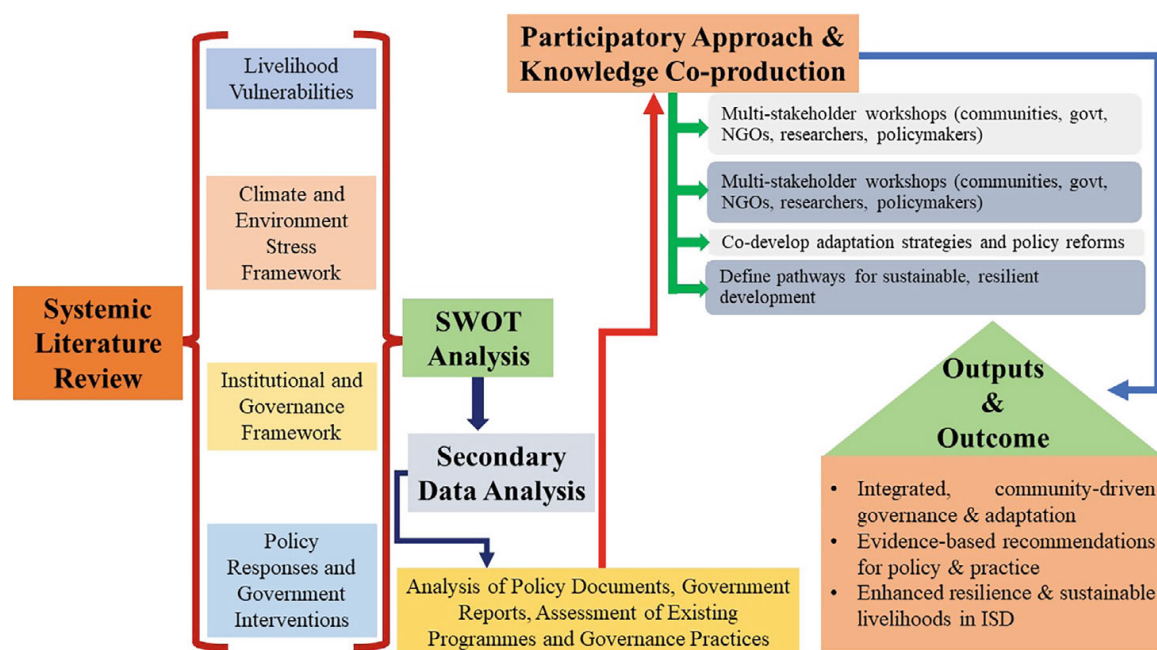


Fig. 5.1 Methodological framework of the study

and weaknesses is essential for developing robust, adaptive governance mechanisms that support resilient livelihoods in the Sundarbans.

This study aims to critically examine the complex interplay (Fig. 5.1) between climate change impacts, livelihood vulnerabilities, and governance shortcomings in ISD. It seeks to understand how the compounding effects of sea-level rise intensified institutional inefficiencies exacerbate cyclonic activity and land salinisation, ultimately deepening socio-economic marginalisation. Special attention is given to rural households whose economic security is intricately tied to natural resource-based livelihoods.

The research further evaluates existing governance frameworks for their capacity to support climate-resilient development, equitable resource access, and inclusive planning processes. By identifying institutional bottlenecks and policy deficits, the study proposes targeted reforms such as decentralised governance, improved inter-agency collaboration, enhanced community participation, and increased investment in ecosystem-based adaptation approaches.

Moreover, the study highlights local communities' adaptive strategies in response to escalating environmental stressors. These include seasonal and permanent migration, diversification of income sources, cultivation of saline-tolerant crops, and the formation of self-help and community support groups. While these grassroots adaptations underscore the resilience and agency of local populations, they also reveal the urgent need for systemic interventions in the form of supportive policies, infrastructural development, and robust institutional frameworks.

5.2 Geographical and Socio-Economic Context of the ISD

It is a unique geographical and ecological entity in the Ganges-Brahmaputra deltaic region (Fig. 5.2). It is home to the world's largest mangrove forest, which supports a rich biodiversity and provides critical ecosystem services (Bharati et al. 2016). The delta's dynamic riverine system, including the Ganges River's distributaries, shape its physical characteristics. However, these rivers have become increasingly disconnected from their upstream sources, resulting in acute freshwater scarcity during dry seasons and elevated surface water and soil salinity (Uddin et al. 2024). This hydrological alteration has had profound implications for the region's ecological integrity, adversely affecting mangrove health, biodiversity, and the overall ecosystem services on which millions of inhabitants depend (Akram et al. 2023).

The lower Gangetic Delta, often referred to as ISD, comprises an intricate archipelago of 103 low-lying, densely populated deltaic islands situated at the confluence of the Ganges-Brahmaputra-Meghna river system and the Bay of Bengal (BOB). Geographically, it is bounded between 21°32' and 22°40' N latitude and 88°05' to 89°00' E longitude, covering nearly 10,000 km² within the Indian state of West Bengal. Historically dominated by dense mangrove cover, the delta has witnessed extensive anthropogenic transformations, with over 54 islands reclaimed for agriculture by constructing approximately 3500 km of earthen embankments to resist daily tidal incursions (SBR 2008). Today, the region presents two distinct landscapes: a protected eastern sector dominated by mangrove forests and a western sector characterised by reclaimed agricultural land and rural settlements. About 2482.33 km² of this reclaimed land is used for coastal agriculture, with rice as the principal crop. According to official estimates, 60–65% of the 4.37 million inhabitants are directly engaged in agricultural activities, while up to 95% may indirectly depend on it (Bagchi 2017). Nonetheless, landlessness is prevalent, with 54% of households lacking ownership, contributing to a substantial population of agricultural labourers. In addition to rice, cash crops such as chilli, cotton, watermelon, cucumber, and betel leaves are cultivated.

Demographically, the delta supports nearly five million people whose livelihoods are intricately linked to ecosystem services (Prasanya et al. 2024). These include artisanal fishing, crab and prawn seed collection, aquaculture, and the extraction of fuel, fodder, and honey from the forest (Mitra 2023). Despite their socio-economic importance, these services often remain underrepresented in official statistics and are declining due to population pressures and ecosystem degradation (Vishwapriya and Devaiah 2024). The rural economy relies heavily on natural resources, rendering it highly susceptible to environmental changes and governance deficits.

The broader Gangetic Delta region, which encompasses the ISD, is among the most densely populated areas in the world, with a population exceeding 400 million (Ghosh 2011). The ISD, home to approximately 4.5 million people, is particularly vulnerable to recurrent tropical cyclones, storm surges, and associated flooding. Rising sea surface

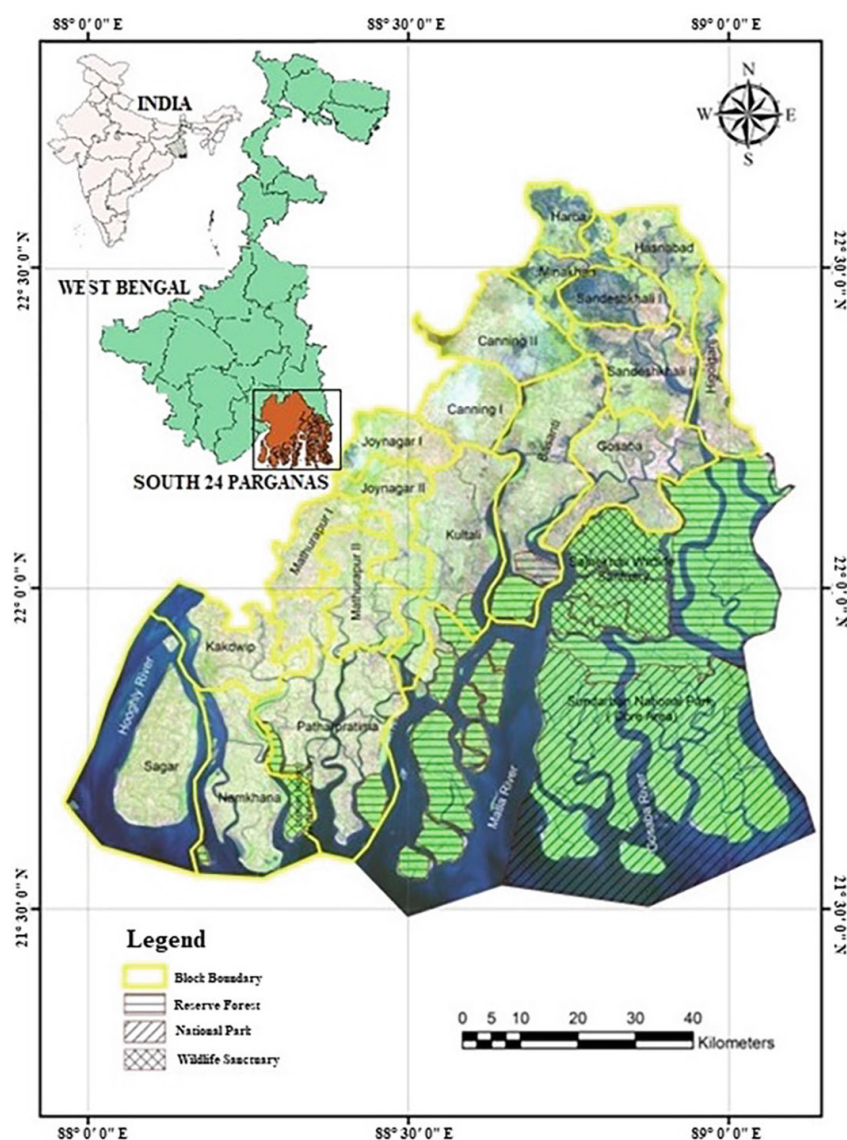


Fig. 5.2 Map of ISD

temperatures in the Bay of Bengal, increasing at 0.5 °C per decade, have created ideal conditions for cyclone formation (Yadav et al. 2024). There has been a 17% increase in the intensification of cyclonic disturbances into cyclones and a 25% rise in severe cyclonic storms over the northern Indian Ocean, especially during the pre-monsoon and post-monsoon periods (Deshpande et al. 2021). Recent cyclones, including the 2007 event named “Sidr,” the 2009 cyclone “Aila,” the 2013 cyclone “Phailin,” the 2019 cyclone “Bulbul,” the 2020 cyclone “Amphan,” and the 2021 cyclone “Yaas,” have severely disrupted livelihoods, damaging access to food, water, shelter, and health services. Rising soil salinity and waterlogging in several riverside Community Development (C.D.) Blocks have significantly affected agricultural productivity, resulting in a 30–40% decline in

yield potential (Ghosh and Mistri 2020). These impacts have exacerbated food insecurity, unemployment, poverty, and migration (Mondal et al. 2022). The entrenched poverty cycle, strongly linked with agricultural decline and outmigration, has persisted for decades (Hajra and Ghosh 2018). Over 34% of the ISD's population still lives below the poverty line, and approximately 75% of households have at least one member who has migrated outside the region to sustain basic livelihoods (Hazra and Ghosh 2018). These socio-economic pressures have considerably undermined local coping capacities and increased vulnerability to environmental stressors.

Given the projected trajectory under a business-as-usual scenario, ecosystem provisioning and regulating services are expected to deteriorate further by 2030, intensifying rural poverty (Hussain et al. 2024). Addressing the sustainability of this complex socio-ecological system demands integrated strategies that target both environmental restoration and livelihood enhancement. Key biophysical constraints such as water stress, siltation, and drainage congestion aggravated by the disruption of freshwater flows from upstream must be mitigated (Haque and Nehar 2023).

5.3 Livelihood Vulnerabilities in the Sundarbans

Livelihoods in the ISD are highly vulnerable to various environmental stressors, significantly undermining local communities' resilience. Among the most pressing challenges are salinity intrusion, riverbank erosion, and frequent cyclones. Rising salinity levels driven largely by reduced freshwater inflow from upstream sources have led to the degradation of agricultural soils and a marked decline in productivity (Sarkar et al. 2024). This growing salinisation of soil and water resources has forced many farmers to either shift to salt-tolerant crops or adopt unsustainable practices that are often financially burdensome (Granados-Olivas et al. 2023). Erosion, particularly along the delta's riverbanks and coastlines, continues to reduce the available land for cultivation and habitation, intensifying economic insecurity and displacement risks (Barua et al. 2020). Recurrent cyclones amplify these vulnerabilities by causing widespread destruction of infrastructure, loss of standing crops, and prolonged disruptions to fishing and other livelihood activities (Mukherjee and Siddique 2024).

In the 1980s, livelihood vulnerability emerged to describe how people navigate and survive under adverse socio-environmental conditions (Scoones 2009). Livelihoods are the means and capabilities people rely on to satisfy essential needs such as food, shelter, clothing, health, and social belonging. Meeting these needs requires access to assets and forms of capital, both tangible and intangible (Gaillard et al. 2009). Vulnerability in this context refers to the degree to which individuals or systems cannot withstand and recover from the impacts of climate change and natural hazards (IPCC 2001). Coastal disasters often disrupt the foundations of livelihood systems, damaging income sources, personal property, community infrastructure, and social networks.

The IPCC framework disaggregates vulnerability into three core dimensions: exposure, sensitivity, and adaptive capacity (Yang et al. 2021). These dimensions are critical in evaluating the scope and intensity of damage and identifying intervention areas for achieving sustainable livelihoods. Based on this framework, tools such as the Livelihood Vulnerability Index (LVI) have been developed to assess the susceptibility of households to risks such as poverty, food insecurity, and environmental shocks (Hahn et al. 2009; Mukherjee et al. 2019). Households in similar geographical settings may display varying levels of resilience due to differences in resources, social capital, and institutional access (Cardona and Barbat 2000). These differences often manifest through distinct coping strategies, resistance thresholds, and adaptive capabilities (Buckle et al. 2001). Understanding how vulnerability is distributed across space and social groups is crucial before initiating any policy or planning interventions. It requires systematic documentation and household-level data collection to support local disaster risk reduction (Quader et al. 2021). Although government agencies often prioritise reconstruction and rehabilitation after disasters, the extent of recovery also depends on how effectively individuals and communities can adapt and respond to evolving risks. Strengthening these coping capacities remains essential for building resilience and ensuring more secure and sustainable livelihoods (Pomeroy et al. 2006).

Economic insecurity in the ISD is shaped by the dominance of informal, low-income livelihoods such as subsistence farming and artisanal fishing, which remain highly sensitive to climate variability and ecological stress (Kaschek 2021). Limited employment opportunities, poor access to financial resources, and weak service delivery systems contribute to persistent poverty and reduced well-being. As environmental degradation continues to erode traditional livelihood bases, migration has become a necessary strategy for survival. Many younger members of households migrate to urban centres or other regions in search of wage labour, often leaving behind dependents who face additional emotional and economic strain.

Human-wildlife conflict and restricted access to forest-based resources also impose significant livelihood limitations. Habitat loss from salinity and erosion has increased encounters with species such as tigers and crocodiles, often resulting in deadly conflict and long-term fear within communities. Policies aimed at biodiversity conservation frequently limit access to fuelwood, fodder, and other essential forest products, which forces households to seek alternative sources that may not be ecologically or economically viable. Managing ISD as a socio-ecological system involves difficult trade-offs between ecological integrity and human development. Achieving sustainability in this region depends on integrating conservation goals with the livelihood needs of its most vulnerable residents, recognising that resilience cannot be built without ensuring social and economic justice.

5.4 Climate Change and Environmental Stress in the Delta

Climate change poses significant environmental stress in ISD through several critical factors. One of the most pressing concerns is rising sea levels, which exacerbate tidal flooding and saltwater intrusion into freshwater sources and agricultural lands, threatening the region's biodiversity and affecting local communities' livelihoods by reducing the availability of arable land and freshwater resources. ISD, often termed the "biowall" of the coastal region, is particularly vulnerable to climate-induced changes. Recent studies show that South Asian countries, including India, are especially at risk from the impacts of climate change (Hijioka et al. 2014). India was ranked third in the Global Climate Risk Index in 2013, highlighting its population's vulnerability (Kreft et al. 2014).

Air temperatures over the Bay of Bengal have risen by 0.019 °C annually between 1985 and 2000, and projections indicate an increase of 1 °C by 2050 if current trends persist (Hazra et al. 2002). A more accelerated warming pattern was observed between 1993 and 2007 compared to earlier decades (Hazra et al. 2010). Sea surface temperatures (SST) in ISD have also increased notably, rising by 0.5 °C per decade during the pre-monsoon periods between 1980 and 2007 (Mitra et al. 2009). This warming trend has been linked with shifts in rainfall patterns, with monsoon and post-monsoon rainfall decreasing while pre-monsoon rainfall has increased slightly (Mandal et al. 2013). The changing rainfall regime has resulted in delayed monsoons, erratic rains during harvest periods, and rising vulnerability to crop damage and pest attacks (Rao and Filho 2015).

Salinity intrusion has become a significant threat across the delta, with the eastern Sundarbans recording an increase of 6 ppt over three decades, a rate much higher than the average across the Indian Ocean (Mitra et al. 2009). The northern areas, traditionally less saline, now report levels as high as eight ppt, while the southern parts experience salinity between 8 and 20 ppt. Soil salinity has sharply increased in many areas from 0.1 to 5.25 ppt, well beyond the safe thresholds for staple crops like rice (Haldar and Debnath 2014).

The increased frequency and intensity of cyclones further strain the region. The Bay of Bengal, though contributing to less than 6% of global tropical cyclones, accounts for the majority of the fatal ones, with ISD experiencing severe impacts (World Bank 2014). Cyclones like Aila in 2009 affected millions, caused over 300 deaths and led to massive economic losses exceeding \$550 million in India alone (Rudra 2010). The rise of sea level in the region is also notable. From 1991 to 1999, ISD and adjoining Bay of Bengal saw a relative sea-level rise of 3.14 mm/year (Hazra et al. 2002). Tidal gauge data from the last 25 years across four locations in the delta suggest an even more alarming rate of 8 mm/year, with spikes of 12 mm/year between 2002 and 2009 (Hazra et al. 2010). This rise far exceeds the global average reported by the IPCC (2014), which estimated an increase of 3.2 mm/year from 1993 to 2010.

Erosion remains a significant concern. The region has experienced a land loss of 44 km² between 2001 and 2009, and about four islands, Bedford, Lohachara, Kabasgadi,

and Suparibhanga, have been entirely submerged due to rising sea levels and erosion, displacing around 6000 families (Hazra and Bakshi 2003). Embankments, which play a crucial role in protecting against storm surges and sea level rise, are also under stress. A large proportion of the 3638 km-long embankment network in ISD is in a vulnerable state, with the length of such stretches increasing from 470 km before Cyclone Aila to around 1000 km in its aftermath (Hazra et al. 2010; World Bank 2014).

The impact of these environmental stressors on agriculture is particularly severe. Rising salinity levels and increased flooding make it difficult to maintain traditional farming practices, significantly reducing crop yields and agricultural productivity (Kumar et al. 2021). Farmers must adopt high-cost and often unsustainable strategies to sustain production. Fishery-based livelihoods are also disrupted due to water temperature and salinity changes, which alter fish populations and habitats (Okafor-Yarwood et al. 2023). Meanwhile, erosion and tidal flooding threaten residential areas, heightening displacement risks and social vulnerabilities (Harms 2024).

These cascading stressors position ISD as a climate hotspot with acute socio-ecological vulnerabilities. Despite the presence of adaptation practices, many of them fail to address the complex interplay of environmental and livelihood challenges in the region. Effective responses require systemic and inclusive adaptation strategies informed by local knowledge, adaptive governance, and sustainable environmental management (Kumar et al. 2021). Balancing ecological conservation with livelihood security is vital to safeguarding the future of the Sundarbans.

5.5 Institutional and Governance Framework

Institutional and governance frameworks are crucial in managing ISD, particularly in forest and coastal zone governance. The Sundarbans, a unique ecosystem with mangrove forests and diverse wildlife, require a governance structure that balances conservation with the needs of local communities. Forest governance involves managing mangrove forests, critical for biodiversity conservation, and providing ecosystem services such as coastal protection and carbon sequestration. However, the effectiveness of these regulations is often challenged by inadequate enforcement and conflicting interests between conservation and economic development (Kumar et al. 2021).

Coastal zone governance is equally important, as it involves managing the impacts of sea-level rise, erosion, and cyclones on coastal communities and ecosystems (Duxbury and Dickinson 2007). These require coordinated efforts to implement climate-resilient infrastructure and sustainable land-use practices. The governance of ISD involves multiple levels of authority, including state, central, and local governments. The central government plays a key role in setting national environmental conservation and disaster management policies, while state governments are responsible for implementing these policies at the regional level. Local authorities, such as panchayats and municipalities, are crucial for

engaging with local communities and ensuring that governance decisions reflect local needs and priorities.

However, there is often a disconnect between policy intent and implementation, with local authorities facing challenges related to resource constraints and bureaucratic inefficiencies. Non-governmental organisations (NGOs) and civil society actors play a vital role in delta management by advocating for community rights, supporting sustainable livelihoods, and promoting environmental conservation. These organisations often work closely with local communities to develop and implement projects that enhance resilience to climate change impacts. Additionally, NGOs can facilitate stakeholder engagement and participatory governance processes, which are essential for ensuring that governance decisions are inclusive and responsive to local needs (Kumar et al. 2021).

The effectiveness of NGOs can be limited by funding constraints and the need for greater coordination with government agencies to ensure policy alignment and impact. Overall, effective governance in the ISD requires a collaborative approach that integrates the roles of state, central, and local authorities with those of NGOs and civil society actors. This collaboration is crucial for addressing the complex socio-ecological challenges faced by the region and ensuring sustainable development that balances human well-being with environmental conservation. By fostering such partnerships, it is possible to develop governance frameworks responsive to the needs of both the environment and local communities, ultimately enhancing the resilience of ISD in the face of climate change and other environmental stressors.

5.6 Livelihood Transitions and Emerging Opportunities

ISD, home to one of the World's largest mangrove ecosystems, has traditionally supported various livelihoods closely linked to its unique natural environment (Gopal and Chauhan 2006). For generations, communities in this region have depended on agriculture, fishing, and forest-based activities such as collecting fuelwood, honey, medicinal plants, and other forest products for survival. These activities have not only sustained local households but have also shaped the cultural and ecological identity of the region. However, the changing environmental and socio-economic conditions pose serious challenges to these traditional ways of living (Mahmood et al. 2021).

ISD has recently faced intensified environmental stress, including rising salinity, increasing coastal erosion, frequent cyclones, and tidal surges (Hasnine and Nagdeve 2024). These climatic pressures are steadily degrading the land and water resources on which local livelihoods depend. Due to saltwater intrusion, agricultural land is becoming less fertile, and freshwater sources are shrinking. At the same time, fishing and crab collection are becoming more unpredictable, often due to ecological degradation and overharvesting (Chandra and Sagar 2003). The region's limited infrastructure, poor

road connectivity, irregular electricity, insufficient healthcare, and underdeveloped education facilities adds to the hardship. Most families have small landholdings or work as agricultural labourers, and stable, year-round employment opportunities are scarce. In this context, migration has emerged as a key livelihood strategy. People, particularly young men, increasingly move out of ISD temporarily or permanently to find work in other parts of the state or country. Many work as wage labourers in construction sites, brick kilns, or small factories. While these jobs are often low-paying and physically demanding, they provide a crucial source of income that many families in ISD have come to rely on. The money sent back by migrants to their family members plays a vital role in the local economy. These funds meet daily household expenses, support children's education, access better healthcare, and sometimes even invest in small businesses or housing improvements. Remittances often buffer against the financial uncertainty caused by crop failure or poor fishing seasons. As a result, migration is no longer just a response to crisis but becoming a deliberate strategy for survival and future planning. This shift towards migration has also brought about social changes. While traditional occupations still hold cultural importance, many younger people aspire to move beyond land and resource-based livelihood limitations. Migration has created new connections between rural and urban areas, exposing families to new ideas, opportunities, and ways of life. At the same time, it has placed emotional and social stress on families, especially those left behind. Nonetheless, migration and remittances have become essential to how households in ISD adapt to a changing environment (Moreda [2023](#)).

Aquaculture has emerged as a viable substitute for conventional fishing, particularly in light of ecological degradation. Alongside this, eco-tourism creates job opportunities by leveraging the region's biodiversity. Wage labour in urban construction and manufacturing sectors is also expanding, especially among migrants, offering a new channel of income diversification. These shifts reduce reliance on ecologically vulnerable activities and lay the groundwork for more sustainable development. Migratory movement, particularly male labour outflow, remains a significant coping mechanism in response to declining rural opportunities. While this reduces local economic strain and brings in remittances that modernise agriculture, raise land value, and stimulate rural entrepreneurship, it also creates labour shortages and strains traditional occupations such as farming on saline lands.

Women's cooperatives and self-help groups are vital in this transformative phase. Traditionally confined to domestic roles, many women now participate in micro-enterprises like small-scale aquaculture, tourism, and value-added production. Cooperatives have facilitated access to training, financial credit, and market tools essential for empowering women and sustaining livelihood ventures. As male outmigration continues, women increasingly shoulder familial and financial responsibilities, gaining confidence and societal visibility. Recent trends also show a rise in female outmigration, driven by aspirations for higher education and formal employment, marking a shift in gender dynamics.

Several underutilised natural resources offer further potential. Honey and wax, harvested from wild and box bees, yield hundreds of quintals annually, yet collectors receive limited returns due to a lack of local processing. Establishing honey processing and candy-making units can enhance income by adding value locally. Similarly, mangrove plants like *Ceriops decandra* produce tannins in fisheries and leather industries. At the same time, various species offer natural dyes, medicinal properties, gums, resins, and edible products like wild fruits, tender leaves, and mushrooms. Reviving these traditional resources through controlled harvesting and local processing can revitalise grassroots economies.

5.7 Policy Responses and Development Interventions

The Sundarban Delta, a region of critical ecological significance, is increasingly vulnerable to the intersecting threats of climate change, environmental degradation, and socio-economic fragility. In response to these challenges, the Indian government has introduced several policy frameworks to safeguard the region's natural ecosystems while promoting sustainable development in coastal and deltaic zones. One key legislative tool is the Coastal Regulation Zone (CRZ) Notification of 2018, a revision of the earlier 1991 notification issued under the Environment Protection Act of 1986. This regulation governs developmental activities along the coastline by classifying areas into four categories: CRZ-I (ecologically sensitive regions), CRZ-II (urbanised coastal areas), CRZ-III (rural settlements), and CRZ-IV (islands) (Table 5.1). These zones are delineated based on environmental sensitivity, geomorphology, and demographic features, aiming to protect coastal biodiversity while permitting regulated development (Prasad 2020).

Table 5.1 Different level Governance body of ISD

Governance	Institutional body	Policy stakeholders
Global	International bodies	UNESCO International union for conservation of nature (IUCN)
National	Central government	Ministry of environment, forest and climate change national biodiversity authority
Regional	State government	Department of environment, government of West Bengal sundarban affairs department West Bengal biodiversity board
Territorial	Local bodies	Gram panchayats (village councils) Local forest committees—JFMC, FPC Irrigation department
Endemic/ tropical	Non-governmental organisations (NGOs)	Various national and international NGOs work on conservation, climate adaptation, and community development

Complementing the CRZ framework, the National Conservation Strategy and Policy Statement on Environment and Development of 1992 emphasises the importance of conserving wetlands, particularly mangrove ecosystems (Mohanty et al. 2024). It recommends decentralised planning mechanisms to prevent resource depletion, contamination, and the adverse impacts of natural disasters. Similarly, the National Environment Policy of 2006 calls for an Integrated Coastal Zone Management (ICZM) approach that encourages collaborative governance models to align ecological preservation with economic advancement (Frost, 2009).

The Forest Rights Act (FRA) of 2006 is pivotal in empowering forest-dependent communities, especially indigenous groups. It acknowledges their traditional rights over forest lands and resources, promoting their active participation in conservation and resource stewardship even within protected areas like wildlife sanctuaries and national parks. This legislation fosters a more equitable framework for environmental governance by addressing historical exclusions (Das 2024).

Mangrove restoration initiatives in ISD have gained momentum under these policies, especially in light of increasing climate-related threats. Between 2020 and 2022, the Indian Sundarban initiative facilitated the plantation of more than 71 million mangrove species and 52 million mangrove associates. These efforts were intended to reinforce coastal embankments and improve the region's resilience to extreme weather events. Despite a substantial financial investment of approximately 1.23 billion Indian rupees, the program encountered operational setbacks, including delayed wage disbursements and insufficient community involvement. These issues led to reduced local engagement and diminished trust. Moreover, although the mangrove ecosystem provides critical services such as carbon storage, erosion control, and biodiversity conservation valued at nearly USD 19 billion annually, the lack of communication about these benefits has further limited grassroots participation.

To enhance the long-term viability of such restoration projects, linking them with carbon credit markets could generate financial incentives for local stakeholders. Equally important is the need for effective dialogue between scientists, policymakers, and communities to set pragmatic expectations around ecological recovery timelines. Scientific input during the planning stages is vital for outlining realistic benchmarks for the growth and environmental functionality of mangrove plantations. The misalignment between scientific timelines and public expectations was evident during Cyclone Yaas when newly planted mangroves were prematurely expected to serve as effective natural buffers.

The success of future restoration programs will also depend on sustained resource planning and inter-agency cooperation. Engaging stakeholders, including community members, throughout all project development and implementation stages, is crucial. Recognising this, the Government of West Bengal has recently engaged academic institutions to conduct independent assessments and facilitate participatory research, signalling a more inclusive and evidence-based approach to coastal management. A collaborative framework that brings together local knowledge, scientific expertise, and

policy instruments is essential to ensure the durability and effectiveness of ecological interventions.

Nevertheless, challenges persist, particularly at the implementation level. One of the major obstacles is the persistent gap between policy design and on the ground execution. While national policies often present well-structured solutions for disaster resilience and environmental protection, their actual application is hindered by logistical constraints and bureaucratic inefficiencies. Moreover, insufficient public engagement in the planning phases leads to interventions that often fail to align with the specific needs of local populations, exacerbating existing vulnerabilities.

Emergency relief efforts following natural disasters like cyclones are indispensable for short-term recovery. However, they rarely translate into strategies for building long-term resilience. Likewise, development schemes intended to improve livelihoods—such as aquaculture and eco-tourism face constraints in terms of funding, infrastructure, and access to markets. Without sustained support, these initiatives may fall short of their intended goals.

Emerging technologies and innovative governance practices offer promising avenues to address these gaps. Artificial intelligence (AI) and remote sensing can significantly enhance disaster preparedness and environmental monitoring. Yet, these technologies require reliable infrastructure and capable institutions, often underdeveloped in remote regions like ISD. Additionally, technological adoption must be inclusive and reflective of community needs, thereby underscoring the importance of participatory governance frameworks.

The history of forest policy in ISD offers insights into the evolution of conservation approaches. During colonial rule, sections of the delta were declared “protected forests” in 1878 to maximise timber extraction, significantly curtailing the rights of local inhabitants. This designation facilitated the conversion of forest land for agricultural and commercial purposes. By 1943, these areas were upgraded to “reserved forests,” with even more stringent restrictions on resource use.

Following India’s independence, the emphasis on conservation intensified. The Sundarbans National Park was declared a UNESCO World Heritage Site in 1987, reinforcing its ecological significance. The National Forest Policy of 1988 introduced a shift toward community participation, laying the groundwork for Joint Forest Management (JFM) programs launched in 1990. These initiatives attempted to balance conservation objectives and local livelihood needs.

Further progress was made through enacting the FRA in 2006, which sought to rectify historical exclusions by formally recognising the rights of tribal and forest-dwelling communities. Despite this, many beneficiaries remain unaware of their entitlements, and bureaucratic red tape impedes meaningful participation.

In recent years, community-led organisations have actively bridged these governance gaps. Projects like “The Community Forest,” spearheaded by the Kolkata Society for Cultural Heritage, involve over 3500 families in mangrove restoration and sustainable

livelihood generation. Similarly, Mukti's "Green Defence" program empowers women through self-help groups to take part in mangrove plantation activities, thereby enhancing both environmental and socio-economic resilience.

Education and outreach also play a key role in fostering environmental stewardship. Initiatives like the Environment Academy incorporate creative methods such as music, drama, and visual arts to instil ecological awareness among youth. These programs emphasise the value of combining indigenous knowledge systems with scientific understanding to promote sustainable management of fragile ecosystems.

5.8 Adaptive Strategies and Local Resilience

Adaptation strategies are defined as purposeful actions that assist human and ecological systems in coping with actual or anticipated changes, especially those induced by climate variability and extremes (Lawler et al. 2013). In the ISD, where rising sea levels, frequent cyclones, saline intrusion, and livelihood disruptions are increasingly common, formulating adaptive strategies has become essential. In light of these challenges, policymakers are exploring the Generic Adaptation Decision Framework (GADF) to rationalise decisions between localised resilience measures and managed retreats (Danda et al. 2019). The GADF guides choices based on a comparative economic viability analysis, environmental impact, and socio-political acceptability (Fig. 5.3).

The decision to adopt localised resilience measures is supported when socio-economic well-being can be sustained at a reasonable cost. If, however, the cost of protection outweighs the value of what is being preserved, and if managed retreat offers better long-term returns (net benefits of ex-situ adaptation), it may justify population resettlement

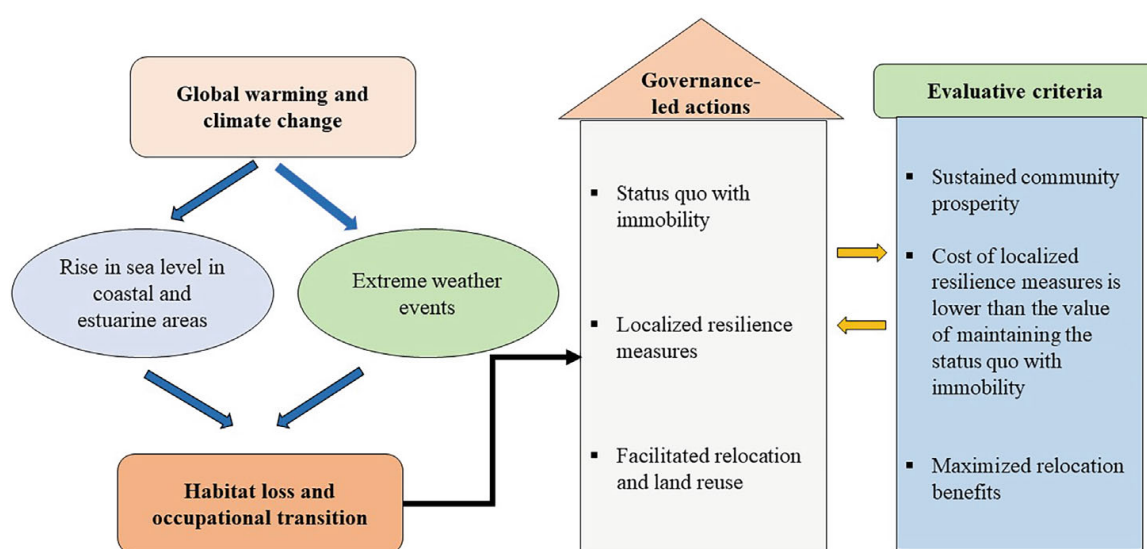


Fig. 5.3 Generic adaptation decision framework

and policy-driven relocation. This process involves a comprehensive valuation of ecosystem services, costs, benefits, and possible scenarios through comparative static analysis. Within this broader framework, two pillars of resilience stand out in the Sundarbans context, i.e. community based adaptation initiatives and strengthening of social capital and institutions.

5.8.1 Community-Based Adaptation Initiatives

Community-based adaptation initiatives play a central role in enhancing climate resilience across the ISD by actively engaging local stakeholders in the restoration, protection, and sustainable management of natural and agricultural systems. A prominent strategy is mangrove restoration, which supports biodiversity, enhances coastal protection, and sequesters carbon, thus contributing to both environmental and livelihood goals. Such initiatives have improved soil blue carbon pools and increased humic and fulvic acid concentrations, though sustained external support remains crucial for their continuity.

Water management forms another critical component. Given the region's vulnerability to saltwater intrusion and freshwater scarcity, local solutions, such as rainwater harvesting through pond and canal renovation and community-managed irrigation systems, help maintain freshwater sources, support post-monsoon crops, and generate seasonal employment (Padhy et al. [2021](#)).

Alternative farming practices are equally vital. Traditional agriculture in the delta faces threats from salinity and flooding, prompting a shift toward salt-tolerant crop varieties (e.g., Luna Swarna, Luni Shree), organic farming, and integrated crop-livestock-fish farming systems. Land-shaping technologies, particularly farm ponds and paddy-cum-fish models, are financially viable interventions that address salinity, drainage congestion, and irrigation challenges. These improve productivity and income and reduce pressure on fragile ecosystems.

Additionally, promoting less perishable cash crops such as chilli and sunflower and establishing community seed banks for climate-resilient varieties can improve food security and disaster readiness. Freshwater aquaculture in community ponds offers supplementary income, particularly for landless and marginal farmers. Physical infrastructure also contributes to resilience. The construction of multi-purpose cyclone shelters provides emergency refuge and can serve as schools or community centres during normal periods. Improved village roads, pucca jetties, solar lighting, and mobile health camps enhance basic services and reinforce community engagement in environmental stewardship.

5.8.2 Strengthening Social Capital and Institutions

A robust foundation of social capital and local institutions is indispensable for effectively implementing and sustaining adaptive strategies in ISD, including investments in capacity building, governance reforms, and empowerment of grassroots organisations like self-help groups (SHGs).

Capacity building entails equipping communities with knowledge and skills in climate adaptation, disaster preparedness, and sustainable resource management. Training programs focused on sustainable agriculture, mangrove conservation, and alternative livelihoods can empower local actors to lead initiatives and reduce dependency on external interventions (Kumar et al. [2021](#)).

Local governance reforms aimed at decentralisation and participatory planning must ensure adaptation strategies reflect community needs and are implemented effectively. Strengthening institutions like panchayats and municipalities enables more responsive and inclusive governance, allowing communities to better navigate environmental and socio-economic challenges.

Self-help groups (SHGs) catalyse collective action, especially among women, by facilitating access to microfinance, training, and market opportunities. SHGs can potentially drive the adoption of eco-friendly practices such as organic farming, small-scale aquaculture, mushroom cultivation, floriculture, and apiculture. Additionally, promoting village-based enterprises such as sewing, piggery, duckery, and seedling nurseries diversifies income sources and reduces dependency on fragile mangrove ecosystems. These institutions also function as intermediaries between communities and funding agencies, enhancing access to resources and ensuring that adaptation actions are well-supported and context-specific. Empowering these social structures enhances resilience and reinforces social cohesion and collective well-being (Pandhare et al. [2024](#)).

5.9 Socio-Economic Transformation and Pathways Forward

The socio-economic transformation of ISD is a complex but necessary shift from vulnerability to resilience, aimed at improving the lives of local communities and ensuring sustainable development in the face of environmental challenges. This change requires a mix of economic growth, social support, and care for the environment. Adaptation strategies in the region depend on factors like history, community behaviour, gender roles, social connections, and the fragile ecosystem, making each community's needs and recovery process unique. Therefore, it is important to include local perspectives and evolving ideas about adaptation that focus on people and nature. Looking at the situation through social and ecological lenses highlights key issues such as land ownership disputes, loss of traditional knowledge, misuse of funds, and weak public health systems (Bhowmick [2023](#)).

Another critical step toward building resilience in ISD is promoting economic diversification, especially as traditional livelihoods like fishing and farming face increasing risks from climate-induced challenges such as rising salinity and frequent cyclones. Transitioning into alternative income-generating sectors such as aquaculture, eco-tourism, and wage labour offers a pathway to economic stability and reduced vulnerability. However, this shift demands structured support through skill development, credit access, and strong market linkages to ensure local communities can adapt effectively. The Sundarban mangrove ecosystem is central to diversification as it offers various ecosystem services. These include provisioning goods like food, timber, medicinal plants, and bio-resources used for renewable energy; critical ecological functions such as nutrient cycling, habitat provision, and water transport; and vital regulating services like air and water purification, erosion control, storm buffering, and flood mitigation (Walters et al. 2008). The mangroves also provide breeding and nursery grounds for commercially important fish and shellfish species, making them indispensable to local fisheries. Juvenile fish benefit from the mangrove's structural complexity, which offers protection from predators and ideal feeding conditions. In addition, non-timber forest products such as honey, wax, and medicinal plants contribute significantly to household incomes (Saifullah and Jewel 2021). With its unique biodiversity, including the Royal Bengal Tiger, estuarine crocodiles, and migratory birds, ISD also holds immense potential for eco-tourism, which can further strengthen local economies while promoting conservation.

Recurrent natural disasters in ISD have significantly altered traditional livelihoods, particularly agriculture, by narrowing the range of viable livelihood options. Once practised biannually, paddy cultivation has largely shifted to a monocrop system due to increasing soil salinity, unpredictable rainfall, and cyclone induced disruptions. This change reflects a broader adaptation strategy where livelihood practices are increasingly intertwined with educational attainment and local cultural context. In rural areas like the ISD, education and culture are deeply interrelated; cultural norms shape educational systems and, in turn, influence livelihood choices. As a result, education plays a transformative role in rural development by enhancing individual capabilities and fostering a mindset of innovation and adaptability essential for coping with environmental and socio-economic stresses. Improving access to quality education, particularly in subjects like environmental science, technology, and entrepreneurship, equips communities with practical skills to pursue sustainable livelihoods and navigate emerging challenges. Additionally, education empowers local populations to engage meaningfully in participatory governance and decision-making processes, ensuring that development initiatives align better with the community's specific needs, values, and aspirations (Mousazadeh 2024).

A comprehensive analysis of healthcare distribution in ISD, conducted using primary and secondary datasets, highlights significant disparities in health services across different areas and population groups. Approximately 4.3 million residents in the region face persistent health challenges, including malnutrition, reduced life expectancy, and widespread prevalence of waterborne and vector-borne diseases. Women, in particular,

experience irregular and inadequate dietary intake, contributing to high rates of maternal, infant, and child mortality, along with a large proportion of underweight children (Ghosh and Mistri 2020). In this context, healthcare plays a crucial role in facilitating socio-economic development. Ensuring access to quality healthcare services is fundamental to improving public health, especially in environmentally vulnerable regions like ISD, where ecological degradation exacerbates health risks. Enhancing healthcare infrastructure and increasing awareness through health education can significantly reduce disease susceptibility, improve living standards, and bolster economic resilience. Healthier populations are better equipped to engage in livelihood activities and adapt to socio-environmental challenges.

Technology plays a transformative role in rural development by offering innovative solutions to socio-economic challenges. It can be leveraged to enhance climate resilience through early warning systems for cyclones and floods, significantly reducing the risk of loss of life and property. Additionally, digital technologies can facilitate access to markets, improve agricultural productivity through precision farming, and support the development of sustainable livelihoods such as eco-tourism. However, adopting technology requires robust infrastructure and institutional capacity, which may be lacking in remote regions like ISD. Therefore, investments in digital infrastructure and capacity building are essential for harnessing the potential of technology in rural transformation.

Despite India's longstanding commitment to mangrove conservation through stringent environmental legislation, top-down protectionist strategies have often fallen short of ensuring long-term ecological sustainability. Recognising these limitations, the government introduced a more participatory model in the early 1990s under the Joint Forest Management (JFM) program, which aimed to empower local communities and stakeholders, including NGOs and Community-based Organisations (CBOs), to actively engage in the management of forest resources (Selvam 2003; DasGupta and Shaw 2013). This community-based co-management (CBMM) model marked a significant shift in mangrove governance in India, offering a collaborative framework that integrates traditional knowledge, local needs, and conservation priorities. NGOs, in particular, have played a crucial role as intermediaries, facilitating dialogue between forest departments and resource-dependent communities, forming local user groups, and mobilising self-help initiatives (Sundar 2000). However, the effectiveness of NGOs remains uneven. While they have contributed significantly to awareness building and community mobilisation, their long-term impact is often constrained by the project-based nature of their interventions, lack of sustained funding, and absence of formal authority in dispute resolution, especially in heterogeneous communities divided along caste or livelihood lines. Furthermore, the discretion to include NGOs in JFM initiatives lies with the forest department, leading to inconsistent application of co-management strategies across regions. Despite these challenges, successful case studies such as NGO-led mangrove restoration in Pondicherry demonstrate the potential for civil society engagement to achieve superior conservation outcomes compared to solely government-led initiatives (Datta et al. 2012).

The collaborative model is particularly critical due to the region's complex socio-ecological dynamics and vulnerability to climate-induced disasters. With over 4.3 million residents dependent on mangrove ecosystems for livelihood and protection, a decentralised and inclusive approach to mangrove management is essential for long-term resilience. The Joint Mangrove Management (JMM) model typically involves three key stakeholders: local forest departments, mangrove-dependent communities, and facilitating NGOs. However, these user groups are further differentiated into resource-dependent and resource-independent communities, complicating coordination and equitable participation (Kathiresan 2011). NGOs and CBOs operate with limited legal and tenurial rights despite their central role, often undermining their authority and continuity. The current governance structure also allows forest departments full discretion over the formation and dissolution of Joint Mangrove Management Committees (JMMCs), leaving little room for institutional stability or community ownership. To address these limitations, a growing consensus exists on integrating JMM holistically with national climate change adaptation strategies and disaster risk reduction frameworks. Doing so could enhance technical and financial capacities, mobilise larger resource pools, and motivate vulnerable coastal populations to actively engage in mangrove conservation and restoration (Datta et al. 2012; DasGupta and Shaw 2013). Mangroves are ecological assets and function as natural buffers against storms, tidal surges, and erosion, reducing disaster vulnerability in coastal rural areas. Therefore, any future direction in mangrove governance must prioritise statutory recognition of community rights, institutionalise participatory governance, and promote integrated frameworks that link environmental sustainability with economic empowerment and disaster resilience. This approach would improve conservation outcomes and strengthen coastal communities' socio-economic fabric, making them active stakeholders in the stewardship of critical ecosystems.

5.10 Conclusion

5.10.1 Synthesis

ISD exemplifies a fragile balance between human communities and their natural environment, where livelihoods have traditionally depended on agriculture, fishing, and forest resources supported by mangrove ecosystems and tidal rivers. However, this equilibrium is increasingly disrupted by environmental stressors such as salinity intrusion, coastal erosion, frequent cyclones, and broader climate change impacts, including sea-level rise and rising temperatures (Sarkar et al. 2024; Hazra et al. 2010; Mukherjee and Siddique 2024). These pressures degrade traditional livelihoods, compelling residents to adopt coping mechanisms like migration, livelihood diversification, and community-driven initiatives, including mangrove restoration and sustainable water management (Chandra and

Sagar 2003; Padhy et al. 2021). Governance structures are multilayered but often hampered by weak enforcement, bureaucratic inefficiencies, and limited participation from local communities (Kumar et al. 2021; Das 2024). Building resilience requires strengthening social capital, decentralising governance, and empowering local groups, particularly women's self-help organisations (Pandhare et al. 2024). Existing policies such as the Coastal Regulation Zone Notification, Forest Rights Act, and community co-management frameworks provide important foundations but face implementation and integration challenges with climate adaptation strategies (Prasad 2020; Mohanty et al. 2024). Adopting emerging technologies and participatory governance approaches offers promising avenues for sustainable development (Dasgupta et al. 2020; Banerjee and Dutta 2023). Achieving sustainable livelihoods in this climate-sensitive delta ultimately depends on balancing ecological conservation with socio-economic empowerment.

5.11 Recommendations

To address the complex vulnerabilities of the Sundarbans, livelihood diversification and emphasis on ecological sustainability are essential. Introducing salt-tolerant crops and integrated aquaculture systems can stabilise food production and incomes while alleviating pressure on wild fisheries and forests (Mahmood et al. 2021). Eco-tourism and community-based conservation offer alternative livelihood opportunities that foster biodiversity conservation and economic benefits (Saifullah and Jewel 2021). Empowering marginalised groups, especially women, through skill development and micro-enterprises strengthens social inclusion and resilience (Moreda 2023; Pandhare et al. 2024). Renewable energy technologies like solar and biogas help mitigate energy scarcity, supporting value addition and market access. Enhancing community-based disaster preparedness and natural resource co-management improves adaptive capacities (Paul et al. 2021). Digital tools that link local producers with wider markets can increase profitability and reduce exploitation. These strategies collectively promote an integrated approach grounded in ecological care, social justice, and technological innovation to build a sustainable future for the Sundarbans.

5.11.1 Limitations and Future Strategies

Nature-based solutions (NBS), such as mangrove restoration, offer substantial ecological benefits but encounter barriers, including socio-economic inequalities, insufficient institutional frameworks, and socio-political complexities like land tenure disputes and low community engagement (Chowdhury et al. 2021; Ghosh and Jana 2019; Mukhopadhyay and Saha 2020). Fragmented governance and lack of coordinated policy enforcement hinder the scaling and sustainability of these solutions (Roy and Pal 2022). Moving forward,

participatory governance models that empower local stakeholders, foster knowledge co-production and ensure equitable benefit-sharing are imperative (Dasgupta et al. 2020). Strengthening governance across multiple levels and embedding climate resilience into NBS frameworks are crucial for tackling the Sundarbans' dynamic environmental and livelihood challenges (Banerjee and Dutta 2023). These comprehensive strategies can create adaptive, inclusive, and sustainable outcomes consistent with the socio-ecological complexity of the region.

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