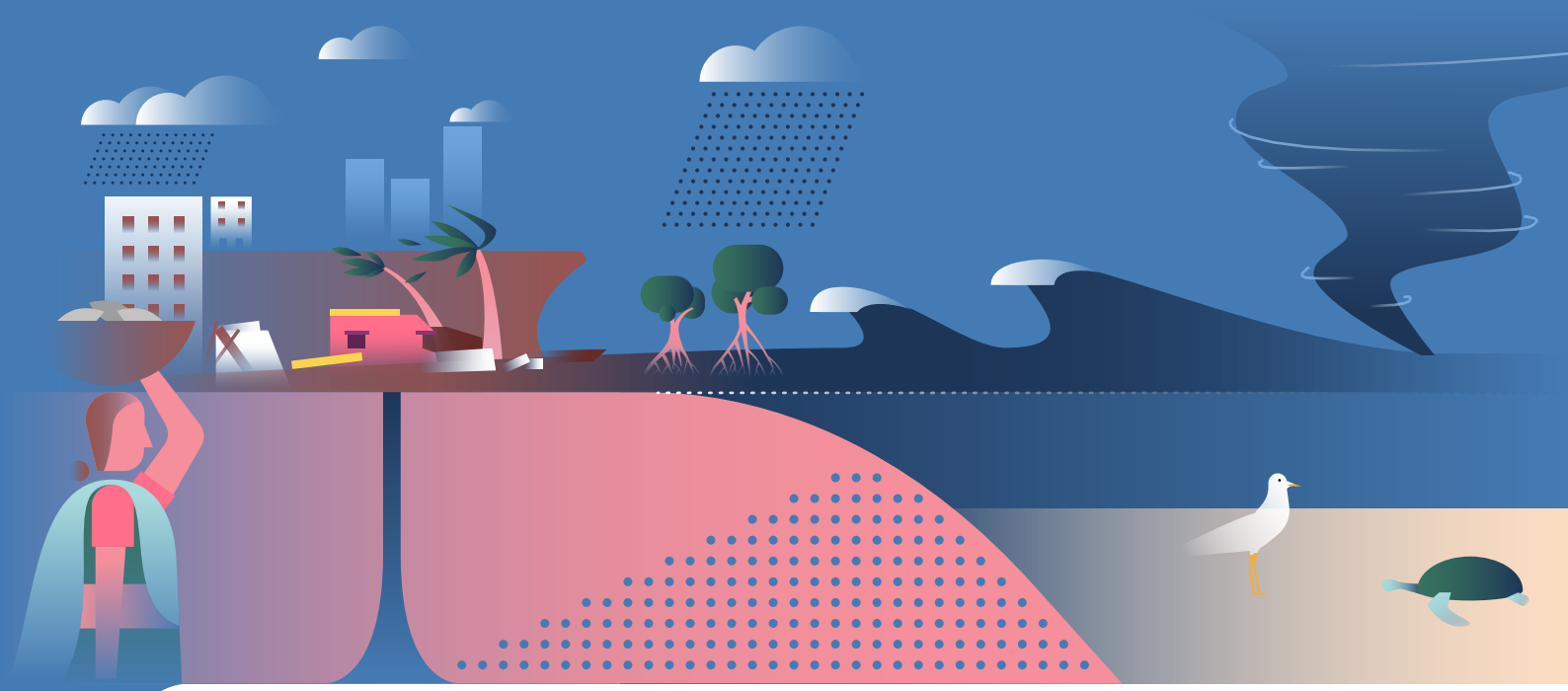

Issue Brief | March 2026

SUSTAINABLE FUTURES COLLABORATIVE

Strengthening Coastal Resilience in India

A Multi-hazard Approach to Adaptation Governance

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1. Introduction

Coastal zones are the most productive and dynamic ecosystems on earth, supporting extensive economic activity, natural resources, and livelihoods (Neumann, Ott, and Kenchington 2017). However, climate change is increasingly placing pressure on these regions through multiple interacting coastal hazards, such as sea-level rise (SLR), cyclones, storm surges, floods, and erosion (Hoffmann and Reicherter 2014; Anagha and Shukla 2025).

India, with an extensive coastline of approximately 11,098 km, stretching across nine states and four union territories (Figure 1), hosts rich marine biodiversity, diverse ecosystems, and more than 250 million people within 50 km of the shoreline. This coastline is vital to both the national and state economies, as these ecosystems underpin local livelihoods, industries, and development projects, making climate impacts on the coast particularly consequential for human well-being and economic stability (Roy et al. 2023; Sreelakshmi et al. 2024; Puthucherril 2025).

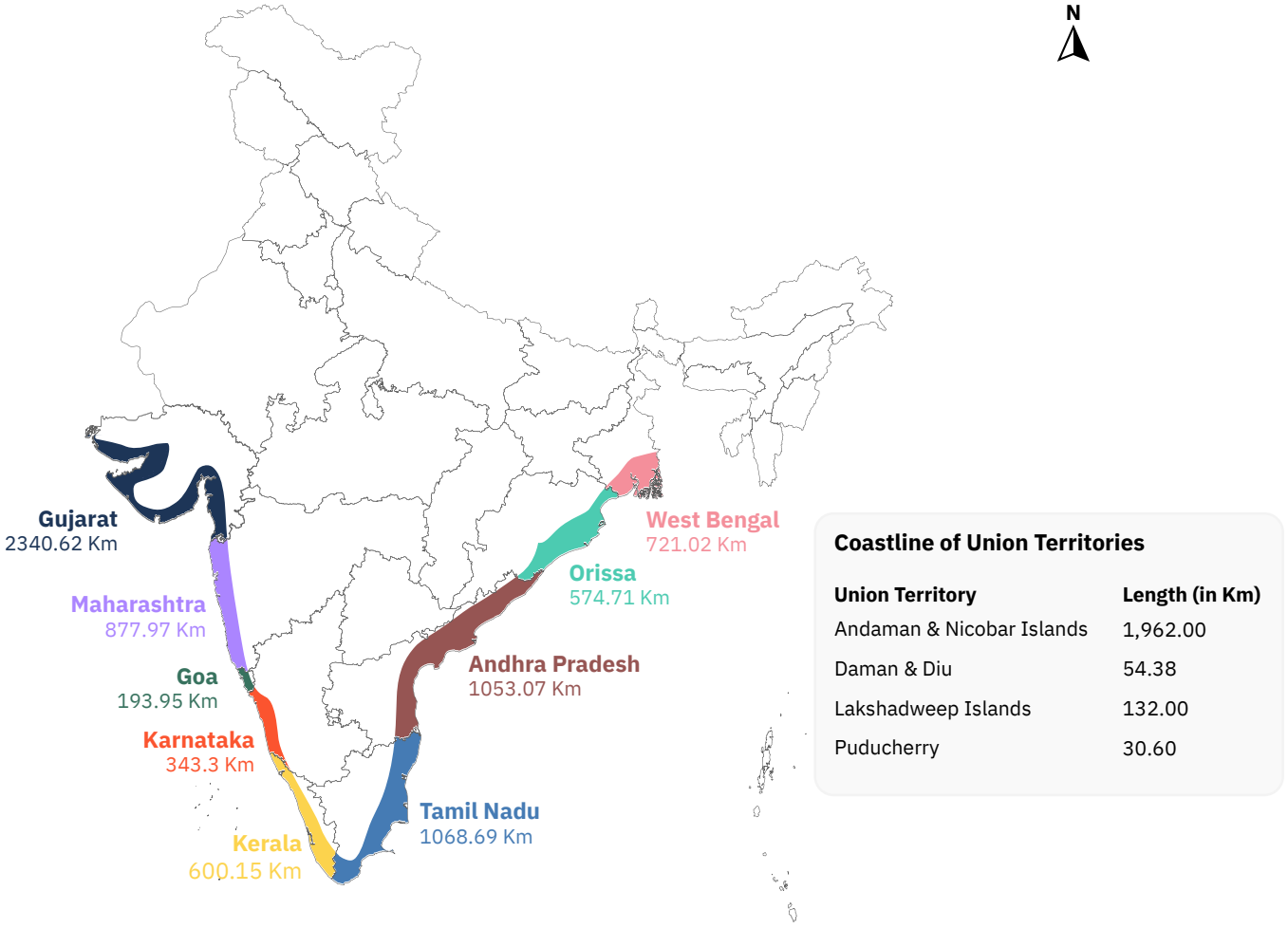

Figure 1. India's total coastline measures 11,098.81 km, with Gujarat, Andhra Pradesh, and Tamil Nadu together accounting for approximately 40% of the total length
Source: Authors' visualisation based on Ministry of Ports, Shipping and Waterways 2025

Recent studies indicate that India's coastal regions are experiencing accelerating trends in climate-related hazards. Observed changes include relative SLR along both the east and west coasts, increasing frequency and intensity of cyclones in the Bay of Bengal and the Arabian Sea, more frequent coastal flooding and erosion, and growing saltwater intrusion into coastal aquifers and agricultural lands (Gills et al. 2024; Malakar et al. 2021; Dutta et al. 2025; Government of India 2023; Puthucherril 2025; Prusty and Farooq 2020). These climate-driven hazards, together with non-climatic pressures such as coastal development, population growth, subsidence, and shoreline modification, are collectively transforming India's coastal regions into high-risk zones and exacerbating existing social and ecological vulnerabilities (Gills et al. 2024; Padhan and Madheswaran 2023; Jennath and Paul 2024; Sreelakshmi et al. 2024).

Managing the complex risks emerging from these hazards depends critically on how coastal governance is structured. Over the past decade, India has taken important steps to assess climate vulnerability and develop adaptation measures for coastal regions through initiatives such as the National Coastal Mission (NCM) under the National Action Plan on Climate Change (NAPCC), and vulnerability assessments supported by the National Centre

for Coastal Research (MoEFCC 2023). **However, vulnerability assessments and adaptation planning remain focused on single hazards and are often implemented in silos** (Anagha and Shukla 2025; Jyotsna et al. 2024; Puthucherril 2025). This fragmented approach overlooks the cascading and compounding[1] nature of coastal hazards and limits the effectiveness of risk mitigation.

A significant body of literature shows that interactions between acute coastal hazards, such as cyclones and storm surges and chronic coastal hazards, such as SLR, amplify impacts across social and ecological systems (Tansel 2025; Haer and de Ruiter 2024). Hence, continued reliance on single-hazard planning can result in blind spots and maladaptation[2] (Barnett and O'Neill 2010; Haer and de Ruiter 2024).

In this issue brief, we highlight why strengthening coastal resilience in India requires moving beyond single-hazard planning and adopting an integrated understanding of interacting coastal hazards. We do this in the following sections: First, we explain the major coastal hazards, their dynamic interaction and latest trends. We follow the coastal hazard taxonomy,[3] which is based on physical processes and focuses on five priority hazards based on likelihood, severity, and impact on both human and natural systems (Gills et al. 2025). Second, we review India's coastal governance landscape to highlight how fragmented governance and single-hazard approaches constrain effective adaptation. In the end, we suggest shifting the focus of coastal adaptation planning toward a multi-hazard, systemic approach to ensure long-term resilience of coastal ecosystems and communities.

We use the term adaptation to refer to the process of adjusting to observed or projected climate impacts to reduce harm. Resilience denotes the capacity of coastal socioecological systems to absorb, cope with, and respond to interacting hazards while retaining their foundational structure and functions. Within this framing, adaptation measures, whether institutional, infrastructural, or nature-based, are mechanisms for building long-term resilience.

A shift toward a comprehensive, multi-hazard framework that integrates physical, ecological, and socio-economic factors is essential for building long-term coastal resilience.

1 Cascading effects refer to a chain of events where an initial event triggers following events. Compounding can be simple or interactive. Simple compounding refers to the cumulative effect of multiple hazards acting independently. Interactive compounding refers to the combined effect of hazards when one hazard modifies, amplifies or trigger another. As a result, the overall impact will be greater than the sum of individual effects.

2 Maladaptation refers to negative consequences of climate adaptation

3 Taxonomies of coastal hazards categorize them based on physical process (geological, mereological and hydrological process), framework (coastal hazard wheel), and vulnerability assessment (vulnerability of coastal regions to natural and human-induced hazards).

House destroyed by sea surge in Valiyathura, Kerala Credit: Prasoon Kiran

2. Multiple and overlapping coastal hazards in India

India's coastal regions are exposed to a range of climate-induced hazards, such as cyclones and associated storm surges, coastal flooding, and SLR. In this section, we examine the complex and nonlinear interactions among selected hazards. We begin by outlining the criteria used to prioritise five hazards. We then examine current trends, followed by a discussion of interactions among these coastal hazards and the resulting compounding impacts.

2.1 Scope and hazard selection

The frequency and severity of coastal hazards have increased in recent decades due to climate change and anthropogenic pressures (Gills et al. 2024; Subramanian et al. 2023). While less frequent events such as tsunamis and emerging stressors, including marine and atmospheric heatwaves, are also important hazards to the coast, this issue brief focuses on five hazards: cyclones and associated storm surges, coastal flooding, coastal erosion, SLR, and saltwater intrusion.

Cyclones and associated storm surges, along with coastal flooding, are acute hazards that generate high-intensity impacts over short periods. In contrast, coastal erosion, SLR, and saltwater intrusion are chronic hazards that progressively reshape coastlines and undermine livelihoods over time (Hasnine and Nagdeve 2025).

These hazards are selected because they represent the most frequent and damaging risks along tropical coastlines (Anagha and Shukla 2025; Tanim et al. 2022; WMO 2023) and also the most common hazards addressed through separate sectoral programmes and institutions in India. This makes them

well-suited to diagnosing how single-hazard governance can inadvertently generate multi-hazard risk over time. This narrowed scope allows for a clearer examination of interactions among hazards that directly affect coastal land, infrastructure, ecologies, and human settlements.

2.2 Accelerating trends of coastal hazards

Over the past few years, coastal hazards have increased in their form and intensity. Cyclones in India have historically caused extensive infrastructure damage, habitat loss, and livelihood disruption along the east coast, particularly in states such as Odisha and West Bengal (Gills et al. 2024). Recent trends indicate that the frequency and intensity of cyclones along the west coast are also increasing (Malakar et al. 2021; Deshpande et al. 2021). Between 2019 and 2024, India experienced 27 cyclones, out of which four were severe and caused significant infrastructure damage and livelihood loss (Barua 2025). Cyclones often trigger storm surges that, when combined with heavy rainfall and high tides, result in compound coastal flooding. These cyclone-driven flood dynamics show how acute events can accelerate chronic shoreline change and salination, thereby intensifying the impacts of other hazards.

Coastal flood frequency has increased in recent decades, with extreme rainfall events three times more frequent than pre-1950 levels (Roxy et al. 2017). The Malabar coast has shown an average of 8% increase in pre-monsoon flood intensity per decade (Kuntla, Saharia, and Jain 2025), reflecting climate change-driven SLR and high-intensity rainfall. The time series data of High Tide Flooding Days (HTD) from 1979 to 2015 shows the increased frequency of HTDs over the past few decades (See Figure 2) (Climate Change Knowledge Portal n.d.; Dutta et al. 2025).

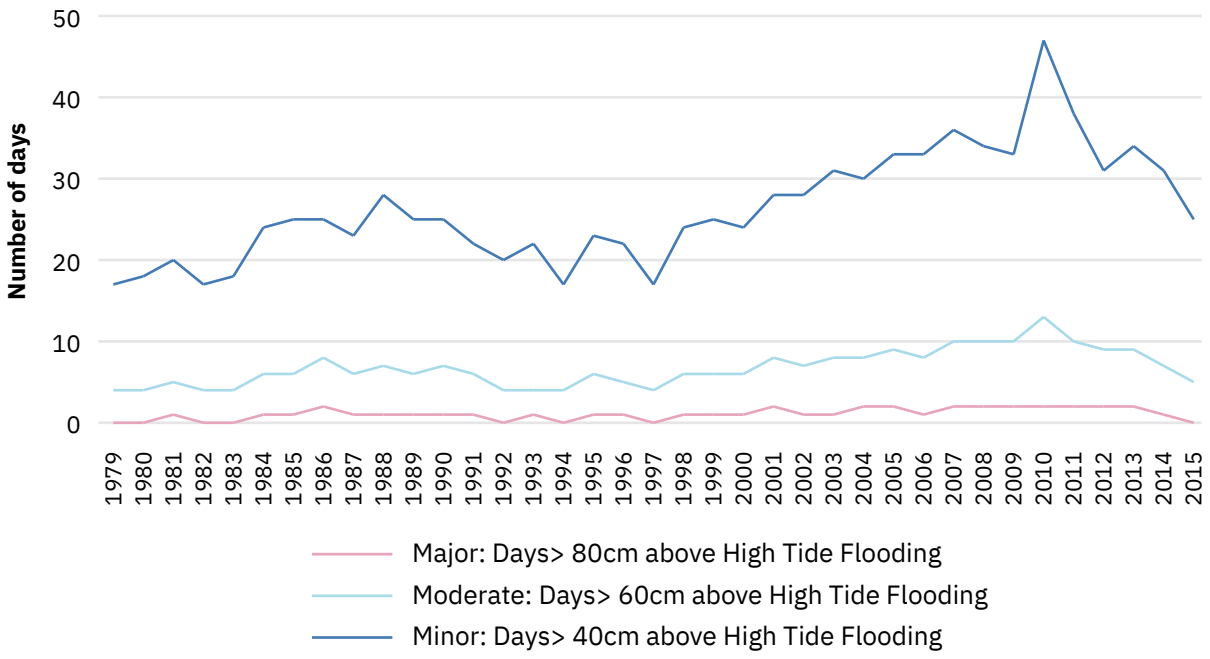

Figure 2. The number of minor and moderate High Tide Flooding Days in the Indian Exclusive Economic Zone has increased between 1979 and 2015
Source: Climate Change Knowledge Portal n.d.

Between 1990 and 2018, 34% of India's coastline was under varying degrees of erosion. This represents a 0.6% increase in erosion relative to the previous assessment. Currently, over 50% of the coastlines in West Bengal and Puducherry, and large stretches of Kerala and Tamil Nadu (Figure 3), are experiencing severe erosion (Kankara et al. 2018; Government of India 2023). Erosion is intensified by cyclones and SLR, contributing to the loss of landmass and the degradation of sensitive ecosystems such as mangroves and turtle nesting beaches.

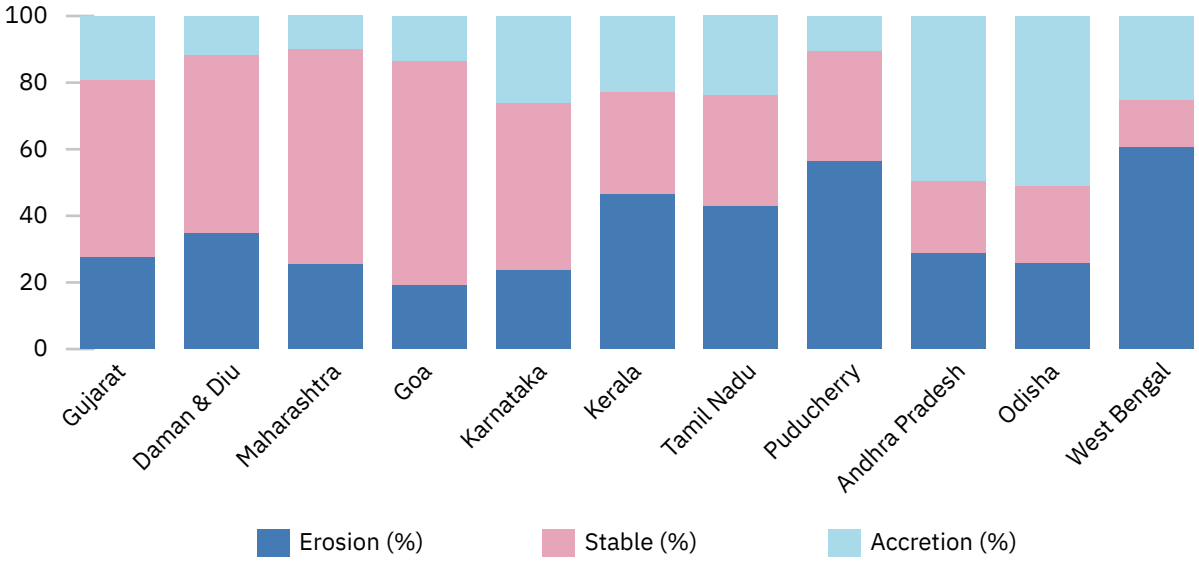

Figure 3: Shoreline status of Indian mainland states and UTs between 1990-2018, showing high erosion in West Bengal and Puducherry and notable accretion in Andhra Pradesh and Odisha
Source: Authors' visualisation based on Ministry of Earth Sciences 2023

SLR along India's coastline shows a steady acceleration over the past century. **According to the Ministry of Earth Sciences (2023), the rate of sea-level rise along the Indian coast has increased from about 1.7 mm per year to 3.3 mm per year over the past two decades.** SLR threatens wetlands, agricultural lands and coastal settlements across India. In Odisha districts including Ganjam, Puri, and Balasore are experiencing flooding and inundation, impacting millions. Sensitive ecosystems such as Bhitarkanika National Park, Balukhand-Konark Wildlife Sanctuary and areas around Chilika Lake are at risk of permanent inundation (Government of Odisha, n.d.). SLR could lead to the loss of up to 12,541.5 km² of wetlands in Gujarat (Government of Gujarat 2014), while in Karnataka, continued rise could submerge about 461 km² of coastal land over the coming century (Puthucherril 2025).

Areas impacted by saltwater intrusion along India's coasts have also expanded significantly over recent years. Manivannan and Elango (2019) report that the total affected area increased from approximately 2,100 km² in 2007 to nearly 2,600 km² by 2017, representing an additional 500 km² nationwide. Saltwater intrusion into groundwater aquifers is further

exacerbated by SLR, groundwater over-extraction, and aquaculture expansion, which constitute serious coastal hazards that particularly affect freshwater availability in deltas such as the Mahanadi and Godavari (Prusty and Farooq 2020; CoCHAP n.d.; Motevalli et al. 2018; Kumar M. et al. 2024). This directly undermines drinking-water security and agricultural productivity.

2.3 Interaction between multiple coastal hazards

Coastal hazards rarely occur as isolated events. Instead, they interact with one another in ways that amplify impacts, extend damage over time, and increase overall risk (Tansel 2025).

Figure 4 illustrates the dynamic interactions among SLR, coastal flooding, cyclones and associated storm surges, coastal erosion, and saltwater intrusion. SLR plays a central role by raising baseline water levels along the coast. Higher sea levels increase the extent and depth of coastal flooding, intensify storm surges during cyclones, and accelerate shoreline erosion by allowing waves to act further inland. These processes, in turn, weaken natural and built coastal defences, thereby increasing coastal vulnerability to subsequent events.

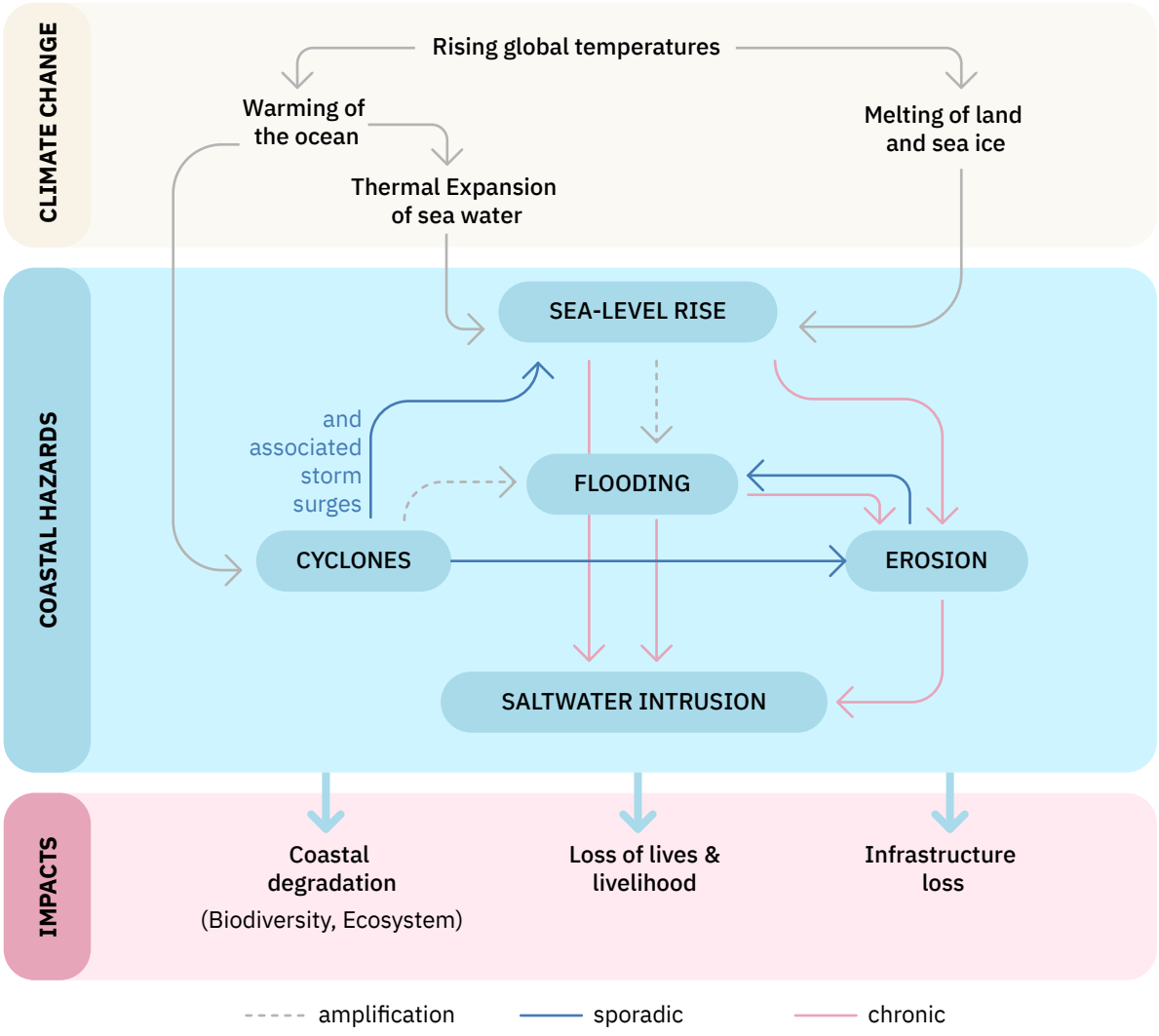

Figure 4. Simplified model of interactions between multiple coastal hazards
Source: Authors' analysis

Cyclones and associated storm surges act as acute triggers within this system. During extreme events, storm surges and heavy rainfall cause widespread coastal flooding, which can rapidly erode shorelines and push saltwater into soils, rivers, and aquifers (Barui et al. 2025; Dutta et al. 2025). Coastal erosion further compounds these risks by lowering land elevation and protective buffers, thereby increasing exposure to future flooding and saltwater intrusion (Stanic et al. 2024).

Saltwater intrusion represents a chronic outcome of repeated flooding, erosion, and rising sea levels. As saltwater penetrates freshwater systems, it degrades agricultural land, drinking water sources, and ecosystems, thereby reinforcing long-term vulnerability (Prusty and Farooq 2020; CoCHAP n.d.).

Together, these five hazards form a vicious cycle in which slow-onset processes and extreme events interact, creating cascading and compounding impacts that translate into ecosystem degradation, loss of livelihoods and lives, and infrastructure damage.

2.4 Compound impacts of overlapping coastal hazards

From the discussion above, it is clear that coastal hazards do not occur in isolation. Acute hazards, such as cyclones, storm surges, and flooding, accelerate chronic processes, such as erosion and salinisation. In contrast, chronic hazards like SLR increase baseline exposure and make subsequent storms or floods more destructive. Due to the cascading and compounding nature of hazards, India's coastline becomes a dynamic multi-hazard environment, in which single-hazard planning is inadequate (Anagha and Shukla 2025; MoEFCC 2018).

Recent evidence shows that these interactions are already producing compound impacts. Tide-gauge analyses along the Indian coast document compound flooding driven by the concurrent occurrence of extreme rainfall with storm surges or elevated sea levels (Dutta 2024). In Mumbai, heavy rainfall during high tide leads to substantially higher mortality than the same rainfall at low tide, with projected SLR further amplifying these losses (Bearpark et al. 2025). In the Indian Sundarbans, storm surges during Cyclones Amphan and Yaas breached embankments, triggered lasting saltwater intrusion and cropland degradation, and demonstrated how acute flooding can lock in chronic vulnerability (Barui et al. 2025; Ghosh and Mistri 2023).

Although the risk is shaped by compound effects of multiple hazards, India's coastal governance and adaptation approach is organised around fragmented institutional and infrastructure responses and single-hazard programmes. In the following section, we discuss this mismatch and explain how it impedes the translation of coastal adaptation actions into long-term resilience.

3. India's coastal adaptation strategy – where it stands today

India's coastal adaptation strategy comprises a combination of legislation, hard and soft engineering measures, Nature-based Adaptation (NbA), and the Integrated Coastal Zone Management programme (Puthucherril 2025). Although this strategy reflects a gradual evolution in coastal management, it follows a 'single-hazard logic' that treats interconnected risks as isolated incidents. This section reviews three major components of this strategy: governance, current engineering and NbA measures, and the operational limits of Integrated Coastal Zone Management (ICZM), with a focus on its current status and the gaps that persist.

3.1 Fragmented governance landscape

Coastal governance in India is characterised by a dense policy and institutional landscape, comprising multiple legal frameworks, ministries, and scientific institutions at the national level (See Figures 5 and 6). While this framework may appear comprehensive, Figure 5 maps these legal instruments and shows a heavy skew towards operational management rather than proactive, long-term adaptive resilience.

Institutional limitations and reactive planning focus

At the national and state policy level, the NAPCC and the State Action Plans on Climate Change (SAPCCs) guide adaptation planning and climate change mitigation in the country (Government of India 2008). The National

Dredging sand at the mouth of the Kovalam backwaters/Great Salt Lake in Chennai, Tamil Nadu Credit: Aaran Patel

Coastal Mission, under the NAPCC, promotes sustainable coastal resource management, strengthening institutional mechanisms for integrated coastal governance, and building resilience to climate impacts.

However, translating these national goals is constrained by financial and institutional limitations. The NCM has suffered from insufficient institutional support, inconsistencies in budget allocation (reduced from ₹195 crores (BE 2022-23) to ₹50 crores (BE 2024-25)), and significant underutilisation of the budget. In 2024-25, the ministry spent only 13.8% (₹1.10 crore) of the ₹8 crore (RE) up to 31.1.2025 (Department-Related Parliamentary Standing Committee on Science and Technology, Environment, Forests and Climate Change 2025). This persistent underfunding hinders the NCM's functioning and undermines efforts to build long-term resilience.

Beyond budget constraints, a critical conflict exists between the vision of long-term climate action plans and on-ground realities. While national and state climate action plans focus on adaptation to existing risks and mitigation of future risks, national and state Disaster Management Plans (DMPs) become important documents when risks manifest as disasters. In practice, the urgency of disaster response often overrides long-term planning, leaving the coast in a vicious cycle of reactive recovery instead of planned adaptation. Similarly, Pillai et al. (2025) analysis of heat resilience shows that responses focus on immediate heat-wave relief rather than long-term adaptation, highlighting a broader governance pattern in India. Such reactive approaches become particularly problematic given the compound nature of coastal risk, where hazards manifest as both immediate shocks (e.g., cyclones and floods) and long-term shoreline changes (e.g., erosion and sea-level rise).

Poor compliance with the CRZ notification

The Coastal Regulation Zone (CRZ) Notification, issued under the Environment (Protection) Act, 1986, forms the core coastal regulatory framework, supported by instruments such as the Environmental Impact Assessment (EIA) Notification, 2006, the Wildlife (Protection) Act (WLPA), 1972, the Forest (Conservation) Act, 1980, and the Biological Diversity Act, 2002. Within this architecture, the Coastal Zone Management Plans (CZMPs), prepared in accordance with the principles of the Integrated Coastal Zone Management Plan (ICZMP) (Puthucherril 2025), provide spatial guidance for coastal development and protection (Jyotsna et al. 2024). However, its implementation remains a major bottleneck. Although all states have completed coastal zone mapping under the CRZ notification 2019, CZMP preparation and implementation remain uneven across states. For example, only Kerala has prepared CZMPs for all coastal districts. This leaves long stretches of the coast in other states without clear plans, potentially leading to unregulated development that increases vulnerability. Further, the Government of India's Comptroller and Auditor General (CAG) 2022 audit report noted non-compliance with CRZ notification at both the pre- and post-clearance stages, indicating procedural bypassing and weak regulatory oversight (Comptroller and Auditor General of India 2022).

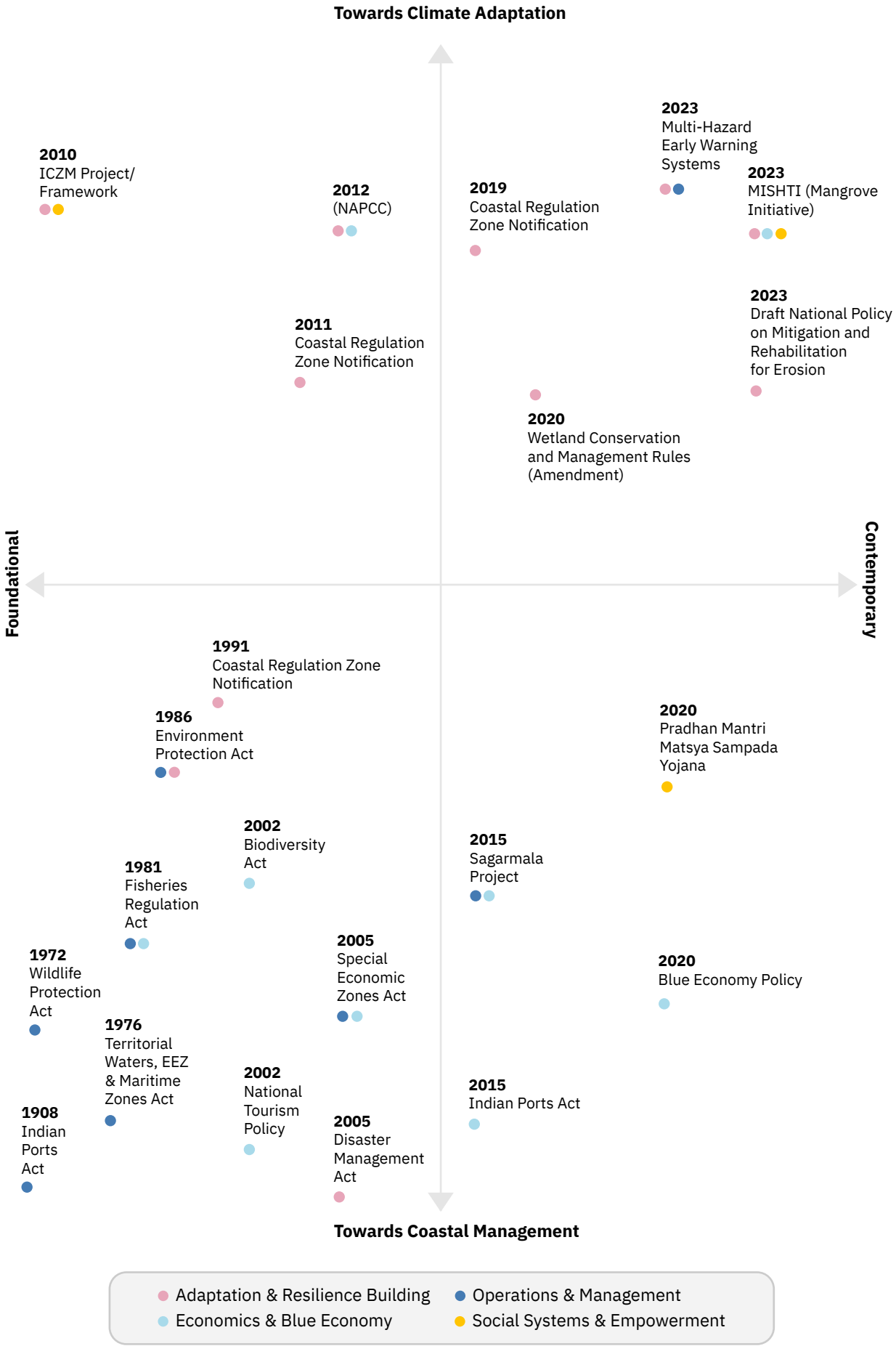

Figure 5: National-level policies and acts relevant to the coast in a coordinate plane. The vertical axis depicts two paradigms (coastal management and climate adaptation), and the horizontal axis moves from foundational to contemporary policies and acts. The top-right quadrant shows frameworks closely related to adaptation.
Source: Authors' compilation

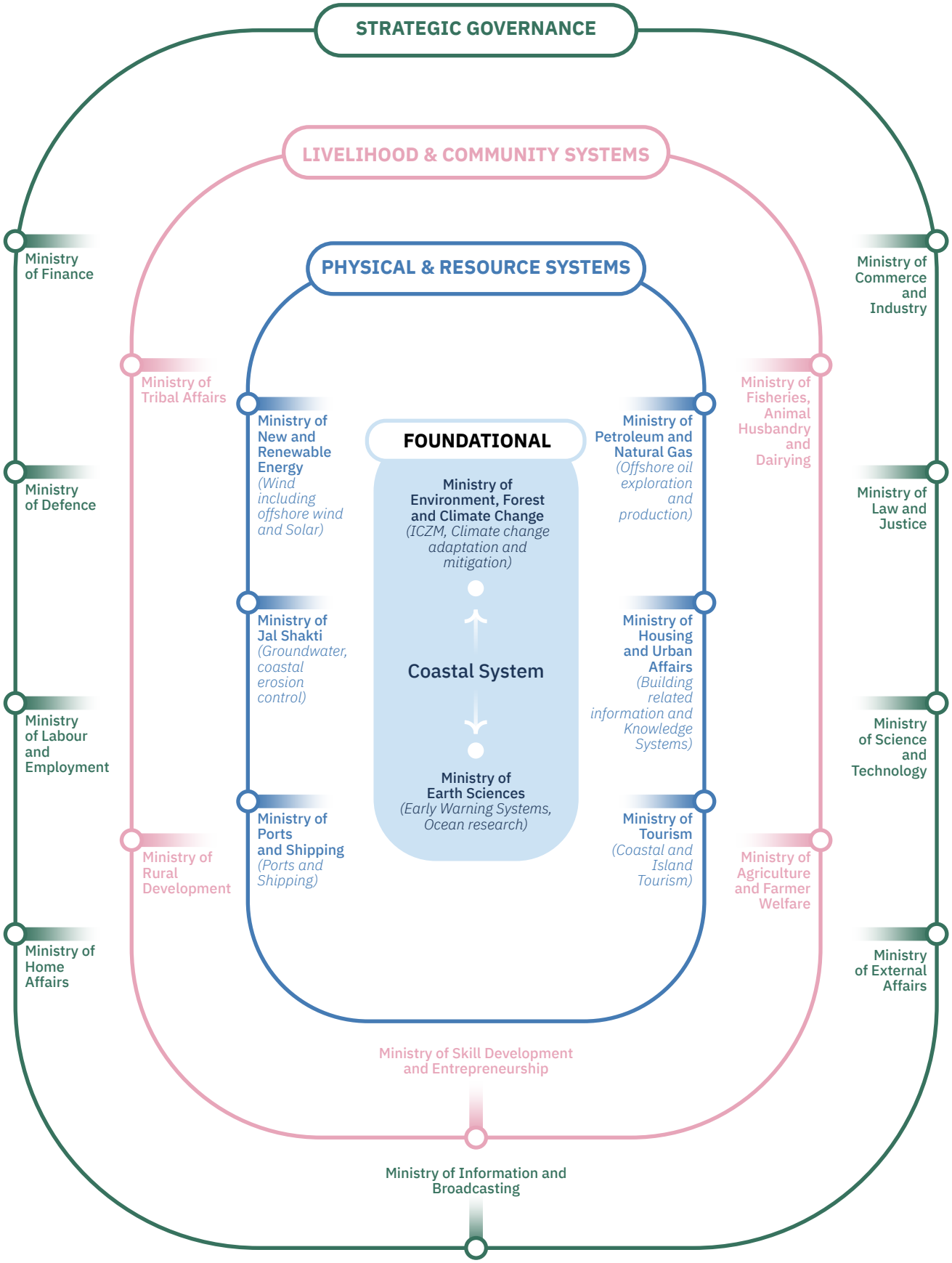

Figure 6: This figure maps Union ministries with direct or indirect mandates over coastal systems, illustrating the dense, multi-layered, and fragmented nature of coastal governance. The ministries are organised into four functional layers. At the centre are the foundational anchoring ministries responsible for climate regulation, environmental safeguards, and scientific knowledge. Surrounding this core are ministries governing physical and resource systems, including infrastructure, energy, water, and extractive sectors that shape risk exposure and vulnerability. The next layer depicts livelihood and community systems, comprising ministries responsible for fisheries, agriculture, rural development, tourism, and skills development, which mediate social and economic resilience along the coast. The outermost layer encompasses ministries with broader strategic governance mandates that influence coastal outcomes through fiscal, security, and regulatory mechanisms.
Source: Authors' visualisation based on MoEFCC 2018 and MoES 2025

Overlapping mandates and policy conflict

The MoEFCC leads regulatory and management oversight, supported by technical agencies such as the National Coastal Zone Management Authority (NCZMA) and the National Centre for Sustainable Coastal Management (NCSCM),[4] which provide policy coordination and scientific support. Parallelly, the Ministry of Earth Sciences (MoES) serves as the primary technical arm of the government for understanding oceans and coastlines, supported by the Indian National Centre for Ocean Information Services (INCOIS)[5] and the National Institute of Ocean Technology (NIOT).[6] In addition, allied ministries with significant coastal mandates such as the Ministry of Jal Shakti (flood management and coastal protection measures), the Ministry of Ports, Shipping and Waterways (shipping and marine development), the Department of Fisheries (marine and coastal fisheries), and the Ministry of Home Affairs through its disaster management division also shape coastal governance outcomes through their sectoral policies and investments (MoEFCC 2018; MoES 2025). At the state level, State Coastal Zone Management Authorities (SCZMAs), along with the concerned state line departments such as forest, environment and water departments, play a crucial role in coastal governance.[7]

Despite this density, the system suffers from fragmentation. Allied ministries, ranging from the Ministry of Agriculture to the Ministry of Jal Shakti, share overlapping mandates, often leading to policy conflicts. For instance, port expansion under the Sagarmala programme (Ministry of Ports, Shipping & Waterways) is inconsistent with a nearby mangrove restoration effort driven by the MoEFCC. Likewise, the National Cyclone Risk Mitigation Project (NCRMP) under the Ministry of Housing & Urban Affairs conflicts with uncoordinated erosion schemes under the Ministry of Jal Shakti, thereby fragmenting holistic coastal resilience. While inter-ministerial committees such as the Coastal Protection and Development Advisory Committee (CPDAC) and the Sagarmala Coordination and Steering Committee (SCSC)[8] exist, their authority to mandate cross-sectoral planning to integrate disaster risk, climate change, and biodiversity is often advisory rather than absolute. These overlapping mandates and competing development priorities limit coordination and implementation of suitable adaptation measures.

4 https://ncscm.res.in/

5 https://incois.gov.in/site/index.jsp

6 https://www.niot.res.in/

7 This is not an exhaustive list of departments involved in coastal governance at the state level. Similar to the national level (see Figure 6), there are allied departments in the states which have mandates related to coastal governance

8 CPDAC is a high-level inter-ministerial committee under the Central Water Commission (MoJS) that deliberates on coastal erosion solutions and appraises coastal protection works by the states. SCSC, chaired by the Cabinet Secretary, facilitates inter-ministerial coordination for Sagarmala's port-led development projects.

3.2 Engineering trap and dominance of single-hazard interventions

Current coastal adaptation efforts in India are largely implemented through physical infrastructure, designed to reduce exposure to specific hazards (Rodriguez 2008). These measures are typically planned and implemented as stand-alone responses to single hazards, rather than as part of an integrated multi-hazard adaptation strategy. As a result, coastal infrastructure has evolved in silos, with limited consideration of how different hazards interact or how interventions addressing one risk may amplify others over time. This reinforces path dependency (Nunn et al. 2021), in which investments continue to favour visible short-term protection over systemic long-term resilience.

Dominance of hard and soft infrastructures

Adaptation actions have been implemented primarily through engineered protection, with hard and soft measures deployed to stabilise shorelines or control water movement in response to isolated hazards.

Hard engineering structures such as seawalls, revetments, breakwaters, bulkheads, and groynes have been the most common methods to mitigate the risks of coastal disasters. They are built along coastlines to protect shorelines by dissipating the energy of waves and currents. While hard structures offer immediate physical protection, they often disrupt sediment transport, alter nearshore dynamics and result in ecological trade-offs. Continuous coastal armouring along the coasts of Tamil Nadu and Puducherry, for example, has led to beach narrowing, habitat loss and submergence of land and built areas. These changes have adversely impacted marine ecosystems and reduced nesting habitats for species of conservation importance, such as the olive ridley turtle (Roy et al. 2023; Puthucherril 2025).

Hard structures also lead to the shifting of erosion to adjacent stretches of coast. Failure of these structures is common when erosion continues beneath or around the structures (Jennath 2024; Puthucherril 2025). Another key reason for this is due to the planning of these protection measures at site scale (e.g. protecting a specific settlement), rather than at the sediment cell scale (Ramesh et al. 2021).[9] As a result, measures that stabilise one stretch often shift erosion to another site, leading to repeated cycles of protection, failure and expansion of coastal armouring over time.

On the other hand, soft engineering approaches, including beach nourishment (the addition of sand to eroding beaches) and geosynthetic installations such as geotubes and geotextile barriers, seek to work with natural coastal dynamics rather than against them. However, the effectiveness of these

9 A sediment cell is a stretch of coastline where the inputs of sand from outside and losses to adjacent beaches are small. Morphological features that bound sediment cells are large headlands or major shifts in coastal orientation. The volume of sand in a sediment cell is fixed and efforts within a sediment cell have only a small influence on adjacent cells. The length of the sediment cell can vary from 300 km (eg. stretch between Kollam and Koyilandy in Kerala) to 3 km long (eg. Mirya Bay in Maharashtra)

measures depends on appropriate site selection, scientific planning, and consistent maintenance. Experiences from places such as Poonthura and Chellanam in Kerala show that inadequate design and implementation of geotubes can lead to structural failure and foster scepticism among communities about the efficacy of these measures (Jennath 2024).

Although positioned as more flexible alternatives, soft engineering measures are often implemented under the same single-hazard-focused framing, aimed at correcting localised erosion or inundation rather than addressing the broader coastal risk profile or long-term shoreline dynamics. Additionally, over the past decade, all coastal states have prioritised hard structures over mixed approaches in budget allocation.

Notably, resource allocation and infrastructure choices are skewed toward individual hazards, such as coastal erosion and saltwater intrusion. Figure 7 highlights state-wise expenditure on projects addressing broader coastal protection efforts, with large expenditures concentrated in a few states and a clear preference for hard structures in both completed and ongoing projects.[10]

A similar pattern is observed in activities undertaken to manage saltwater intrusion (See Figure 8), where spending is dominated by hard engineering interventions, with limited investments in soft measures.

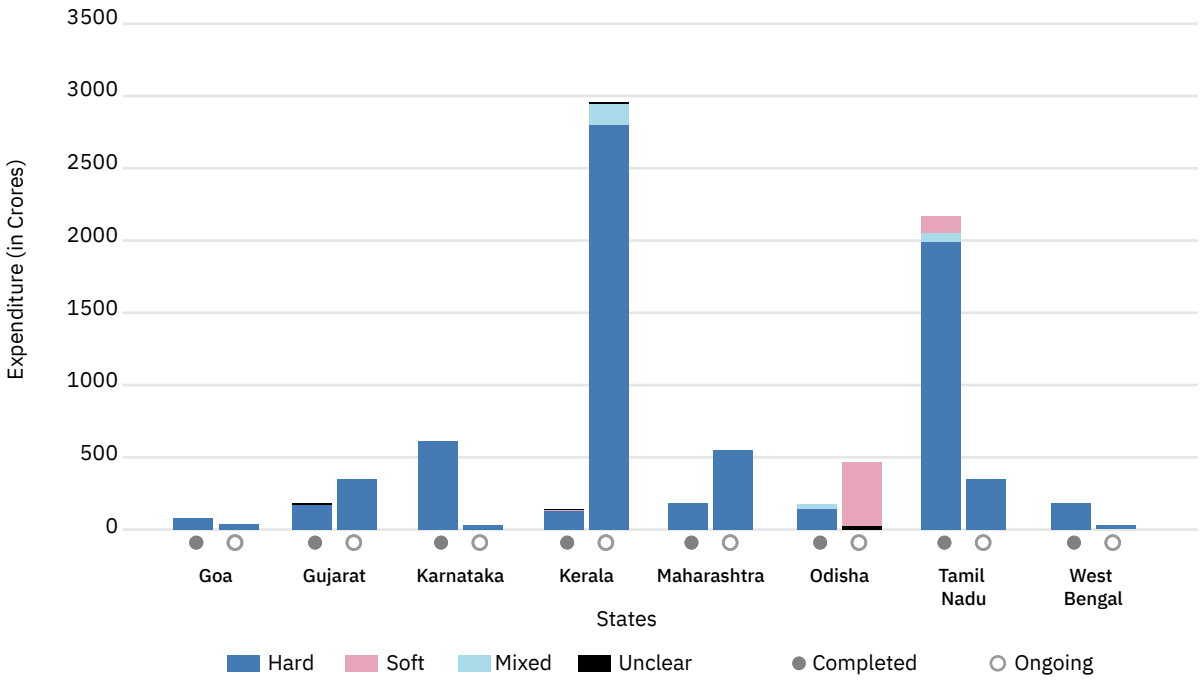

Figure 7: State-wise expenditure for completed and ongoing projects to prevent coastal erosion
Source: Authors' compilation based on CWC 2024

10 Due to the lack of readily available, comparable expenditure data for the other hazards discussed in this brief, our analysis relies on data related to protection measures against coastal erosion and saltwater intrusion. Although limited in scope, this data clearly indicates a strong focus on hard engineering solutions.

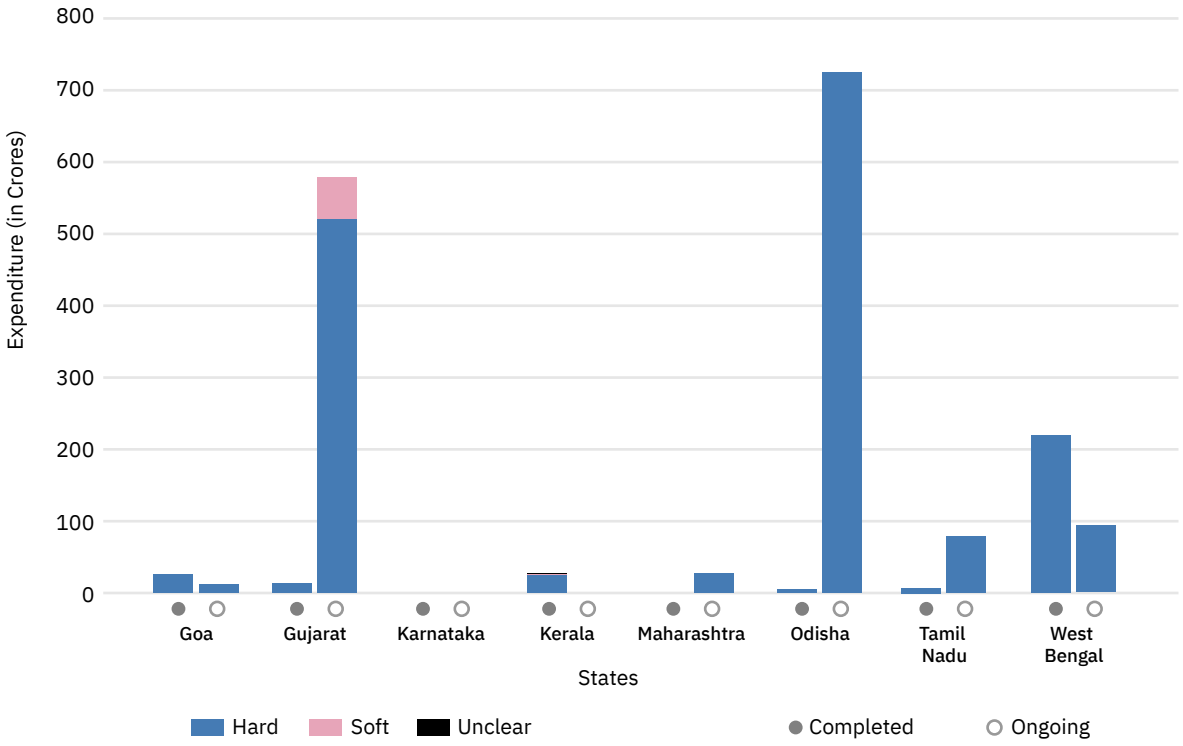

Figure 8: State-wise expenditure on completed and ongoing projects to control saltwater intrusion
Source: Authors' compilation based on CWC 2024

Unrealised potential of Nature-based adaptation

Nature-based adaptation (NbA) measures for the coast include dune restoration, vegetation planting, and mangrove afforestation (NIUA 2025). NbA provides enhanced protection against coastal hazards and significant co-benefits, including carbon sequestration, habitat restoration, and socioeconomic benefits, while having a lower environmental impact than civil engineering measures. The Mangrove Initiative for Shoreline Habitats & Tangible Incomes (MISHTI)[11] scheme by the Government of India is an important advancement in this regard.

Even though NbAs are recognised globally as viable options for addressing many coastal hazards, governments often prefer hard structures as immediate responses. The lack of scientific and technical processes to support NbA is considered the main reason that forces the government to continue with the business-as-usual engineering approach (Puthucherril 2025).

However, considering the complexity and dynamic nature of the coastal environment, transitioning to NbA by completely rejecting engineering measures is not ideal either. There are specific cases or areas, such as coastal cities with high population density, where hard engineering might be a better option than NbA. In contrast, restoration efforts would be better suited to regions with evident degradation (Puthucherril 2025; Huynh et al. 2024).

11 https://www.indiascienceandtechnology.gov.in/programme-schemes/societal-development/mangrove-initiative-shoreline-habitats-tangible-incomes-mishti

Seawall constructed with rubbles and tetrapods in Ullal, Karnataka Credit : Aditya Valiathan Pillai/SFC

This indicates that the major challenge is not choosing between engineering solutions and NbA, but having a framework that enables context-specific integrated management strategies.

3.3 Integrated Coastal Zone Management and its implementation gaps

Integrated Coastal Zone Management (ICZM) is intended to provide the overarching governance framework for coordinating coastal conservation, development, and risk reduction across sectors and hazards. In principle, it should provide the institutional and governance architecture for managing multi-hazard coastal risk, but its potential has not been fully realised in countries like India.

In India, ICZM is embedded in the CRZ notification and coastal management policies, but it has been operationalised through a World Bank-supported project launched in 2010 (World Bank Group 2020). The objectives of the project were to develop capacity for sustainable coastal management and to pilot integrated approaches in three states: Gujarat, Odisha and West Bengal. In phase 1, it supported capacity building, delineation of the coastal hazard line, and mangrove restoration in the pilot states (Puthucherril 2025). However, despite these efforts, the project's ability to drive integration across sectoral agencies has been limited by implementation gaps.

The CAG 2022 report found that important outputs central to integration were not delivered. For instance, hazard lines were mapped but not demarcated on the ground, and the Integrated Management Plans (IMPs) for Critically Vulnerable Coastal Areas (CVCA)[12] were not prepared. Delays in preparing ICZM plans in pilot states led to investments in unrelated activities without

12 As per CRZ 2011 notification, 12 ecologically sensitive areas were identified as Critically Vulnerable Coastal Areas. Integrated Management Plans were to be prepared for these areas, considering conservation of mangroves, local community needs and impact of natural disasters

Sand mining near Thottappally Spillway, Kerala

Credit: Prasoon Kiran

strategic direction. Additionally, the institutions selected for the project lacked sufficient personnel, hindering capacity-building efforts under the project (Comptroller and Auditor General of India 2022).

These audited issues reveal that while ICZM exists in India as a planning framework, it has not strengthened coordination across institutions or altered the dominance of hard engineering-focused sectoral approaches. The lack of national and state-level plans, on-ground hazard data, and empowered institutions prevents ICZM in India from becoming a mechanism for an integrated approach to coastal resilience. In effect, ICZM remains in project mode rather than functioning as a governance mechanism capable of reshaping sectoral approaches to coastal adaptation.

Without proper hazard line mapping, cross-sectoral coordination, and strong institutional capacity, ICZM cannot function as an integrative framework required for governing compounding impacts and supporting multi-hazard adaptation planning.

4. Towards a multi-hazard approach to coastal adaptation

Considering the structural limitations of the current single-hazard-focused approach, India must transition to a holistic approach that recognises the interactions between multiple coastal hazards and their amplified impacts. Recent international and national assessments (Ramakrishnan et al. 2022; IPCC 2023) emphasise the increased cascading and compounding risks in coastal systems, where multiple hazards interact across time and space.

This reinforces the importance of an adaptation strategy that recognises coastal regions as dynamic systems shaped by interacting physical, ecological and socioeconomic processes.

A multi-hazard approach encourages integrated risk assessments that combine climate science with other sets of knowledge to understand how hazards overlap spatially and temporally. This approach also supports the planning of flexible adaptation strategies for uncertain future climate scenarios, rather than reacting to single events.

In practice, a multi-hazard approach to adaptation involves:

- Understanding how hazards interact with each other
- Integrating risk assessments across coastal, ecological and social dimensions
- Aligning adaptation planning and decision-making across different sectors
- Encouraging shared infrastructure and resources
- Combining different types of adaptation (engineered and nature-based) to create a layered protection.

Overall, the goal of this approach is to strengthen the coast's natural adaptive capacity to ensure long-term resilience of coastal ecosystems and livelihoods. This requires shifting from defending the coast against individual threats to governing the coastal zone as a dynamic, multi-hazard socio-ecological system.

However, the effectiveness of a multi-hazard approach depends on policy and institutional arrangements that support integration across sectors. In India, a fragmented governance landscape and project-based interventions constrain systemic action, even though there is recognition of ICZM and systems based approach to adaptation.

In conclusion, the efforts to implement ICZM and the growing need for a multi-hazard approach to adaptation indicate that the primary challenge for India is not the absence of appropriate frameworks, but rather the active streamlining of governance systems to operationalise action at the system level. Therefore, advancing coastal resilience requires reforms to institutions, coordination mechanisms, and policies at the national and state levels to support ICZM, coupled with a multi-hazard approach that functions as an effective governance tool.

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Acknowledgements

We would like to thank Aman Srivastava, Bhargav Krishna, and colleagues in the Adaptation and Resilience vertical at SFC for their comments on this brief. We would also like to thank Kartikeya Jain, Sonali Verma, and Karthika J for providing editorial and communications support.

Suggested Citation: Sony, R. K., and Escandita Tewari. 2026. Strengthening Coastal Resilience in India: A Multi-Hazard Approach to Adaptation Governance. Issue Brief. New Delhi: Sustainable Futures Collaborative (SFC).

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