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# Adapting to sea level rise: is India on- or off-track?

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Like many other regions worldwide, rising sea levels threaten to inundate India's coastal zones and resources, potentially leaving millions impoverished and displaced. India is set to be among the countries severely impacted by climate change and rising sea levels. Fortunately, India has an adaptation strategy that could mitigate some of these effects and help prolong its resilience. This strategy integrates the tools available through its coastal law, hard and soft engineering measures, and nature-based adaptations. Additionally, India relies on Integrated Coastal Zone Management. This paper explores the challenges of rising seas and India's responses to them. The primary argument is that the absence of coherent policies and laws integrating adaptation actions into a unified framework leads to suboptimal use of limited resources, frequently resulting in significant environmental issues, maladaptation and unsustainability.

KEYWORDS

**sustainable coastal development, integrated coastal zone management, sustainable development goals 13 and 14, coastal erosion, sea wall, hard armouring, geotex tubes, mangrove conservation**

## 1 Introduction

Climate change represents the greatest crisis facing our planet and humanity, with rapidly rising sea levels as its most alarming symptom. The rate of sea level rise (SLR) has more than doubled over the past three decades, clearly indicating the severity of the situation. From 1993 to 2002, this rate was 2.1 mm per year. Since then, it has increased; between 2014 and 2023, it reached 4.8 mm per year (Hamlington et al., 2024). According to predictions by the Intergovernmental Panel on Climate Change (IPCC), global sea levels are likely to rise by an average of 15 to 30 centimetres by 2050, with even greater increases anticipated in tropical regions (Intergovernmental Panel on Climate Change, 2022). Rising sea levels will directly impact nearly a billion people living in low-lying coastal zones. Furthermore, it is forecast that by the end of this century, extreme sea-level-related events, which previously occurred once every century, might become annual occurrences. In just two decades, coastal areas that currently experience one or two flooding events could witness more than one hundred such incidents each year (UN General Assembly High-level plenary meeting on Addressing the existential threats posed by sea-level rise, 2024a). While an existential crisis looms large for Small Island Developing States (SIDS), the impacts will be equally disruptive in larger coastal countries like India, where millions will need to adapt to storms, flooding, and erosion. Some may even be compelled to relocate.

The adverse effects of SLR infringe upon human rights, resource use, and development at both macro and micro levels, as well as a country's statehood, along with its maritime zones and boundaries. No continent or region will be immune to this multifaceted challenge, leaving no one safe from the impending disaster (UN General Assembly High-level plenary meeting on Addressing the existential threats posed by sea-level rise, 2024b).

India, situated in the tropical regions of the northern hemisphere, boasts a coastline that stretches approximately 7,517 km. The peninsular coast of mainland India, which accounts for 5,423 km of this length, forms an inverted triangle that divides the northern portion of the Indian Ocean into two significant marine ecosystems (LMEs): the Arabian Sea and the Bay of Bengal. The coastlines of the archipelagic Andaman and Nicobar Islands and the Lakshadweep Islands, which extend for 2,094 km, also comprise part of coastal India, significantly contributing to its overall length and the associated maritime zones and resources. India's coastline is more than just a geographical feature; it is a treasure trove of marine biodiversity, remarkable in various aspects, and home to numerous marine species. This coastline encompasses diverse sensitive ecosystems such as mangroves, seagrass, creeks, coral reefs, salt marshes, mudflats, dunes, estuaries, lagoons, and other vegetated wetlands. More importantly, the coastline also supports large populations of people (nearly a quarter of its population, or over 40 million residents, live within fifty km of the shoreline), industry, and development projects. A significant portion of the coastal residents are ordinary fisherfolk who rely on either low-powered or traditional crafts to catch fish, along with those whose livelihoods depend on aquaculture, salt pan activities, and farming. These coastal regions play a crucial role in sustaining India's national economy as well as that of the coastal States. They are the cornerstone of local communities' subsistence economies in various ways. However, these coastal areas and their resources are under significant stress. Poorly managed resource exploitation, unsustainable coastal development that threatens access to and usage rights over beachfront and other coastal resources, land-based sources of marine pollution, and the introduction of invasive species are notable threats that have severely degraded India's coastlines. Sea level rise (SLR) and climate change will worsen these issues. India is expected to be among the most affected countries by this phenomenon, highlighting the need for its policymakers to take responsible action regarding its coastline. With appropriate policies and measures, India can mitigate these threats and ensure a sustainable future for its coastlines, resources, and the communities that depend on them.

This paper's primary objective is to explain the challenges India faces as a result of SLR, how its law and policy responses regarding adaptation are evolving, along with their positives and drawbacks, and what India needs to do to harness these elements to weave a coherent, sustainable coastal development paradigm. Given the complexity of the issues addressed in this paper, it focuses only on those posed by SLR to mainland India. Although the challenges facing the Andaman Nicobar and the Lakshadweep Islands, as well as their marine areas and responses, are similar to those of mainland India, this paper will not address them due to the marginal differences in law and policy frameworks.

Now, regarding the structure, the paper is organized into five parts. Part 2 explains the phenomenon of SLR as it unfolds in India, the projected rates, and the possible related impacts. Since India's coastline is grappling with the negative consequences of unsustainable coastal development, an overview will also provide some of the core challenges facing the country's coastline that are relevant in the context of SLR. This will help illustrate the magnitude of the problem. Part 3 offers an overview of the law and policy responses supporting adaptation measures to protect India's coastline. India employs a three-pronged adaptation strategy to address SLR. The first is based on zoning, setback lines, and regulating development in coastal zones through the Coastal Regulation Zone Notification of 2019. The second involves reinforcing the coastlines via hard and soft engineering structures. Finally, India implements nature-based adaptation measures grounded in an ecosystem approach along several stretches of its coastline to protect it from a rising sea. An overview of all these approaches, including the supportive legal and policy framework, will be discussed. Even though nature-based adaptation holds great promise, India has a general ambivalence towards it, with a preference for hard armouring. Part 4 concerns this tug-of-war between hard and nature-based adaptation approaches. It emphasizes that integrated coastal zone management (ICZM) can facilitate convergence between the various strategies and measures, allowing adaptation efforts to be streamlined to support coastal sustainability. Based on the discussions in the previous parts of this paper, certain actionable recommendations are proposed to revamp India's approach to coastal management and climate change adaptation in Part 5. Finally, the paper concludes in Part 6 by re-emphasizing the importance of ICZM in facilitating coastal climate change adaptation to SLR.

Before proceeding, it is pertinent to ask why India's experience in addressing SLR matters. Several reasons can be offered, which can be examined at two levels. The first includes socio-economic and environmental factors, while the second pertains to governance issues. The socio-economic and environmental factors that justify this study are: 1) India is the most populous country (17 percent of the world's population), with a significant percentage of this population (nearly 25 percent) residing near the coast. When discussing SLR-related displacement at the global level, one of the primary arenas where this situation will unfold is India's coastline, where millions are at risk of displacement. This not only poses serious social repercussions but could also lead to significant economic loss, as the coastal areas host infrastructure of colossal proportions. For instance, India's commercial capital, the coastal city of Mumbai (nearly 20 million inhabitants), formed by amalgamating seven islands into one landmass through land reclamation over the years, is sinking at a rate of 2 mm per year due to subsidence. This, combined with SLR, could prove particularly disastrous. Additionally, since 2000, not a single year has passed without Mumbai being struck by some extreme weather event linked to climate change, resulting in financial losses amounting to millions of dollars. Therefore, given these challenges related to population density in coastal areas and the financial and infrastructural investments therein, it is crucial to

understand India's adaptive response to SLR; 2) Despite India's contribution to global carbon emissions being only 4 percent (between 1850 and 2019), similar to several other countries in the global South, it is compelled to address a phenomenon in which it had a limited role (Answer provided by Ashwini Kumar Choubey, Minister of State in the Ministry of Environment, Forest and Climate Change, in response to the Unanswered Question raised by Dahl Singh Bisen, Lok Sabha, Unstarred Question No. 1698 to be answered on 13.02.2023). Despite economic constraints, India has opted for a green transition and is the first country in the G20 bloc to achieve the Paris climate goals. It has also developed a climate change adaptation policy and invests heavily in Integrated Coastal Zone Management; and 3) As a tropical country whose landmass is bordered by the waters of the two arms of the Northern Indian Ocean, India boasts varied and unique marine biodiversity resources – the Sundarbans, renowned for its Sundari mangrove trees, the beaches in the State of Odisha, known for the arribada of Olive Ridley Turtles, the coral reef areas along Andaman and Nicobar, Lakshadweep, the Gulf of Mannar biosphere reserve, and the Gulf of Kutch are noteworthy. India's marine biodiversity, a vital component of its natural capital, is significantly threatened by SLR and other factors, compelling India to act on adaptation and rendering this experience valuable to other similarly situated countries.

Regarding governance aspects, the reasons are: 1) India is a federal polity with a unitary character, and its coastal area is divided among nine states and four union territories (a total of 66 districts). Two union territories, the Andaman and Nicobar Islands and Lakshadweep, as mentioned above, are islands. Given these characteristics and due to historical factors, India's environmental law and policy tend to be more centralized. Consequently, while the Union Government and its ministries (the primary nodal ministries which deal with the coastal and ocean areas are the Ministry of Environment, Forest and Climate Change (MoEF&CC) and the Ministry of Earth Sciences (MoES)) have the primary responsibility to develop laws and policies on several matters relating to the environment, including adaptation to SLR, the implementation largely falls onto the states. This necessitates dialogues on the need for "cooperative federalism" in the context of coastal climate change adaptation, rendering India's experience instructive. 2) The Supreme Court of India, often regarded as the most powerful constitutional court in the world, is India's apex court, occupying the pinnacle position in its pyramidical judicial structure. Below the Supreme Court are twenty-five High Courts, the highest courts of appellate jurisdiction in each state and union territory, with the subordinate judiciary positioned below. The Supreme Court and the High Courts enjoy extensive jurisdiction, which they meaningfully and imaginatively employ to adjudicate environmental cases, significantly influencing the development of India's environmental jurisprudence. Along with the higher judiciary, the specialized body of the National Green Tribunal (NGT), established with an exclusive mandate to swiftly resolve environmental cases to help reduce the litigation burden in the higher courts, has significantly reframed India's environmental law. Therefore, the legal interpretations from the higher judiciary and the NGT, along with the laws and policies emanating from the executive, are especially pertinent for understanding India's experience in adapting to the challenges posed by SLR.

## 2 Understanding the problems of sea level rise, unsustainable coastal development and related challenges in Coastal India

The increased presence of greenhouse gases in the atmosphere contributes to global warming, which, in turn, leads to the thermal expansion of the oceans and accelerates the melting of Arctic and Antarctic ice sheets and glaciers, adding more water and raising sea levels (Nicholls and Cazenave, 2010). Higher global temperatures will trigger rising sea levels at rates that can overwhelm coastal areas, leading to significant instability and profound changes. Sea level rise will cause coastal flooding and saltwater intrusion into freshwater ecosystems and land, damage coastal infrastructure, displace communities, and devastate ecosystems. Additionally, there are other impacts. The rise in sea surface temperature alters storm patterns and intensities. Due to the surge in greenhouse gases, the oceans, as carbon sinks, absorb more $CO_2$, which lowers pH levels, disrupting the carbonate balance in the ocean and negatively affecting marine organisms with calcareous skeletons.

Regarding the rates of sea level rise (SLR), the IPCC has observed that global mean sea levels have been rising at an unprecedentedly rapid pace in recent decades. In line with these global trends, the sea level along India's coast is estimated to increase by approximately 1.7 mm annually. However, sea level changes along India's coast are not uniform and are influenced by local geographical factors (Reply from Ashwini Kumar Choubey, Minister of State in the Ministry of Environment, Forest and Climate Change, to the question posed by Sujeet Kumar in Rajya Sabha Unstarred Question No. 510, to be answered on 02.12.2021). The National Aeronautics and Space Administration's (NASA) sea level projection tool visually presents the sea level projection data detailed in the IPCC 6th Assessment Report (AR6). It refers to various climate change scenarios predicting potential SLR rates in different parts of the world, including regions in India, by 2100 based on various shared socioeconomic pathways (SSPs). Adopting SSP3-7.0, it predicts that by 2100, the sea level will rise to approximately 0.59 m for Tuticorin, 0.57 m for Chennai, 0.54 m for Vishakhapatnam, 0.59 m for Paradip, 0.20 m for Sagar, 0.75 m for Diamond Harbour, and 0.73 m for Haldia, all located on India's eastern coast. For certain cities and towns on the western coast, it notes the following: 0.71 m for Cochin, 0.63 m for Mormugao, 0.58 m for Mumbai, and 0.82 m for Bhavnagar.

Another recent study of 15 coastal cities (Tier I cities—Chennai and Mumbai; Tier II cities—Haldia, Kozhikode, Kochi, Mangaluru, Thiruvananthapuram, and Visakhapatnam) and towns (Kanniyakumari, Panaji, Paradip, Puri, Thoothukudi, Udupi, and Yanam) in India, again utilizing the SLR scenarios from the IPCC, AR6, revealed an alarming rise in sea levels along India's west and

east coasts between 1987 and 2021. Mumbai experienced the largest increase in sea levels (4.44 cm), followed by Haldia (2.726 cm), Visakhapatnam (2.381 cm), Kochi (2.213 cm), Paradip (0.717 cm), and Chennai (0.679 cm). The annual increase in sea levels was as follows: Mumbai (0.315 cm), Visakhapatnam (0.181 cm), Kochi (0.158 cm), and Paradip (0.108 cm). The report further notes that among the 15 cities, future SLR will be greatest in Mumbai. Using the SSP2-4.5 (medium-emission) scenario from the IPCC, the SLR by 2100 is projected to reach 76.2 cm for Mumbai, followed by Panaji (75.5 cm), Udupi (75.3 cm), Mangaluru (75.2 cm), Kozhikode (75.1 cm), Kochi (74.9 cm), Thiruvananthapuram (74.7 cm), and Kanniyakumari (74.7 cm)) (Center for Study of Science, Technology and Policy, 2024).

Therefore, it is evident that the seas surrounding India are rising and will continue to do so for an extended period. Regarding impacts, it is important to note that the Indian coastline is already experiencing the detrimental effects of climate change and sea-level rise (SLR). Its coastlines are increasingly being battered by extreme weather events, with the sudden surge linked to climate change. India's east coast ranks among the most cyclone-prone areas in the world. Between 1891 and 1990, nearly 262 cyclones occurred within a 50 km-wide strip along the east coast, 92 of which were severe. A significant increase in cyclonic storms has already affected India's coastline. Between 1891 and 2006, Tamil Nadu experienced approximately 32 cyclonic storms, 30 of which were severe. By 2011, the total number of cyclonic storms impacting the Tamil Nadu coast had risen to 44, representing a sharp increase of 37.5 percent from 2006 to 2011. Additionally, rising cyclone intensities lead to higher wind speeds and storm surges, which devastate agriculture in the coastal districts. One of the more recent cyclonic storms to have hit the Tamil Nadu, Kerala, and Lakshadweep coastlines is 'Ockhi', which wreaked unprecedented havoc. It resulted in more than 250 deaths apart from the colossal material and environmental losses (The Cyclone Ockhi - Its Impact on Fishermen and damage caused by it, 2018). This disaster laid bare the chinks in India's ability to put in place a credible system of advanced cyclone warnings and comprehensive disaster mitigation preparedness.

Another aspect of the issue is that coastal zones in India face numerous threats from non-climate drivers, which lead to extensive degradation in many areas. When combined with climate-induced stressors, these pose a serious challenge. For example, erosion has long been a concern in India's coastal regions, resulting in significant land loss. Approximately 33% of the country's coastline is experiencing varying erosion levels. Since 1990, the National Centre for Coastal Research (NCCR) in Chennai, under the Ministry of Earth Sciences (MoES), has monitored shoreline erosion using remote sensing data and GIS mapping techniques. An analysis of mainland India's 6,632 km coastline between 1990 and 2018 revealed that around 33% of the area is experiencing varying degrees of erosion. Several factors contribute to this, including wave action, the interception of littoral drift, changes at river mouths, and sand mining. From 1990 to 2016, India experienced the most severe coastal erosion in West Bengal (63%), Pondicherry (57%), Kerala (45%), and Tamil Nadu (41%). Tide gauge observations at the Diamond Harbour port in West Bengal indicate a sea level rise of 5.7 mm, a high rate attributed to the region's subsidence of 4 mm per year (Government of West Bengal, 2012).

Sea level rise (SLR) will inundate extensive sections of India's coastline. The districts of Ganjam, Puri, Jagatsinghpur, Kendrapara, Bhadrak, and Balasore in Odisha face the threat of flooding and inundation, potentially impacting millions. Key coastal ecosystems such as Bhitarkanika National Park, Balukhand-Konark Wildlife Sanctuary, Chandrabhaga Beach, and the areas surrounding Chilika Lake are at risk of permanent inundation (Forest, Environment & Climate Change Department Government of Odisha - Forest, n.d., p. 100). With a rise in sea level of 0.1 to 0.5 metres, wetland losses ranging from 2,508.3 km² to 12,541.5 km² could occur in Gujarat (Government of Gujarat, Climate Change Department, State Action Plan on Climate Change, p.44.). If SLR persists over the next century, 461 km² of coastal wetlands in Karnataka will also be submerged (Environmental Management & Policy Research Institute and The Energy and Resources Institute, 2012, p. 94). The Wild Ass Sanctuary and the Kutch Desert Sanctuary, located in the Great Rann of Kutch, which hosts seasonal salt lakes supporting flamingos and providing the last remaining habitat for Indian wild asses, will similarly be adversely affected by SLR.

Temperature increases will threaten mangroves, potentially leading to reduced tree height, smaller leaf size, decreased productivity, and alterations in species composition and phenological patterns. Rising sea surface temperatures cause bleaching events that impact corals. The bleaching events of 2010 and 2016 in the Gulf of Mannar have significantly diminished coral cover (MoEFCC, 2023, p. 343).

Climate change will impact precipitation patterns, leading to cascading effects. The 2018 southwest monsoon season saw unprecedented downpours along the west coast, resulting in intense flooding and significant losses. In May of that year, extensive areas of coastal Karnataka, particularly Mangaluru city, faced flooding. Then, in July, Mumbai in Maharashtra experienced severe flooding that brought this megacity to a halt. Ultimately, the season ended with the entire state of Kerala grappling with a deluge in August, which caused nearly 500 fatalities. The Kochi airport, the largest airport in Kerala, closed for over two weeks for the first time due to rain and flooding. Moreover, changing precipitation patterns will negatively affect rain-fed rice farming in coastal Karnataka. Coastal alluvial aquifers are highly permeable and are hydraulically connected to sea or estuarine water. The rapid pace of urbanization, indiscriminate groundwater extraction from coastal aquifers, sand mining from riverbeds, and the diversion and impoundment of river water in upstream areas exacerbate the situation. Saline water is encroaching into coastal regions, threatening freshwater supplies for domestic and irrigation purposes. The situation is already critical, and with the rise in sea levels, it will further deteriorate. Notably, due to SLR, freshwater resources in thirteen coastal districts of Tamil Nadu will face seawater intrusion. In the Rajkot district of Gujarat, there has been a significant increase in the number of farmers seeking loans, and some have been forced to change their cropping preferences. Coconut plantations in several villages have been devastated. Given the lack of surface water

sources in coastal Andhra Pradesh and the intensive nature of aquaculture operations, the region heavily relies on groundwater. Seawater intrusion due to SLR has exacerbated the crises and has heightened soil salinity, reducing its productivity (Environment Protection Training and Research Institute, 2012, p. 75).

Like in other regions, the fisheries sector plays a vital role in supporting both national and provincial economies and provides livelihoods for many, especially those who are economically disadvantaged. The effects of climate change and sea-level rise (SLR) on the fisheries sector across India are diverse. Rising water temperatures, changes in precipitation, wind speed, wave action, and SLR can lead to significant ecological and biological transformations in marine fisheries. For example, between 1960 and 2009, the sea surface temperature (SST) in the coastal waters of Kerala, one of the most productive fishing areas in the country, increased by 0.6°C, from 28.0°C to 28.6°C (Department of Environment and Climate Change, 2014, p. 67). This change has resulted in alterations to the life history traits of various fish species, particularly within pelagic fisheries. The increase in temperature has led to faster growth rates, earlier maturation, and reduced fish longevity. Sardines and mackerels, two vital species in the coastal waters of Kerala, are quickly disappearing from these waters (Hussain et al., 2021; Dash et al., 2024). Several other significant fish species and high-value shrimp have also become increasingly scarce in catches, while pufferfish have surged and now pose considerable damage to fishing nets. Consequently, these issues present serious livelihood concerns for the fishing community, who already face declining fishing days due to rough seas and restrictions on venturing out to sea (Department of Environment and Climate Change, 2014, pp. 67–8). Nonetheless, some scientific studies suggest that climate change could benefit fisheries. Reduced snow cover over Eurasia is believed to strengthen the south-westerly monsoon winds. This increased wind strength may disturb deep water, leading to a rise in nutrients in the surface waters, which in turn supports greater phytoplankton production and may enhance fish populations. Between 1997 and 2004, there was a 300 percent increase in phytoplankton production (Tamil Nadu State Action Plan for Climate Change, 2014, p. 60).

Perhaps the most profound impact of climate change and sea level rise (SLR) will be on people. An overwhelming majority of India's population lives in rural areas and relies on natural resources, which are highly sensitive to climate change, for their livelihoods. Over the past two decades, extreme weather events, including cyclones and rising sea levels, have inflicted significant devastation in coastal regions, leading to a surge of migration to urban cities and towns. It is predicted that by 2050, nearly 45 million Indians will be at risk from SLR, and many of them will become climate refugees, even though this will primarily involve internal displacement (Singh et al., 2020).

Despite considerable scientific consensus regarding climate change and its impacts, numerous uncertainties remain. Nonetheless, it is clear that climate change, SLR, and their consequences are predominantly negative and are a reality that is gradually and undeniably unfolding before us. Based on this overview, the following section examines India's legal and policy approaches to addressing the challenges posed by SLR.

## 3 India's legal and policy approach to sea level rise

Adapting to climate change involves implementing measures to mitigate its negative impacts or harness its positive aspects by making the necessary adjustments to current development paths. These measures range from technological solutions, such as sea defences or flood-proof houses on stilts, to individual behavioural changes, like reducing water use during droughts. Additional strategies include developing early warning systems for extreme events, efficient water management, enhanced disaster and risk management, insurance options, and biodiversity conservation.

In the context of SLR, as early as 1991, the Intergovernmental Panel on Climate Change (IPCC) identified three primary adaptation strategies concerning the coastal zone: retreat, accommodate, and protect. A planned retreat is a proactive adaptation to prevent and remove further influxes of people and investment from areas vulnerable to severe erosion, flooding, and weather events. Accommodation involves advanced planning and recognizing that some coastal zone values will inevitably be lost. The last of the three adaptation measures is protection, which seeks to insulate coastal residents from harmful impacts by constructing various forms of defensive coastal armouring (IPCC and WMO, 1992, p. 135). No measure is superior to the others; the choice depends primarily on real-world conditions. India's adaptation strategy to SLR employs a three-pronged approach: first, adaptation through zoning, the creation of setback lines, and regulating development in coastal zones using the instrumentality of coastal law; second, a civil engineering approach involving the construction of hard structures, primarily seawalls, to counteract a rising sea; and third, nature-based adaptation measures, focusing primarily on the conservation of mangroves, seagrass beds, and coral reefs. These strategies are examined below to understand India's approach to adapting to SLR. However, reviewing the general legal and policy framework relevant to climate change adaptation before delving into these is pertinent.

Despite the growing severity of the devastation caused by climate change in India each year, the country still lacks comprehensive legislation to address these challenges. Nevertheless, the Government of India strongly emphasizes adaptation and has launched several initiatives to integrate it into policy. In its Nationally Determined Contribution under the Paris Agreement, improved coastal management prominently serves as an adaptation focus area. Identified adaptation measures include defining the coastal regulation zone, implementing Integrated Coastal Zone Management (ICZM), marking coastal hazard lines, and issuing the Island Protection Zone Notification of 2011. Furthermore, India has committed to creating a carbon sink of 2.5 to 3 billion tonnes of $CO_2$ equivalent through enhanced forest and tree cover by 2030. Given their significant potential for carbon sequestration, mangroves are crucial in achieving this ambitious target. At the national level, India has established the National Action Plan on Climate Change (NAPCC, 2008), which encompasses eight National Missions that address various sectoral aspects of climate change. The NAPCC promotes awareness of climate change, adaptation, mitigation, energy efficiency, and

natural resource conservation while fostering overall economic growth. Its focus is on measures that advance development objectives and address climate change. Concurrently, the recognition that climate change impacts vary across states, sectors, and locations—and that unique approaches are necessary to respond to specific sub-national contexts—has resulted in all states in India developing State Action Plans for Climate Change (SAPCCs) in alignment with the broad parameters set by the NAPCC.

In terms of conserving and protecting its unique coastlines, resources, and marine environment while promoting sustainable development, India emphasizes adaptation on two levels: 1) enhancing the ability of coastal communities to cope with the impacts of climate change, and 2) safeguarding fragile and vulnerable coastal ecosystems while fostering ecosystem resilience (MoEFCC, 2023, p. 572). Regarding sea level rise (SLR), India's primary policy response to adapt to the associated challenges originates from the National Coastal Mission of 2017, which is founded on the NAPACC. With the ambitious goal of "transform [ing] India's coastal [and] marine sector into the world's best-managed productive ecosystem in a phased manner," it aims to address the impacts of climate change on coastal and marine ecosystems, infrastructure, and communities by integrating adaptation and mitigation measures. It also strives to introduce marine spatial planning, protect nearly 1,500 km of medium and highly eroding coastlines, enhance sewage and industrial effluent treatment capacity, strengthen natural barriers, improve job generation opportunities for coastal communities, reduce pressures on coastal and marine ecosystems, and boost their productivity (Reply of Ashwini Kumar Choubey, Minister of State in the Ministry of Environment, Forest and Climate Change, to the question posed by Sujeet Kumar Rajya Sabha Unstarred Question No. 510, to be answered on 02.12.2021). The National Coastal Mission comprises several sub-missions, including Shoreline Protection and Management, Coastal and Marine Spatial Planning, Conservation and Sustainable Use of Ecologically Sensitive Marine and Coastal Ecosystems and their Services, Marine Coastal Pollution Abatement, Sustainable Island Development, Coastal Beach Clean-up and Development, and Climate-Smart Coastal Villages and Cities. Each sub-mission is overseen by a designated lead ministry of the Government of India, which collaborates with other relevant ministries and departments, state governments, union territory administrations, and additional agencies (MoEF&CC, 2017, p. 6).

As previously noted, a legislative gap exists concerning how India should address climate change, particularly in relation to adaptation to sea level rise (SLR). In this context, India's Supreme Court, for the first time, in *MK Ranjitsinh v. Union of India* (MANU/SC/0274/2024), a case arising from the deaths of the Great Indian Bustard caused by collisions with overhead transmission wires installed at solar panel projects, explicitly acknowledged that adverse environmental consequences, such as rising sea levels, disproportionately affect socially, geographically, and economically marginalized citizens. Consequently, it articulated a right to be free from the adverse effects of climate change as a distinct fundamental human right recognized by Articles 14 (right to equality) and 21 (right to life) of the Constitution, asserting that this right and the right to a clean environment are two sides of the same coin. This powerful assertion by the Supreme Court that citizens have a fundamental right to be free from the adverse consequences of climate change implies an obligation on the part of the other branches of the state to take action to respond to the detrimental impacts of climate change, which includes developing and implementing measures to adapt to SLR. If a failure leads to citizens suffering adverse consequences, they have access to judicial remedies, which can compel the state to act. Furthermore, the Court established an expert committee to evaluate the scope, feasibility, and extent of installing overhead and underground power lines in a priority area designated for conserving this species.

Another impactful intervention in the development of law and policy came from the NGT in "In re: News item published in the Newspaper The Hindu dated 19.03.2023 titled "India's Sinking Island" (National Green Tribunal, Original Application No. 249/2023), which directed its attention toward SLR, sinking islands, and climate change adaptation. The report indicated that several maritime islands along India's coast and riverine islands were vulnerable to erosion and submergence, with SLR and global warming being the primary causes. It stated that many of the country's 1,382 islands were threatened by unseasonal cyclonic storms, sea erosion, and new development projects. One island had already disappeared from the map. Additionally, due to SLR, saline water had intruded into these islands' available drinking water sources. In response to this news item, the NGT took suo motu cognizance of the issue and issued notices to the Ministry of Earth Sciences and the MoEF&CC, requiring them to submit responses (National Green Tribunal, Original Application No. 249/2023). Given the dangers of rising sea levels and the risk of low-lying lands, including inhabited islands, being submerged, it was deemed crucial to provide protection. Accordingly, the NGT directed the establishment of a committee to study the impact of SLR and formulate policies and measures to safeguard the islands from submergence, erosion, saline intrusion, flooding, and other adverse environmental effects.

## 3.1 Discussion

India's biggest challenge is to sustain its rapid economic growth and eradicate poverty while addressing the global threat of climate change. In doing so, India must re-emphasize its commitment to its civilizational legacy of prioritizing the environment and maintaining ecological balance. These tasks are more manageable said than done. As previously mentioned, India lacks legislation on climate change, particularly regarding responses to the challenges posed by sea-level rise (SLR). The closest existing regulation to address this is the CRZ, 2019, which, as will be explored in the next section, is based on *ad-hoc*ism rather than fostering a coherent strategy to tackle the diverse challenges that SLR presents. What remains is a hodgepodge of policies and laws that fail to overcome

the fragmented nature of the underlying regime needed to create a sustainable framework for the rapidly deteriorating coastal zones. Against this backdrop, one must recognize the judicially acknowledged right to be free from the adverse effects of climate change, including SLR, as well as the efforts by the National Green Tribunal (NGT) to develop policies or motivate their creation for SLR and the associated issues of sinking islands. Nonetheless, since the judiciary and the NGT lack the necessary tools and resources to implement and secure these rights or policies, enforcement is left to the unpredictable nature of the executive branch, whose indifference necessitated these interventions in the first place. Ultimately, India requires robust legal and policy frameworks to proactively plan for and respond to the challenges posed by SLR.

## 3.2 Adapting to sea-level rise through coastal law

In several stretches along India's coastline, instead of the once pristine beaches, sandbanks, dunes, lush coastal forests, and mangrove swamps, one can see haphazardly placed houses, slums, high rises, resorts, and ports—an eyesore often at the very edge. As the seas rise, these areas risk submergence, a scenario that could have been avoided had scientific coastal planning been implemented, which would have ensured sustainable coastal development. Since the 1990s, India has attempted to proactively manage its coastlines and establish normative guidelines in its coastal law to facilitate development. The legal framework of coastal law provides tools such as setback lines, hazard lines, zoning, and Integrated Coastal Zone Management (ICZM). Additionally, it prescribes measures to protect and conserve the coastal environment, positioning India's coastal law as one of the primary mechanisms to address the challenges posed by sea level rise (SLR). Despite the benevolence of the coastal law, which, if implemented fully, would have significantly mitigated degradation and secured sustainable coastal development, India's coast is far from an ideal scenario, revealing the coastal law's shortcomings (Puthucherril, 2011).

India adopted its first coastal law, the Coastal Regulation Zone Notification of 1991 (CRZ, 1991). The primary focus of this coastal law was to protect the coastal and marine environment, and it established a regulatory scheme to achieve this goal. However, scarcely had the ink dried on its text before it became evident that this coastal law was at odds with greedy corporate interests, which aimed to construct more ports, expand private control over coastal land, and open additional resorts, often at the expense of coastal ecology and local communities' access to beaches and fishing grounds. Since then, the CRZ 1991 has been amended over 25 times to weaken its regulatory strength, allowing violators to slip through the regulatory nets with ease. These amendments rendered the coastal law a complete hodgepodge, resulting in its replacement in 2011 by a new legal framework that emphasized regulation and management. Known as the Coastal Regulation Zone Notification of 2011 (CRZ 2011), it failed to produce any recovery, and the downward spiral persisted, ultimately culminating in the Coastal Regulation Zone Notification of 2019 (CRZ 2019) (Puthucherril, 2024).

The starting point of the CRZ 2019 is the definition of the "coastal regulation zone" (CRZ), which refers to the territorial area that determines its applicability. The CRZ comprises two components: the water area and the coastal stretches. The water area extends from the low tide line (LTL) to the territorial water limit of 12 nautical miles, including the bed area. For tidally influenced water bodies connected to the sea [CRZ 2019, Explanation to (ii)], the CRZ encompasses the land area between the high tide line (HTL) and up to fifty metres or the creek's width, whichever is less, on the landward side along the tidal-influenced water body. The extent to which development along such tidal-influenced water bodies must be regulated is based on a salinity concentration of five parts per thousand measured during the driest period of the year [CRZ 2019, Explanation to (ii)]. Additionally, it incorporates the water and the bed area between the LTLs of the banks of the tidally influenced water body. Regarding the land area, specifically, the CRZ includes the area between the high tide line (HTL) and up to 500 metres on the landward side along the seafront [CRZ 2019, Explanation to (i)], as well as the 'intertidal zone' [the land area between the HTL and the low tide line (LTL)]. The Notification also contemplates a 20-meter CRZ from the HTL on the landward side for inland backwater islands and islands along the mainland coast. Based on this comprehensive definition, the CRZ Notification 2019 classifies the CRZ into five separate categories (CRZ-I, CRZ-II, CRZ-III, CRZ-IV, and Areas that Require Special Consideration) to conserve and protect the coastal areas and marine waters.

Before delving into the details, it is essential to note that the CRZ Notification 2019 imposes a general prohibitory scheme on eleven activities throughout the entire CRZ, and these general prohibitions are subject to varying degrees of exceptions based on the CRZ category. The eleven prohibited activities across the entire CRZ include the establishment of new industries and the expansion of existing ones, locating port and harbour projects in highly eroding stretches of the coast, the manufacture or handling of oil, the storage or disposal of hazardous substances, land reclamation, bunding or disturbing the natural course of seawater, the discharge of untreated waste and effluents, the dumping of wastes (including industrial solid wastes, construction debris, and fly ash for landfilling). Furthermore, the dressing or altering of active dunes, disposal of plastic into coastal waters, withdrawal of groundwater, and mining of sand, rocks, and other substrata materials are also prohibited. (CRZ 2019, para. 4).

The first zone identified by the CRZ Notification 2019 is CRZ-I, encompassing the most environmentally critical areas. CRZ-I is further subclassified into CRZ-IA and CRZ-IB. CRZ-IA consists of ecologically sensitive areas (ESAs) whose geomorphological features are vital for maintaining coastal integrity. They serve as natural barriers against coastal hazards and help uphold the biological health of the coast by offering direct and indirect ecosystem services that support coastal livelihoods. Consequently, their conservation and protection are crucial. The CRZ Notification 2019 identifies the following sensitive coastal and marine ecosystems as ESAs:

mangroves, coral reefs, sand dunes, biologically active mudflats, protected areas (including biosphere reserves), salt marshes, turtle nesting grounds, habitats of horseshoe crabs, seagrass beds, bird nesting grounds, sites of archaeological significance, and heritage sites. In CRZ-IA areas, most activities are generally prohibited. However, exceptions may apply, such as eco-tourism initiatives supported by an eco-tourism plan and roads constructed on stilts, provided they undergo a detailed environmental impact assessment. The CRZ Notification 2019 outlines general and specific conservation, protection, and management measures. The general measures require satellite data to identify ESAs and delineate their boundaries in the Coastal Zone Management Plan (CZMP). Special measures are recommended for different ESAs, considering their unique conservation needs. (CRZ 2019, Annexure- I).

The CRZ-IB is the intertidal zone between the LTL and HTL. In this intertidal zone, certain activities are permitted, such as land reclamation, bunding for foreshore facilities, and defence and security-related projects. This also includes coastal erosion control, salinity ingress prevention measures, activities requiring waterfront access, facilities for non-conventional energy sources, and those related to oil and natural gas exploration and extraction. Additionally, facilities for receiving and storing petroleum products and liquefied natural gas, modernization of fish processing units, waste and effluent treatment facilities, desalination plants, and salt harvesting facilities are allowed. (CRZ 2019, para. 5.1.2).

The CRZ-II primarily consists of urban coastal areas. It encompasses areas developed up to or near the shoreline, within existing municipal limits or within other legally designated urban areas that are substantially built up, where the ratio of built-up plots to total plots exceeds 50 percent and has been provided with drainage, access roads, and other infrastructural facilities (CRZ 2019, para. 2.2). Generally, the activities permitted in the CRZ-IB are also allowed in the CRZ-II. Furthermore, the construction of buildings for residential purposes, schools, hospitals, institutions, etc., is permitted in this zone, provided it is on the landward side of an existing road or an authorized fixed structure [CRZ 2019, para. 5.2 (ii)]. Vacant plots in designated areas can be utilized for developing tourism-related projects, subject to the 'Guidelines for Development of Beach Resorts, Hotels, and Tourism Development Projects in the Designated CRZ Areas' (CRZ 2019, para. 5.2 (v) and Annexure-III "Guidelines for Development of Beach Resorts, Hotels and Tourism Development Projects in the Designated CRZ Areas"). Noteworthy among these prescriptions are those requiring appropriate arrangements for treating effluents and solid waste, as well as the prohibition on flattening sand dunes (CRZ 2019, para. 5.2 (v) and Annexure-III "Guidelines for Development of Beach Resorts, Hotel and Tourism Development Projects in the Designated CRZ Areas" (vii) & (iii)). Another crucial requirement is that while private property owners can fence their properties, such fencing must not obstruct public access to the beach (CRZ 2019, para. 5.2 (v) and Annexure-III "Guidelines for Development of Beach Resorts, Hotel and Tourism Development Projects in the Designated CRZ Areas" (ii)).

Relatively undisturbed and predominantly rural areas fall under the CRZ-III classification. Based on population density, CRZ-III is further sub-classified into CRZ-III A (for areas with a population density exceeding 2,161 people per sq km) and CRZ-III B (for areas with a population density below 2,161 people per sq km) (CRZ 2019, para. 2.3.1 and 2.3.2). There is a no-development zone in CRZ-IIIA, which extends up to fifty metres from the HTL on the landward side, and in CRZ-IIIB, this extends up to 200 metres from the HTL on the landward side (CRZ 2019, para. 2.3.1 and 2.3.2). Generally, activities permitted in CRZ-IB are also allowed in CRZ-III. In areas beyond the NDZ, vacant plots can be developed for tourism projects. At the same time, wastelands and non-arable lands can be used for airport development, and fishermen and other local communities can set up 'homestays.' While limestone and atomic mineral mining are permitted, groundwater withdrawal is prohibited except if used by local communities [CRZ 2019, para. 5.3 CRZ-III (iii)].

The water area of the CRZ is classified as CRZ-IV and is further divided into CRZ-IVA and CRZ-IVB. CRZ-IVA refers to the water and seabed area from the Low Tide Line (LTL) up to the boundary of the territorial sea (CRZ 2019, para. 2.4.1). CRZ-IVB pertains to the water and the underlying seabed area between the LTL of the banks of tidally influenced water bodies and the LTL on the opposite side of those banks. Both these sub-classifications fall under a common regulatory framework that permits activities such as traditional fishing, power generation using non-conventional energy sources, erosion control measures, weather radar and ocean observation platforms, facilities for discharging treated effluents into the water, the exploration and extraction of oil and natural gas, the construction of memorials, and projects by the Department of Atomic Energy (CRZ 2019, para. 5.4).

Regarding the areas that require special consideration in the CRZ, the Notification identifies specific ecosystems within the existing CRZ and subjects them to a special regime for enhanced protection. In this context, there are three essential sub-classifications: Critically Vulnerable Coastal Areas (CVCAs), backwater islands and mainland islands, and CRZ areas within the municipal limits of Greater Mumbai. For the twelve ecosystems designated as CVCAs (including the Gulf of Mannar, Gulf of Kutch, Bhitarkanika, etc.), integrated management plans must be prepared for their conservation, and their management must involve participation from the coastal community (CRZ 2019, para. 10.1). Considering the space limitations in the coastal stretches of backwater islands, including those on the mainland coast, a uniform CRZ of twenty metres from the HTL on the landward side is enforced [CRZ 2019, para. 10.2 (ii)]. Management of the backwater and mainland islands is required to follow Integrated Island Management Plans to be developed (CRZ 2019, para. 10.2). For the CRZ-II areas within the municipal limits of Greater Mumbai, all open spaces are designated as 'No Development Zones' to protect and preserve the green lung (CRZ 2019, para. 10.3). Although these open spaces cannot be used for residential or commercial purposes, a floor space index of up to 15 percent is permitted for the construction of civic amenities or sports and recreational activities (CRZ 2019, para. 10.3). The central government must approve the construction of sewage treatment plants in the CRZ-I areas within the municipal limits of Greater Mumbai [CRZ 2019, para. 10.3(ii)].

To facilitate the administration of this complex zoning scheme, all developmental activities are regulated and must conform to the Coastal Zone Management Plan (CZMP). The CZMP must demarcate the HTL and LTL, the hazard lines, and the CRZ areas (CRZ 2019, Annexure-IV "Guidelines for Preparation of Coastal Zone Management Plans"). The hazard line is among the most important tools in the CRZ 2019 for facilitating adaptation to SLR. This line is established by considering the extent of flooding in the land area due to water level fluctuations, sea level rise, and shoreline changes (erosion or accretion) occurring over time. It is used for developing disaster management plans for the coastal environment, including planning adaptive and mitigation measures [CRZ 2019, Annexure – IV (2)].

The image below, Figure 1, titled "CRZ, 2019: Salient Features," encapsulates the salience of the regulatory framework of the CRZ 2019. For development activities or projects in the CRZ-I and CRZ-IV areas, the MoEFCC grants the CRZ clearance based on the recommendation of the concerned Coastal Zone Management Authority (CZMA) [CRZ 2019, para. 7(ii)]. The CRZ clearance for CRZ-II and CRZ-III areas is issued by the concerned CZMA [CRZ 2019, para. 7(iii)]. Projects or activities falling under the CRZ Notification 2019 and the EIA Notification require a composite Environmental and CRZ clearance [CRZ 2019, para. 7(iv)]. Notably, there is also a provision for post-clearance monitoring [CRZ 2019, para. 8(vi) (a)]. The image below - "Figure 1, CRZ, 2019: Salient Features," encapsulates the salience of the regulatory framework of the CRZ, 2019.

### 3.2.1 Discussion

The CRZ 2019, which is based on but supersedes the earlier iterations of the coastal law from 1991 and 2011, aims to conserve and protect the unique environments of coastal stretches and marine areas, ensure livelihood security for fishing and other local communities, and promote sustainable development founded on scientific principles, considering natural hazards and sea-level rise (SLR). It achieves this objective by classifying the coastal zone into different categories and subjecting developmental activities in these zones to varying degrees of management and regulation. In other words, this coastal law's primary regulatory and management tool is zoning. An assessment of its implementation reveals that, unfortunately, zoning in coastal India has not progressed well, with numerous violations of its zoning mandate. Many illegal constructions have been erected haphazardly, showing utter disregard for the law throughout coastal India, diminishing green coastal spaces and their inherent values (Report of the Comptroller and Auditor General of India on Conservation of Coastal Ecosystems, 2022). Often, concerned officials are bribed to obtain necessary permits. The weaknesses in institutional mechanisms, corruption, and vested interests in granting project clearances rather than engaging with these matters are also detrimental. When proceedings are initiated against violators, especially for large projects, they often evade consequences by claiming economic usefulness or highlighting the need to avoid greater inconveniences that a decision against their interests would inflict on people, particularly the project's beneficiaries. To stop such egregious violations and uphold the environmental rule of law, the Supreme Court has intervened harshly against violators in a few cases (*Piedade Filomena Gonsalves v. State of Goa*, AIR 2004 SC 3112). One prominent case involves the construction of four high-rises at Maradu [initially a Panchayat (rural) but now a municipality (urban)] in the coastal city of Kochi (Kerala), located in an area designated as CRZ-III, where no construction was permitted within 200 metres from the coast. The buildings were constructed within this no-construction zone, overlooking the picturesque Vembanad Lake. Although the legal struggle to absolve the violation of coastal regulation norms reached the Supreme Court, the decision was made to order the demolition of the apartment complexes. (*The Kerala State Coastal Zone Management Authority v. The State of Kerala Maradu Municipality*, MANU/SC/0808/2019). However, it remains doubtful whether the underlying message behind the Supreme Court's demolition order has achieved its intended effect, as infrastructure continues to accumulate at the coastal edge in blatant violation of the law, disregarding the reality that these constructions will soon have to contend with rising seas. This will necessitate fortifying these coasts to protect such infractions with more hard engineering structures to keep the sea at bay, ultimately at the taxpayers' expense, resulting in more severe environmental and livelihood issues. In other words, the ineffective implementation of the coastal law is a classic case of maladaptation (Barnett and O'Neill, 2010).

## 3.3 Adapting to sea-level rise through civil engineering

Waterfront cities and towns face increasing threats from rising waters, which can result in inundation, flooding, coastal erosion, and displacement. By 2100, more than a billion people will be at risk of sea level rise (SLR) hazards, and several small island developing states (SIDS) and other islands may be wiped off the map. Civil engineering can help mitigate some of these risks in hard and soft forms. The primary goal of hard structure armouring of coastlines is to dissipate the energy of waves and currents, thus protecting the shores. These structures come in various forms, including seawalls, breakwaters, groynes, and flood embankments. Below is a discussion of some of these hard structures and how India employs them to protect its eroding coastlines. Before delving into the specifics, it should be noted that due to India's federal structure, under the Constitution, while States lack territorial sea and do not possess residual legislative powers, they do have legislative authority over subjects like water and land. This empowers the States to take the lead in implementing hard armouring of coastlines. Nevertheless, under the Union Ministry of Jal Shakti, the Central Water Commission published guidelines titled "Protection and Control of Coastal Erosion in India" in 2020, which provide preliminary design parameters for coastal protection efforts across various stretches of coastline (CSIR-National Institute of Oceanography, 2020).

Seawalls are hard-engineered structures built parallel to the coast to prevent shoreline erosion. They protect the coast from wave

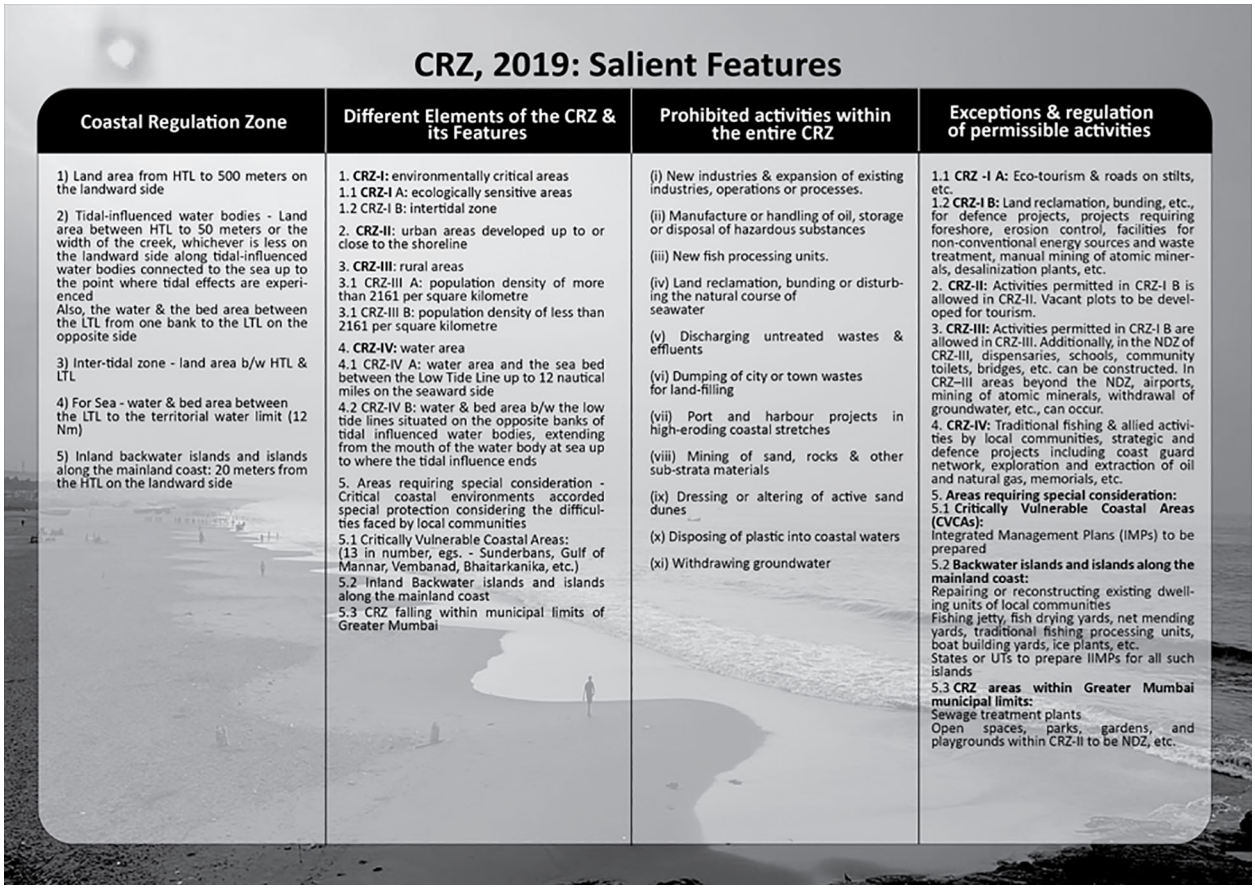


FIGURE 1
CRZ, 2019: salient features.

action by absorbing and deflecting wave energy back into the sea, thereby preventing soil from sliding. Constructed as gravity or pile-supported structures using concrete or stone, they enable coastal properties to withstand wave forces. These seawalls typically feature various face shapes. Curved-faced walls are designed to manage the impact and run-up of large waves, diverting the flow away from the protected area. They require robust structures with solid foundations and toe protection to resist and redirect the force of massive waves. Conversely, stepped-face seawalls have reduced mass and minimize wave run-up and overlap. Combination seawalls combine the benefits of both curved and stepped-face designs. Additionally, there are rubble mound-sloping seawalls (RMS), positioned along the shoreline to absorb and dissipate wave energy with minimal reflection and scouring due to their rough surfaces. Because RMS seawalls are flexible structures, they necessitate regular maintenance. Concrete armour units are used instead in areas with high wave conditions where rocks are not economically viable. While the types of seawalls mentioned above are employed to fortify various parts of India's coastlines, the RMS is the most widely used shore protection structure. For example, the seawalls in Kerala and Tamil Nadu are of the RMS type (CSIR-National Institute of Oceanography, 2020, p. 16).

Revetments are sloping hard structures designed to protect embankments or other shoreline features from erosion. They consist of three main components: the armour layer, which provides essential protection against wave action; the filter layer, which supports the armour by allowing water to flow through the structure, thereby preventing the underlying soil from being washed away; and the toe protection, which stops the displacement of the seaward edge of the revetment. Although they are highly effective at protecting the coastline in the short term, they can be intrusive and may cause problems elsewhere (Newground, 2021b).

Bulkheads are retaining walls designed to hold backfill in place, prevent sliding, and provide light to moderate protection against wave action. They are essential for protecting eroding bluffs by retaining soil at the base, thus enhancing stability and shielding the foundation from erosion and undermining. Bulkheads are used in reclamation projects where additional fill is required towards the sea. They are also employed in marinas and other waterfront structures where deep water is necessary at the shore (CSIR-National Institute of Oceanography, 2020, p. 16).

Groynes are relatively easy to install and less expensive than offshore structures. They are categorized based on their shape and length. Typically, groynes are straight and positioned at a 90-degree angle to the coastline to collect and retain sand in the littoral zone. However, they can also be curved, angled, or have a T-shaped design at the leading edge. In terms of length, groynes are classified as long (if they span the entire surf zone) or short (if they only

extend partway across the surf zone). It is important to note that if the function of groynes is not compatible with their location, they can pose environmental hazards (CSIR-National Institute of Oceanography, 2020, p. 20).

Another significant engineering structure is an offshore breakwater constructed parallel to the shore to mitigate incoming wave energy and the long-shore transport of sand along the beach. Offshore breakwaters are primarily used for shore protection along eroding coastlines, where sediment loss occurs, and a new recreational beach is needed. There are several types of offshore breakwaters, including single-detached breakwaters, multiple-detached breakwaters, and artificial headlands. These structures are not very popular in India because if they are too short, beach erosion may occur, and if they are too long, a tombolo can form, leading to down-drift erosion. Additionally, they are costly to construct, lack aesthetic appeal, and may result in over-toppings (Newground, 2021a).

Hard engineering structures can result in negative environmental and socio-economic consequences. This is exemplified through case studies from the east coast of India, particularly highlighting the adverse effects of sea walls and groynes built in Pondicherry and Tamil Nadu. India's east coast experiences considerable littoral drift (the natural movement of sand), with approximately 6 million cubic meters of sand drifting northward along the coast. The armouring of the coastline with seawalls and groynes in Pondicherry and Tamil Nadu has disrupted the sediment budget, dramatically altering the intertidal marine zone's morphology and morphodynamics. The sea has claimed nearly 300 acres of land, including houses and other structures. As the sandy beaches vanished, so did their aesthetic value, adversely affecting the tourism industry (Balamohan, National Green Tribunal, Original Application No. 63/2017 (SZ), para. 61). This situation also indicated a decline in traditional fishing. Thousands of traditional fishermen could no longer sustain their livelihoods, as they depended on these beachfronts to launch their boats. They were compelled to park and launch their boats from locations outside their villages (Rodriguez et al., 2008).

Second, the *ad hoc* and unscientific construction of seawalls and groynes has led to the destruction of intertidal habitats, impacting marine flora and fauna such as plankton, crustaceans, bivalves, molluscs, and other invertebrates that are integral to the aquatic food chain, which supports fish stocks. It has also endangered the Olive Ridley Sea turtles, a species that returns to their natal beaches to lay eggs. Sea turtles cannot continue their innate life cycles when hard structures are built along nesting beaches. These structures directly threaten and endanger sea turtles by reducing suitable nesting habitats, compelling the turtles into less-than-optimal nesting areas. (Balamohan, National Green Tribunal, Original Application No. 63/2017 (SZ), para. 62-3).

Given its proximity to the Bay of Bengal and the lack of reliable surface water sources, groundwater development in Puducherry is extensive. In the context of water crises, the erosion of the sandy buffer facilitates saltwater intrusion into the aquifers. Both the northern and southern coasts of Puducherry are highly vulnerable to seawater intrusion. Several shallow wells along the coast that local communities relied on for freshwater have become saline. This has led to further cascading effects. For instance, the increased salinity in Puducherry's freshwater has resulted in hundreds of hectares of farmland becoming fallow. In addition to compromising the water's sweetness, the rising salinity has also contributed to increased kidney-related diseases. (Balamohan, National Green Tribunal, Original Application No. 63/2017 (SZ), para. 65).

The erosion also significantly impacted the maritime baselines established in that area, effectively altering the international maritime boundary and the regions of the various maritime zones, raising critical national concerns. The sea walls also caused unintended environmental damage: Many mountains and hillocks were blasted to obtain boulders, and vast amounts of energy were expended to transport the boulders from the mountainous terrain to the shoreline.

As a result of these far-reaching impacts and the typical executive apathy in finding a sustainable solution, the NGT was compelled to intervene. The subsequent cases highlight conflicting approaches. In the first instance, an emergency situation was leveraged to advocate for groynes as a temporary coastal protection measure, which the NGT approved. In contrast, in the second case, decided some seven years later, the NGT seems aware of the damage caused by hard armouring, and it nearly disapproves of solidifying the coastlines.

*O. Fernandes v. Union of India, MoEF* (MANU/GT/0179/2015) highlights the serious situation faced by helpless coastal residents who have been subjected to hard armouring as the only viable solution to coastal erosion. An application was submitted to halt the ongoing construction of sea walls and groynes, and to impose a moratorium on all hard structures due to their disruption of the natural movement of sand. In this case, the disruption affected several coastal districts along a contiguous coastline in Tamil Nadu and neighbouring Puducherry. The Government aimed to build ten groynes as a temporary measure over a sea area of three kilometres to combat the sea erosion that was devastating homes built for Tsunami victims, most of whom were part of the fishing community. The Government's proposal was based on a report submitted by the Department of Ocean Engineering at the Indian Institute of Technology, Madras, which recommended that the groynes could mitigate further sea erosion. Emphasizing the clear duty of the Government to implement erosion control measures, the NGT, acknowledging the urgency of the situation, appointed an Advocate Commissioner to visit the site and report on the factual conditions. The Advocate Commissioner's report revealed the dire circumstances faced by the local population. Although a sea wall was already in place as the sole protection against cyclones and storms, its poor construction led to persistent overtopping and flooding. Given the gravity of the situation and the impending monsoon season, the Tribunal granted the Government temporary permission to construct the ten groynes.

*C.H. Balamohan v. Union of India & Others* (National Green Tribunal, Original Application No. 63/2017 (SZ)) was an appeal filed in the NGT to protect the beaches from human-induced erosion caused by hard structures. It specifically challenged the coastal regulation zone clearance granted to the Public Works

Department of the State of Tamil Nadu for the construction of a series of nineteen groynes. The clearance was contested on the grounds that the groynes would negatively impact the coastal zone by obstructing the littoral drift. In setting aside the contested CRZ clearance due to unsustainability, the NGT stated, "… hard structures may prevent erosion at the said stretch temporarily, but the adverse impact of such measures [is] felt upstream or downstream where erosion begins … [H]ard measures only transfer the problem of shoreline change … There is a need to replace hard structures like seawalls and groynes with softer options such as beach nourishment, sand bypassing, dune planting, and offshore submerged reefs. Thus, the general principle of "working with nature" would be a better approach for cost-effective and sustainable coastal protection measures." More importantly, although the case centred on the proposed construction of groynes in the Tiruvallur District of Tamil Nadu, the NGT recognized that the broader implications of the issue warranted attention from all coastal provinces and territories. Consequently, it directed all coastal provinces and territories to prepare or update their respective environmentally compatible Shore Management Plans. Until then, there would be a prohibition on constructing hard structures for erosion control.

Given the negative environmental consequences of hard engineering structures and the lack of boulders, India, like other coastal countries, is shifting its focus to soft engineering options such as beach nourishment and geosynthetics. Beach nourishment, or beach fill, involves mechanically or hydraulically adding sediment directly onto an eroding beach to replace the sand lost due to erosion or longshore drift. The process entails dredging materials like sand, gravel, and small pebbles from a source area, which can be offshore, near-land, or inland, to replenish the beach affected by erosion. Beach replenishment has been undertaken in several parts of India's coastline; a notable example is the nourishment conducted north of Ennore port (Balamohan, National Green Tribunal, Original Application No. 63/2017 (SZ), para. 22). However, beach nourishment does not stop erosion; rather, it addresses the sediment deficit by adding more sediment sourced from external sites (which is becoming increasingly difficult to obtain), often requiring repeated interventions. (Beach and shoreface nourishment).

Geotextile bags and tubes that can fortify coastlineProtecting the coastal and marine environments are rapidly becoming the "most effective solution of choice." Unlike concrete groynes, which are prone to collapse under intense wave action, especially when the soil is too weak to support the weight of the embankments, geo-tubes or breakwater tubes can adapt and absorb such shocks. They can withstand waves rising to heights of three to four metres and are more economical and environmentally friendly. Essentially, geo-tubes or geotextile tubes are massive tube-like structures made from robust, high-strength geotextiles filled with natural sediment. The sediment is pumped *in situ* through openings in the prefabricated geotextile tubes, forming an enormous monolithic and continuous structure that is placed parallel to the coastline to serve as a seawall, resisting oncoming waves during high tides and significantly alleviating erosion (Geo-Tubes as Sea Walls to check Coastal Erosion in Andhra Pradesh - Ocean Geosynthetics, 2021).

The first geotex tube in India was established in 2010 in Uppada village, Andhra Pradesh, and later in Pentha village, Odisha. However, both are now almost in tatters due to a lack of regular maintenance, which has reduced their effectiveness. Moreover, during the initial stages of their deployment, the designs were inconsistent, and state agencies adopted varying specifications for appraisal, making monitoring challenging. Nevertheless, this has not deterred other coastal States from placing their trust in geotex tubes. Kerala and Tamil Nadu have installed geotex tubes to protect specific sections of their eroding coastlines, and the results are promising. Additionally, the Union Ministry of Water Resources has issued the "Guidelines for Use of Geotextiles/Geotextile Bags/ Geotextile Tubes in Construction of Flood Management Works, 2016" (Geotex Guidelines) to standardize practices. These guidelines pertain to flood management efforts to control riverine and coastal erosion.

### 3.3.1 Discussion

Erosion and accretion are two natural processes that have been occurring since the beginning, making the coastline highly dynamic. In certain areas, erosion may occur at a faster rate than accretion; however, nature has its methods for restoring equilibrium. Presently, what complicates the phenomenon and makes it intractable is that humans continue to build their lives as close as possible to the boundary line that separates land from sea, creating high variability and intensifying erosion. The ongoing phenomenon of sea level rise (SLR) and other severe climatic events, such as cyclonic storms, adds further layers of complexity. All these factors threaten coastal stability, the livelihoods of fishers and others who call this place home, and the future of development projects aimed at supporting economic growth. In many locations where the coastline is rapidly eroding, hard armouring solutions may be the only viable option. These structures can prevent the erosion of coastal landscapes, protect infrastructure, and ensure that populations and economic activities dependent on coastal zones can continue. Typically constructed from concrete, stone, or steel, these structures are fixed within the coastal zone. However, hard armouring also has its drawbacks. Firstly, these structures must function in a coastal and oceanic environment fraught with uncertainty, where conditions can change in an instant. Secondly, if constructed without scientific guidance, they may exacerbate the situation. While hard structures might mitigate erosion in their immediate vicinity, they can contribute to significant erosion and alter the shoreline in other areas. Due to the adverse effects of hard armouring, some coastal States in India have begun to focus on soft engineering options, such as beach nourishment and custom-made geotextile tubes filled with sand and strategically placed. In particular, the soft engineering adaptation measure of geotextile tubes is gaining traction, even if some earlier projects experienced limited success. Geotextile tubes serve as barriers, diminishing the force of oncoming waves to create gentler wave action. These tubes may also assist in depositing sand particles onto the shore, establishing stable and accessible beaches. Compared to sea walls made of rock, which can disintegrate within a few years, geotextile tubes are more sustainable if regular repairs and maintenance are

conducted. However, relying solely on hard and soft engineering as ideal adaptation solutions to SLR oversimplifies the issue. Given the rapidly rising sea levels and their extensive ramifications—including the dynamic nature of the coastal environment and the significant dependence of a large portion of the coastal population on these resources for their livelihoods—a "great wall" is not the optimal solution; rather, what is needed is holistic and integrated coastline management. In this approach, the wall—whether concrete or geosynthetics—forms part of a composite strategy that involves implementing a range of incremental and transformative adaptation measures designed to enhance climate resilience across various temporal and spatial scales. This aspect is discussed in the following two sections.

## 3.4 Adapting to sea-level rise through nature-based solutions

The underlying idea behind soft measures or nature-based adaptation, which include beach nourishment, dune restoration, coastal vegetation planting, mangrove afforestation, and reef conservation, is that they are more in harmony with nature and help implement ecosystem-based conservation approaches. Under certain conditions, natural ecosystems such as mangroves, seagrass beds, coral reefs, and dunes help dissipate wave energy as well as the energy from tides and currents; more importantly, they also provide economic and social benefits while having minimal environmental impact compared to the more intrusive traditional civil engineering methods. Mangroves, often called the "sentinels of the coast," have gained significant favour among the nature-based adaptation measures available to respond to sea level rise (SLR). Therefore, this section will focus on India's laws and policies regarding mangrove conservation.

Often small and shrub-like, mangroves are highly specialized amphibious plants found at the muddy edges of coastlines, where freshwater merges with seawater in tropical and subtropical environments. Mangroves filter out heavy metals from the mud and deposit rich sediments, while their sophisticated salt-filtering systems enable them to absorb the corrosive properties of saltwater. Part of the blue carbon ecosystem spectrum, they are often recognized as some of the best carbon scrubbers. They can sequester more carbon from the atmosphere than any other type of forest—ten times more carbon per hectare than terrestrial forests—storing it in their roots if left undisturbed (The Blue Carbon Initiative, n.d.). Their roots grow upward from the mud into the air, allowing them to breathe and cope with low oxygen levels. More crucially, from a sea-level adaptation perspective, their extensive root system helps slow down the tumult of the sea, acting as a natural first line of defence that can prevent or reduce coastal erosion and flooding.

For a long time, mangrove forests in India have faced relentless pressures from development and have been systematically destroyed. Given the strict nature of legal restrictions and their negative impact on a property's economic value, private property owners often resort to setting them on fire or cutting them down to clear the land. Occasionally, the water source supporting the mangroves is deliberately obstructed by dumping debris or erecting barriers. Once this supply is blocked, the mangroves wilt and wither away. The government also prioritizes development at any cost, ignoring the significant ecological consequences of destroying and clearing mangroves. The underlying notion is that even if a few patches of mangrove forests are cleared, the government can absolve itself of this significant environmental transgression by planting mangroves several times over the number that have been removed, disregarding the simple ecological truth that mangroves are not ordinary shrubs that can be planted anywhere and will quickly regrow to provide ecological services at the same scale and value. Mangroves are highly ecologically sensitive; once lost, they are gone forever. For instance, it took over seven years to restore about 500 hectares of mangroves in Andhra Pradesh at a staggering cost of $3 million. Fortunately, this restoration increased the population of edible crabs and fodder for livestock, thereby boosting local incomes. There was also a rise in otters and birds (Environment Protection Training and Research Institute, 2012, p. 30).

India's total area covered by mangroves is 4,922 sq km (0.15% of the country's total geographical area), which is just over three percent of the global total. The "India: State of Forest Report 2021" categorizes the total mangrove cover as follows: 1) "very dense mangrove" - 1,475 sq km (29.55%); 2) "moderately dense mangrove" - 1,481 sq km (29.67%); and 3) "open mangroves" - 2,036 sq km (40.78%). Compared to the previous assessment of 2019, the report surprisingly reveals a net increase of 17 km² in mangrove cover (Forest Survey of India, Ministry of Environment Forest and Climate Change, 2021). India's mangrove ecosystems boast the highest biodiversity, with 5,746 species, of which 4,822 (84%) are animals (Leal and Spalding, 2024, p. 62). Although mangroves are interspersed along India's coastline, the Sunderbans and Bhitarkanika are particularly notable. The Sundarbans, which straddle both India (40% of the area lies in India) and Bangladesh, constitute the world's largest expanse of mangrove forests and are designated as UNESCO World Heritage sites and biosphere reserves. This region is home to the highest number of Royal Bengal Tigers (the only mangrove forest in the world where tigers are found), along with the Ganges River Dolphin, the Irrawaddy Dolphin, the Indian Python, the Estuarine Crocodile, and over 250 species of birds, reptiles, and more than 120 species of fish. It serves as a flood barrier to the city of Kolkata (the capital of the Indian state of West Bengal), shielding it from cyclonic activity. Not only are the Sundarbans rich in biodiversity, but they also support more than four million residents. There are 102 islands in the Sundarbans, with 54 inhabited by people engaged in fishing, agriculture, and collecting wood and honey (Department of Sundarban Affairs, Govt. of West Bengal, n.d.). India's second-largest mangrove habitat is Bhitarkanika, located along the Odisha Coast. It is a vital Ramsar Wetland known for its saltwater crocodiles and the largest nesting area for Olive Ridley Sea turtles (Department of Ocean Development Integrated Coastal and Marine Area Management Project Directorate, 2021, p. 3). Over 220 species of birds have been recorded here.

Even as coastal communities harness the potential that mangroves and other coastal ecosystems offer to help them adapt to the impacts of climate change and sea-level rise, these ecosystems ironically remain climatically vulnerable. For example, the Sundarbans face a grim prospect of submergence if emissions persist at current levels. The rising Bay has already begun to engulf several small islands within this wetland. The island of Lohachara was one of the first inhabited islands to vanish beneath the sea in 1996, forcing its residents to relocate. As sea levels rise, more saline waters are intruding into the delta, disrupting the hydrological balance and threatening the health of mangroves and soil quality. Reports indicate that many residents of the Sundarbans have started commercially farming brackish water shrimp to offset the increased salinity. However, this has led to several adverse consequences. The health of rural women in the Sundarbans, who are engaged in the poorly paid marginal labour of prawn seed collection—requiring them to stand in saline water for at least six hours—has been significantly impacted. Although the Sundarbans have traditionally been a hotspot for tropical cyclones, rising sea levels and temperatures have intensified these storms, with wind speeds and precipitation levels continuously escalating. These changes have disrupted the region's rich biodiversity. As prey availability has declined, human-animal conflict has increased, along with the number of "tiger widows." (*Shantibala Naskar v. State of West Bengal*, MANU/WB/2555/2023).

Although several laws at the national level, such as the Wild Life (Protection) Act of 1972, the Indian Forest Act of 1927, the Forest (Conservation) Act of 1980, the Biological Diversity Act of 2002, and the Compensatory Afforestation Fund Management and Planning Authority Act of 2016, are relevant to mangrove conservation, heightened protection stems from the CRZ 2019, which classifies areas with mangroves as CRZ-IA (CRZ 2011). Where the mangrove area exceeds 1,000 square meters, a buffer zone of 50 meters along the mangroves must be maintained (this buffer zone is not required for mangroves on private land) [CRZ 2019, Annexure -1, 1.1(ii)(b)]. This buffer zone also falls under the CRZ-IA. As previously mentioned, the CRZ-IA is the most ecologically sensitive zone, and therefore, the coastal law permits no activities except eco-tourism in identified stretches, subject to an eco-tourism plan. If roads must be built through these mangrove areas, which could lead to their destruction, compensatory afforestation of at least three times the mangrove area to be destroyed must be undertaken [CRZ 2019, para. 5.1.1(iii)]. Only the laying of pipelines, transmission lines, conveyance systems, and roads on stilts is permitted within the mangrove buffer [CRZ 2019, para. 5.1.1(ii)].

Legal battles for mangrove conservation have been fiercely contested in courtrooms across India. One such case unfolded in the Bombay High Court to protect the mangroves located on the outskirts of the coastal city of Mumbai. Given the city's rapid development and commercial significance, the mangroves along the Mumbai Metropolitan region, which shield the city from tidal surges, are under significant threat due to limited land availability and a massive population influx. Extensive encroachment on the mangroves has occurred because of rampant development. Between 1990 and 2011, mangrove coverage in Greater Mumbai was reduced by 40%, and it continues to decline; however, the legal requirement for compensatory afforestation has partly mitigated the situation (TERI, 2014, p. 288).

Nevertheless, the judiciary had to intervene to protect the mangroves. The case of *Bombay Environmental Action Group v. The State of Maharashtra* (MANU/MH/0707/2005) represents a landmark decision by the Bombay High Court. While acknowledging the vital role of mangroves, the Division Bench, composed of Justices Riyaz I. Chagla and A.S. Oka, stated that "if a citizen is to lead a meaningful life as contemplated by Article 21 of the Constitution of India, [mangroves] must be preserved and protected." The court affirmed that the "drastic effects" of mangrove destruction on the environment, combined with the state's failure to act for its restoration, constituted a violation of the fundamental rights guaranteed by Article 21. As a result, a complete freeze on mangrove destruction and cutting in Maharashtra was imposed. The court indicated that while the precautionary principle mandates that the state, along with its agencies and instrumentalities, must anticipate and address the causes and consequences of mangrove degradation, the public trust doctrine obliges the state to protect and preserve mangroves, prohibiting their destruction for private, commercial, or any other purposes. However, if such a course of action becomes necessary, the court can only evaluate this effect solely in relation to the public good or interest.

This decision has far-reaching ramifications. It adds a new dimension to the concept of mangrove protection by linking it with the right to life, thus elevating it under the protective umbrella of Article 21, referred to as "the heart and soul of the Indian Constitution" (*National Legal Services Authority v. Union of India*, MANU/SC/0309/2014). The practical implications of this decision impose a duty on the Court to protect and preserve mangroves. Moving forward, any development project in Maharashtra involving mangrove destruction will be subject to judicial scrutiny and monitoring, rather than being left to the discretion of the executive. The case, *National High-Speed Rail Corporation Ltd. v. State of Maharashtra* (MANU/MH/4336/2022), illustrates the practical impacts of this aspect. This case pertains to the Mumbai-Ahmedabad High-Speed Railway Project, which is India's first bullet train initiative connecting the cities of Mumbai and Ahmedabad. This project is notable as it pioneers bullet trains in India; it is expected to not only reduce journey times, but also to decrease costs, carbon footprints, and vehicular traffic pollution. However, as some of the proposed activities would impact an area of 13 hectares of mangrove vegetation consisting of 53,467 trees (CRZ-I), the Maharashtra Coastal Zone Management Authority (MCZMA) denied the petitioner's permission to cut down the mangroves. It directed the petitioner to approach the Bombay High Court seeking relief, especially since this region's Coastal Zone Management Plan (CZMP) had yet to be finalized and approved. In exercising its discretion to favour the project, the Bombay High Court weighed its benefits against the petitioner's commitment to plant over 110,000 mangrove saplings in the area between the piers to be installed, among other safeguards. The

Court concluded that these elements balance development, protection, and environmental conservation. Consequently, the Mumbai-Ahmedabad High-Speed Rail Project was determined to be in the public interest and necessary for the public good, qualifying as a bona fide public utility project.

While these represent the general legal framework aimed at protecting the diverse ecosystem services that mangroves provide, the Central Government has recently launched an initiative—The Mangrove Initiative for Shoreline Habitats & Tangible Incomes (MISHTI)—to develop mangrove and shelterbelt plantations along India's coastline. This follows India's participation in the 'Mangrove Alliance for Climate' and underscores the critical role of mangroves in safeguarding the coast from erosion. The MISHTI is a five-year program that begins in 2023-24, aimed at enhancing mangrove cover along the coastline and on saltpan lands. The scheme primarily targets the Sundarbans Delta, the Hooghly estuary, coastal bays, and other wetlands. Its goal is to conserve and restore the mangrove ecosystem, necessitating government financial assistance to local communities for mangrove planting initiatives and organizing awareness campaigns highlighting the importance of mangroves. Overall, the MISHTI represents a significant advancement toward promoting sustainable development and protecting the vulnerable coastal regions of India. (Mangrove Initiative for Shoreline Habitats & Tangible Incomes (MISHTI) | India Science, Technology & Innovation - ISTI Portal, n.d.).

### 3.4.1 Discussion

As noted above, conserving coastal ecosystems like mangroves is crucial for a tropical developing country such as India, where a large population relies on natural resources for their livelihoods, food, and water security in a context of scarce economic resources and abundant demand. India possesses a remarkable diversity of coastal ecosystems and resources, which form its natural capital base. Unfortunately, the primary issue in India's approach to mangroves and other coastal resource use, management, and conservation is its careless nature, leading to anthropogenic activities such as overfishing, mining, and pollution that stress these coastal ecosystems or eco/bio-shields. In this scenario, climate change and sea level rise will act as stress multipliers, overwhelming these systems entirely. Many believe that these eco-shields hold significant promise in providing sustainable solutions to address climate change. This happens in three ways: 1) mitigation, by ensuring that more carbon is not released into the atmosphere (storing and sequestering carbon); 2) adaptation, acting as natural seawalls that protect coastlines from flooding and erosion while reducing disaster risk; and 3) ensuring the continuance of provisioning services and building resilience (serving as storehouses of biodiversity, contributing to food and water security, and safeguarding livelihoods). Nature-based Approaches (NBA) can, therefore, help create stable and sustainable coastal zones (Nature-based Solutions | IUCN, n.d.). Consequently, India must urgently address anthropocentric threats to leverage nature and optimize the benefits of healthy ecosystems/eco-shields to protect people and avert extensive structural, ecological, and livelihood damage. India must move away from its fragmented approach to conserving coastal ecosystems and enact comprehensive legislation to ensure their health, thereby facilitating the implementation of NBA.

## 4 Understanding the tug-of-war, achieving convergence and streamlining adaptation efforts through ICZM

From the above, it is clear that India has a three-pronged adaptation strategy to address the challenges posed by SLR, which incorporates tools from coastal law, hard and soft engineering, and nature-based adaptation. While there are legal and policy frameworks to support their implementation, the normative guidance provided is far from satisfactory, and the approach remains piecemeal and fragmented. Additionally, there is a continuous tug-of-war between hard and soft armouring measures and NBA strategies. This is despite widespread recognition at the levels of the Government, scientific and policy think tanks, local communities, and civil society groups that NBA measures such as mangrove afforestation, reforestation, dune planting, and reef conservation present the best prospect for adapting to SLR, as they are more environmentally, socially, and economically sound. Global experiences reveal that the less interference there is with coastal processes, the lower the risk of encountering unpredictable, intrusive, and volatile coastal management issues. It is preferable to "work with Nature" rather than against it. In other words, one should avoid trading one environmental problem for another—an approach that aligns with the precautionary principle. Consequently, when a coastline erodes due to human-induced factors, addressing the root of the problem through NBA measures may be the preferable course of action. (*Balamohan, National Green Tribunal, Original Application* No. 63/2017 (SZ), para. 68).

Despite this realization, when beaches begin to erode, and local communities find their livelihoods and homes threatened, they desperately demand protection from the state in whatever way possible, even if it means setting up hard structures as knee-jerk responses. Given the absence of well-defined scientific, technical, and legally sound processes, systems, and protocols to support NBA in addressing these challenges, the government and its agencies continue with foot-dragging and business-as-usual approaches that favour re-engineering the coastal environment with hard structures, which may perpetually alter the coastline and lead to even more severe negative impacts. This situation benefits vested interests—consultants get to design more coastal structures, quarry owners, transporters, and contractors gain from the construction, and politicians can appease their voter bases. However, this leaves the coastal environment and local communities to bear the brunt in the long term. (*Balamohan, National Green Tribunal, Original Application* No. 63/2017 (SZ), para. 69).

While the preference may lean towards NBA, one cannot completely dismiss the utility of hard and soft engineering

solutions. Hard engineering might be the only viable option for waterfront coastal cities and settlements with very high population density and infrastructure along the coastal fringes. Even with mangroves and tidal marshes acting as buffers between land and ocean, under worst-case scenarios of sea-level rise (SLR), these ecosystems would be forced to migrate inland due to rising sea levels. However, this migration would be virtually impossible as the area is fully developed, leading to their shrinkage and eventual destruction. Therefore, in the tug-of-war between hard and soft engineering and non-structural approaches, there is no clear winner; instead, the best strategy for reinforcing any given coastal area largely depends on the specific characteristics of the coastal environment and the interests of the affected communities. For example, hard engineering solutions should be prioritized in areas with significant coastal infrastructure and development projects or where large populations are densely clustered, making relocation exceedingly difficult. In contrast, in regions with ample land, adaptation strategies may need to be adjusted to emphasize land use planning, proper setbacks, and the provision of drainage and water supply systems, as well as erecting barriers against saltwater intrusion, regulating groundwater, and constructing cyclone shelters. In areas featuring mangroves, seagrass beds, coral reefs, wetlands, and others where local communities rely on these ecosystems for their livelihoods, the focus can be on their protection and maximizing their benefits. Where degradation is evident, efforts should concentrate on reforestation and regeneration. Adaptation may also include initiatives aimed at fostering community awareness and enhancing the resilience and livelihoods of coastal communities, such as mangrove and coral reef conservation initiatives, which can, in certain situations, shield coastlines from erosion while simultaneously boosting biodiversity and climate resilience (Klein et al., 2003).

In other words, given that the coastal environment is highly dynamic and is constantly evolving in time and space, its management is complex. Therefore, the focus must be on a hybrid approach that combines hard and soft engineering with nature-based adaptation measures. Moreover, in a country like India, where millions live below the poverty line along its coastlines, relying on coastal resources and the ecosystem for their livelihood, food, and water security, even a slight variation in temperatures or a rise in sea level can disrupt their lives significantly.

In response to these challenges, integrated coastal zone management (ICZM) is globally recognized as the primary method for managing coastal areas and resources, preventing degradation while promoting and sustaining economic development, particularly climate-resilient development. This is set within the broader context of addressing the challenges posed by sea-level rise (SLR) and other climate change impacts on coastal zones (United Nations Conference on Environment and Development, Framework Convention on Climate Change, 31 ILM 849 (Jun. 19, 1993), art. 4(1)(e)). ICZM aims to achieve this by: 1) implementing an ecosystem approach and integrating actions and stakeholders across various fronts to minimize conflicts (tugs-of-war) and maximize benefits. For a federal country like India, ICZM, in a sense, promotes and enhances the concept of cooperative federalism; 2) overcoming the fragmentation that is often a part of sectoral approaches to coastal governance. The goal is not to replace sectoral management but rather to create appropriate connections between various sectoral initiatives to yield a more comprehensive response; 3) transforming top-down bureaucratic models of coastal governance into actions that are more bottom-up, participatory, equitable, inclusive, transparent, and accountable. By providing a platform to support all these efforts, ICZM effectively presents an iterative pathway to implement adaptation (even if it is done incrementally), reduce the vulnerability of coastal areas to natural hazards, climate change, and SLR, and sustain essential ecological processes, life support systems, and biological diversity. It envisions implementing short-term solutions that consider the long-term to deliver no-regret and transformative outcomes (Puthucherril, 2015, pp. 15–6). In short, ICZM is a practical tool for achieving sustainable coastal development (SCD).

Even though Integrated Coastal Zone Management (ICZM) has been prominent globally for several decades, India made its initial steps towards ICZM with the Coastal Regulation Zone Notification of 1991. Subsequent iterations of the coastal law, namely CRZ 2011 and CRZ 2019, feature many aspects that support ICZM. Still, the real boost came with the World Bank-sponsored ICZM project, which assisted the Indian government in building capacity at the national level and piloting ICZM approaches in Gujarat, Odisha, and West Bengal. The primary achievements of this project phase include mapping and delineating the Coastal Hazard Line for India's entire mainland coast and restoring 19,500 hectares of mangroves. The project also led to the development of ICZM plans for the State of West Bengal, the Paradip-Dhamara and Gopalpur-Chilika areas of Odisha, and the Gulf of Kutch in Gujarat, and it enhanced livelihood security for coastal communities in identified stretches (Report of the Comptroller and Auditor General of India on Conservation of Coastal Ecosystems, 2022, p. 52). Other significant initiatives that helped mainstream ICZM included establishing the National Centre for Sustainable Coastal Management (NCSCM) as an autonomous institution under the Union Ministry of Environment, Forest and Climate Change (MoEF&CC) in 2011. The NCSCM serves as India's think tank on sustainable coastal management, supporting and encouraging the nationwide adoption of ICZM based on advanced science and knowledge by networking with communities, government bodies, and national and international institutions to develop scientific, managerial, and policy guidance for coastal areas and ecosystems (National Centre for Sustainable Coastal Management (NCSCM), https://ncscm.res.in/about-us/ (Accessed January 28, 2025)).

Buoyed by the apparent success of its ICZM project, the World Bank sought to collaborate again to support India with an even more ambitious ICZM project to enhance its coastal resources, protect coastal populations from pollution, erosion, and sea-level rise, and improve livelihood opportunities. The 'Enhancing Coastal and Ocean Resource Efficiency' project has two phases: ENCORE Phase 1 and ENCORE Phase 2. Phase 1, ENCORE, covers eight coastal states and three coastal Union Territories. The focus areas

include aiding States in developing ICZM plans, providing support for coastal and marine spatial planning, and developing intangible 'blue' resources such as carbon sequestration, coastal resilience, waste management, and coastal tourism. Even though this project also has the potential to help India achieve its Nationally Determined Contribution targets by supporting longer-term coastal adaptation through the sound management of mangrove forests and seagrass fields, its implementation seems to have run into rough weather (Abebe, 2022, p. 2).

While Phase I of the ICZM project is generally regarded as successful, India's Comptroller and Auditor General notes several deficiencies in a Performance Audit on 'Conservation of Coastal Ecosystems' (Report of the Comptroller and Auditor General of India on Conservation of Coastal Ecosystems Report No. 4 of, 2022, p.52). For example, the ICZM plans were neither prepared on time nor were the Integrated Management Plans for Critically Vulnerable Coastal Areas notified, even after the project's completion. Additionally, many institutes selected for the project operated with insufficient manpower, which hindered the project's capacity-building efforts. Furthermore, the infrastructure created by the project fell into disrepair due to the state authorities' inability to secure maintenance funding. The non-execution of critical projects, which had significant potential to reduce coastal pollution, undermined the project's primary objectives. Lastly, while the hazard line was electronically mapped, the absence of a visible hazard line on the ground obstructed its use as a relevant planning tool (Report of the Comptroller and Auditor General of India on Conservation of Coastal Ecosystems, 2022, p. 52).

While ICZM has gained acceptance in India and a foundation for its development has been established, several significant concerns identified by the Comptroller and Auditor General remain. Many of these can be addressed if ICZM initiatives are aligning with the official institutional and normative framework of the coastal law. This alignment is crucial for India to achieve sustainable coastal development. ICZM must transition from the current fragmented, project-based implementation model to become the primary approach to coastal management. This necessitates thoroughly revising the CRZ 2019, transitioning from the current zoning approach to aligning with the ICZM methodology. Only then can India fully harness the potential of ICZM and effectively implement coastal climate change adaptation while tackling the ongoing challenges inherent in coastal management, thereby creating a win-win, no-regrets scenario. The image below, Figure 2, titled "Adapting to SLR: The 3-Pronged Approach," encapsulates this concept within India's approach to adaptation and coastal zone management.

## 5 Actionable recommendations

Based on the above discussion, certain actionable recommendations are proposed to revamp India's approach to coastal management and climate change adaptation.

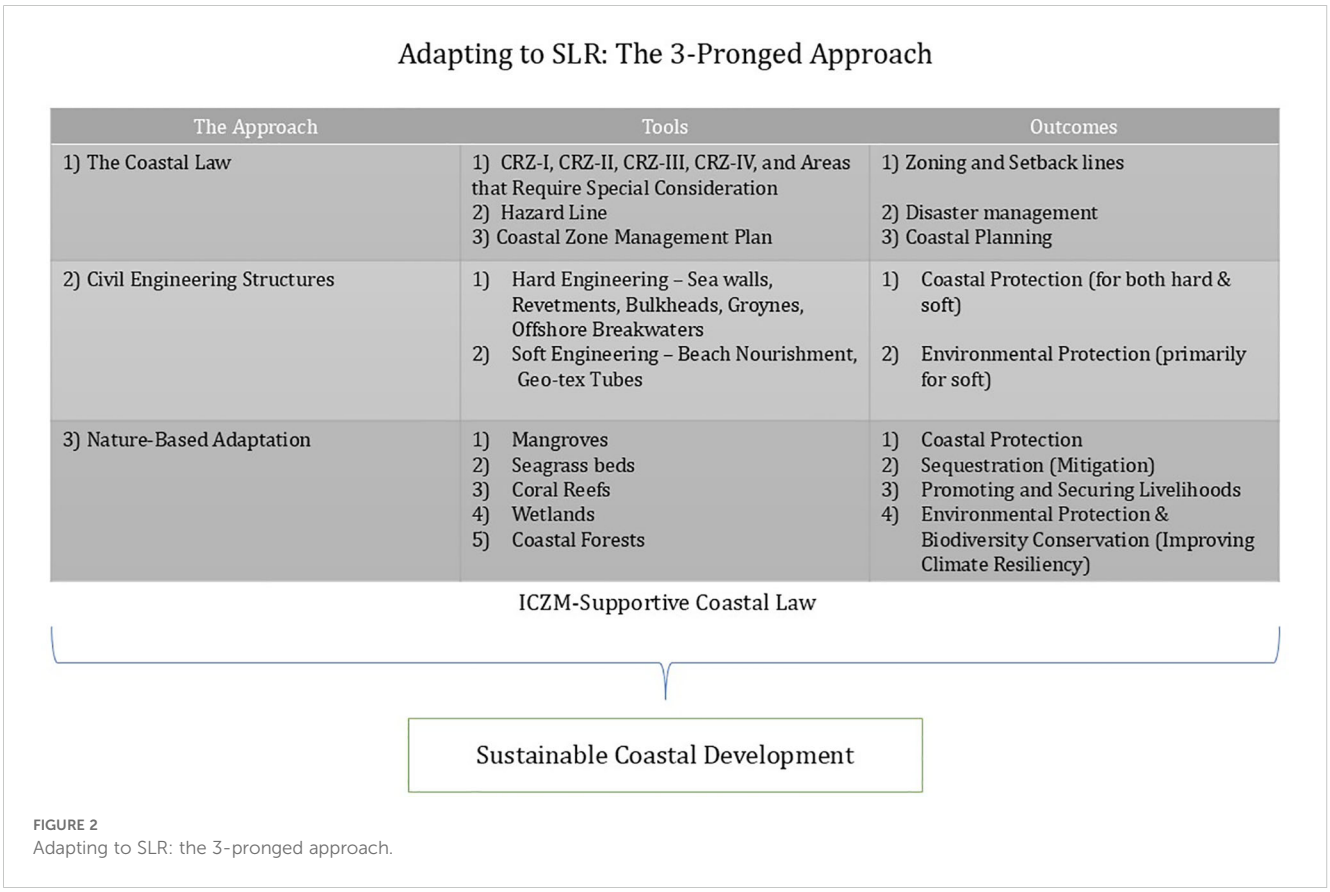


FIGURE 2
Adapting to SLR: the 3-pronged approach.

First, India must address the fragmentation that characterizes its current policy on coastal zone management and adapt to rising sea levels and climate change. Therefore, the emphasis should be on laws and legal frameworks that can serve as the backbone in strengthening and supporting coastal zone management while facilitating adaptation to climate change, thus contributing to sustainable coastal development (SCD). This necessitates that India primarily focuses on the structure of its coastal legislation. India requires a dedicated coastal statute, rather than delegated legislation, to manage its extensive and diverse mainland coastline and provide a measured response to sea level rise (SLR). The first coastal law, the Coastal Regulation Zone Notification, was enacted in 1991. Since then, over two dozen amendments have been introduced to this law, rendering it increasingly inconsistent and ineffective. Although new coastal laws were introduced in 2011 and 2019, surprisingly, these were also structured as delegated legislation, despite an awareness of the issues posed by such a framework. For India, which has the longest coastline in South Asia and is negatively affected by climate change and SLR impacts, a dedicated statute should be established to eliminate the *ad hoc* approach that currently characterizes the national legal framework for coastal management (amending a statute requires legislative assent, while subordinate legislation can be modified easily by the executive). A coastal law will also ensure that while coastal development is pursued, it duly considers the importance of adapting to climate change.

Secondly, India is a classic example of how adaptation measures and sustainable coastal development have been neglected in favour of short-term economic objectives. Therefore, for India to prioritize sustainable coastal development, its coastal laws must be founded on integrated coastal zone management (ICZM), which is globally acknowledged as the primary methodology for achieving sustainable coastal development. For an extended period, coastal management has concentrated on the sustainable use of coastal resources, conflict avoidance and management, and fostering user complementarities. Unlike this approach, ICZM requires a paradigm shift from silo-based mechanisms focused on coastal resource use to one that envisions a dynamic, holistic, and ecosystem-based approach to managing coastal spaces and resources while also emphasizing the need for coastal climate change adaptation.

Since climate change and sea-level rise (SLR) are the most significant factors affecting the coastal and oceanic environment, the central aim of any coastal law must be to establish a proactive framework of rules and measures that help coastal managers adapt to the challenges presented by climate change and SLR, while considering uncertainty and the need for risk management. Coastal law can facilitate climate change adaptation in two primary ways: 1) by enacting measures broadly categorized into retreat, accommodate, and protect, and 2) by reconciling coastal development with essential coastal environmental protection, thereby enhancing the adaptive capacities of coastal communities and the resilience of coastal ecosystems. While coastal law must create pathways to implement the three main adaptation strategies—accommodate (by prescribing minimum ground elevation for new development), retreat, and protect (by reinforcing seawalls and increasing their heights when necessary)—the primary emphasis should consistently be on soft armouring and accommodation, honouring the concept of living shorelines and allowing nature to dictate equilibrium. Hard armouring should only be employed as a last resort (to protect coastal infrastructure). In such cases, coastal law should adhere to the fundamental principle that using hard armouring should not compromise coastal ecosystems in other areas.

There are two key dimensions to implementing ICZM: the first is prescriptive, and the second is functional. Coastal law serves a prescriptive role by establishing norms for economic development and protecting coastal environments. Conversely, the functional aspect is secured through an ICZM plan. Sustainability can be significantly achieved by designing, developing, and implementing a well-considered ICZM plan that integrates development with environmental considerations and balances various interests in the coastal zone. ICZM plans outline specific goals and objectives, identify various stakeholders, enumerate the activities required to achieve these goals, highlight coastal ecosystems requiring urgent management, specify maintenance measures, and, most importantly, establish an implementation schedule. ICZM plans should also be used to advance coastal climate change adaptation, including measures to prevent or mitigate the impacts of natural hazards. As these plans do not operate in isolation, it is essential that they are anchored in the legal framework within which they exist, evolve, and function. A fundamental objective of coastal law is to ensure it not only facilitates the creation of these plans (with input from coastal communities within a specified timeframe) but also outlines guidelines for the actionable components an ICZM plan should include and specifies methods for its implementation. Furthermore, depending on national circumstances, the extent of the coastal zone, the nature of coastal resources, and population concentration, it might be necessary to provide for more than one coastal zone management plan, and in some instances, even establish a hierarchy of plans that begins with a national plan outlining strategic objectives, followed by provincial and then local plans. Since the natural features, concentrations of coastal populations, coastal resources, and challenges affecting coastal areas, including sea-level rise, are not uniform along the coastline, a decentralized and nested format of ICZM plans can enhance focus and facilitate the development of management responses tailored to localized conditions, thereby improving the implementation of ICZM. Additionally, to reflect the dynamic nature of ICZM and the principle of adaptive management, the plan should be subject to periodic revisions and updates.

Finally, given the overwhelming number of people living in India's coastal zones and their reliance on coastal resources for survival and livelihood, coastal law must emerge as social welfare legislation that supports Integrated Coastal Zone Management (ICZM). This legislation should harmonize the actions of various stakeholders in the coastal area and provide coastal communities with opportunities to engage in the ICZM process from the planning stage to its implementation. In doing so, coastal law must empower coastal communities, grant them meaningful roles in coastal zone

management, and acknowledge their traditional knowledge; in the long run, these actions can enhance their adaptive capacities.

## 6 Conclusion

In summary, while it is encouraging to see that India is not entirely off track regarding the policies and legal measures established to address SLR, it is equally discouraging to acknowledge that the country is not fully aligned due to the diffuse nature of its framework and associated initiatives, which resemble a patchwork of regulations, policies, laws, and projects implemented at both the federal and State levels by numerous ministries, government departments, and agencies, sometimes involving community entities through local self-government institutions. Any hesitation in establishing a coherent approach to SLR-related challenges is something India cannot afford, given its vast population residing and earning their livelihoods in coastal areas and the crucial role that coastal resources play in supporting its blue economy, estimated to be worth trillions of dollars. SLR is an emerging issue that presents numerous challenges, some of which may not be immediately apparent. There are no universal, one-size-fits-all solutions applicable uniformly across the board. Therefore, the most effective strategy is to implement a range of adaptation measures grounded in a precautionary and ecosystem-based approach tailored to local geographical, socio-economic and cultural contexts based on the susceptibility and vulnerability of each area. When these adaptation measures are executed within the broader framework of ICZM, it becomes possible to leverage these strategies to maximize their potential in addressing the impacts of SLR while enhancing the overall quality of life and development of coastal communities. However, given the complexity of these issues and the challenges associated with effectively utilizing the ICZM framework, it is crucial to have an appropriate and supportive legal structure to prevent legal uncertainty, lest this may lead to maladaptation and unsustainable coastal development (see Part 5. Actionable Recommendations).

## Author contributions

TP: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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## Conflict of interest

The author declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

## Publisher's note



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