Building Coastal Resilience: A Strategic Framework for Climate-Smart Agriculture in India

White Paper

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Executive Summary

Coastal agricultural landscapes of India sustain the lives of more than one hundred million individuals, nearly half of whom rely directly on farming, fishing, and related occupations for subsistence. The shoreline extends over 11,000 kilometers, from the fertile plains of Gujarat and Maharashtra in the west to the great river deltas of the Ganga–Brahmaputra, Mahanadi, Godavari, Krishna, and Cauvery in the east. Coastal districts comprise multiple agro-ecological zones, ranging from salt-stressed cotton and groundnut belts of Gujarat to coconut-pepper plantations across Kerala and Karnataka, and from vast kharif rice systems in Odisha and West Bengal to integrated rice–fish models across many regions.

During the last fifty years, climatic patterns along the Indian coast have changed significantly. Average temperatures have climbed by nearly one degree Celsius, sea level has been rising at more than 2.5 millimeters per year, heavy rainfall events occur more often, and cyclones are becoming stronger. These shifts accelerate salinity intrusion, prolonged waterlogging, shoreline erosion, and storm surge risks, reducing crop productivity and threatening national food security. Irregular timing of the monsoon further disrupts cropping schedules, while repeated flooding and salt stress damage soil fertility. Economic losses are already high, with annual agricultural damage from cyclones and floods exceeding one billion United States dollars. Smallholder farmers bear disproportionate costs, losing up to fifteen percent yield in years of severe salinity. Fisheries and aquaculture also face damages surpassing two hundred million dollars annually.

To confront such risks, the government of India has established a wide adaptation framework. The National Action Plan on Climate Change coordinates several thematic missions. Among these, the National Mission for Sustainable Agriculture promotes climate-smart methods such as resilient crop varieties, micro-irrigation, and integrated farming in vulnerable zones. Complementary schemes strengthen soil management, increase assured irrigation, and provide insurance linked to weather indices. Coastal Regulation Zone norms, integrated coastal zone projects, and aquaculture rules help protect critical ecosystems, while state-level action plans adapt measures to specific vulnerabilities. Research and extension networks under the National Initiative on Climate Resilient Agriculture have deployed weather stations, piloted climate-resilient villages, and shared localized advisories through Krishi Vigyan Kendra's and digital platforms.

Nevertheless, turning policy into practice faces repeated hurdles. Funding cycles often fail to match agricultural calendars. Data remain fragmented and responsibilities of agencies overlap. Extension resources are limited and community participation is uneven. Farm-level demonstrations show strong potential salinity-tolerant crops improve yields, rice–fish practices diversify income, subsurface drainage and solar desalination reduce salt stress, and digital advisories support timely decisions. Yet widespread adoption is constrained by insecure tenure, small and fragmented holdings, limited access to finance, and gender-based obstacles.

The financing ecosystem consists of allocations from central and state budgets, concessional credit, green bonds, blended finance mechanisms, and multilateral funds including the Green Climate Fund, the Global Environment Facility, and the World Bank. Still, innovative models such as risk-sharing arrangements, performance-linked grants, and micro-loans run by communities need scaling to reduce private sector risk and guarantee predictable support.

Key directions moving forward include aligning agriculture, water, and environmental policies through coordinated ministries, streamlining access to climate finance, embedding resilience into extension training, institutionalizing multi-stakeholder platforms, and strengthening community-driven adaptation. Core principles; community involvement, adaptive planning for multiple scenarios, fair access to technologies, diversification of livelihoods, and contingency planning in real time should guide all interventions.

The roadmap is phased: initial years 2025–2028 focus on building institutions; the second stage 2028–2032 expands and integrates proven demonstrations; the final stage 2032–2040 achieves national transformation and leadership. A specialized Adaptation Financing Unit will coordinate diverse resources, allocate based on performance, and provide fiscal transparency using digital dashboards.

By narrowing the divide between policy and practice, encouraging innovation, and enabling coastal communities, the country can safeguard agricultural productivity, protect rural livelihoods, and establish itself as a regional leader in coastal climate resilience by 2040. This strategic framework delivers a clear, evidence-based pathway to navigate the complex challenges of a rapidly changing climate.

Chapter 1: Understanding Coastal Agriculture and Climate Nexus in India

Assessing Coastal Vulnerabilities, Agricultural Impacts, and the Need for Climate Resilience in Agriculture

1.1 Socio-ecological Profile of Coastal India

The shoreline of India stretches 11,098 km, covering nine states, namely, Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, and West Bengal - and four union territories - Daman and Diu, Dadra and Nagar Haveli, Puducherry, and the Andaman and Nicobar Islands. This extensive coastline borders the Arabian Sea in the west and the Bay of Bengal in the east (Ministry of Earth Sciences, 2023; Sinha, 2025). Coastal landscapes vary from narrow plains and estuaries on the western side, framed by the Western Ghats, to wide river deltas in the east formed by the Ganga–Brahmaputra, Mahanadi, Godavari, Krishna, and Cauvery River systems. The coastal districts accommodate more than one hundred million residents, about 65 percent of whom live in rural settings and rely on agriculture, fisheries, and associated livelihoods (Census of India, 2011). Nearly 45 percent of the local workforce is engaged in farming, while marine and brackish-water fisheries sustain 4.2 million active fishers (Ministry of Fisheries, Animal Husbandry and Dairying, 2024).

The diversity of India's coastal environment drives varied agricultural systems and crop combinations. In the deltaic tracts of West Bengal, Odisha, Andhra Pradesh, and Tamil Nadu, kharif rice covers 11 million hectares, contributing 60 percent of the region's cereal production. In contrast, coastal Gujarat and Maharashtra contain 2.23 million hectares of saline soils where salt-tolerant cotton and groundnut are cultivated under brackish irrigation (Department of Agriculture and Farmers Welfare, 2024). On the south-western coast, Kerala maintains 0.9 million hectares and Karnataka 0.6 million hectares of coconut plantations intercropped with pepper, areca nut, spices, and horticultural crops (Coconut Development Board, 2024). In addition, integrated rice–fish production extends over 2.4 million hectares nationally, with 0.8 million hectares in West Bengal and 0.4 million hectares in Odisha. These systems achieve 4.5–5.2 tonnes rice-equivalent per hectare and generate net incomes of ₹ 85,000–95,000 per hectare, outperforming monoculture systems (World Bank, 2025).

Unfortunately, agriculture along the Indian coast faces multiple climate-linked pressures—rising seas, salinity intrusion, stronger cyclones, heat stress, and waterlogging, all of which reduce crop yields, endanger food security, and weaken rural livelihoods in these fragile agro-ecosystems.

1.2 Observed Climate Impacts (2020–2025)

Indian coastal belts are already showing measurable climate-related changes. Average annual surface temperatures have risen by around 0.8 °C since 1970, with accelerated warming in the last decade (IPCC, 2022).

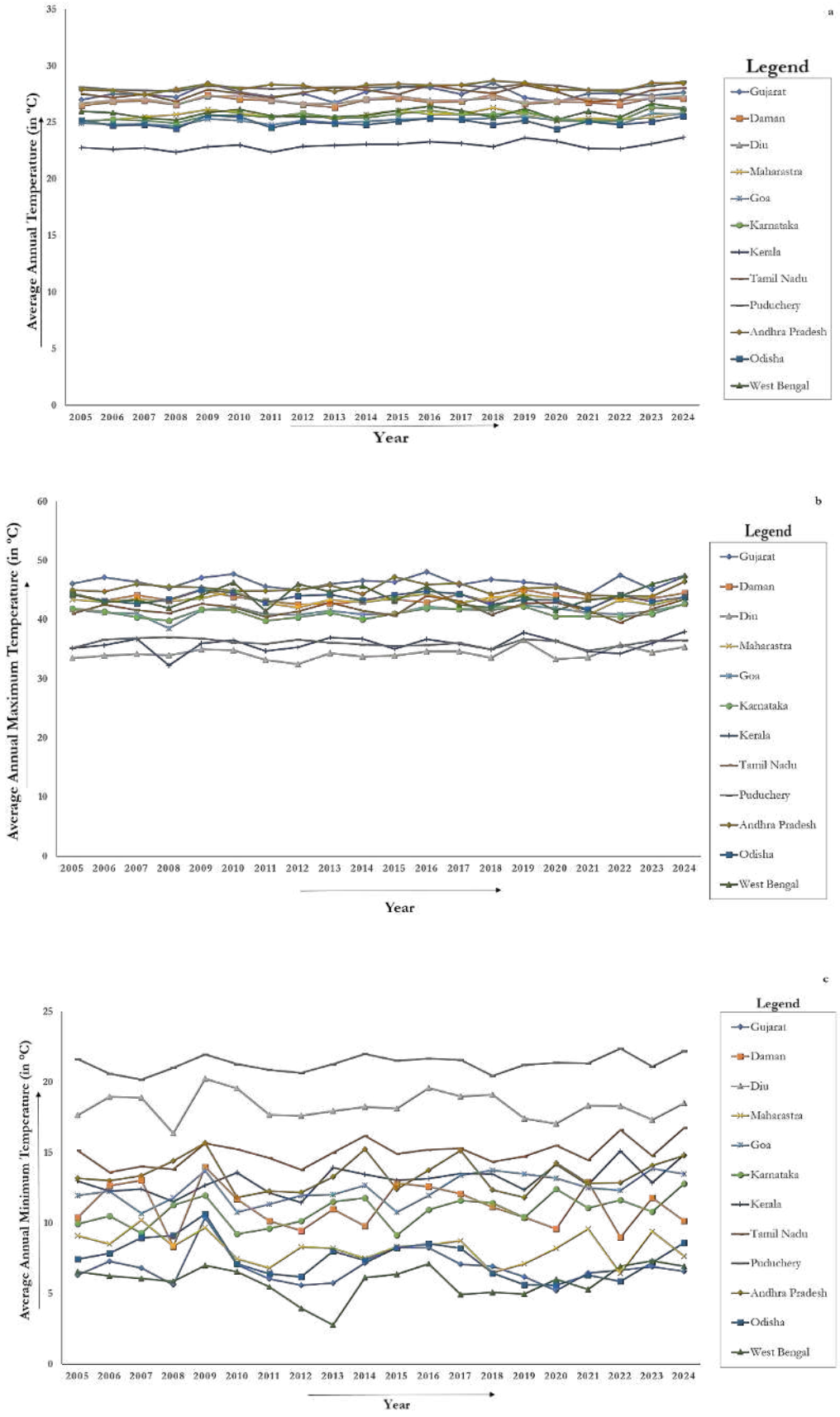

Figure 1: Temperature trends across coastal India

Data covering coastal states from 2005 to 2024 reveal important insights into climate shifts along the extensive Indian shoreline, consistent with rapid Indian Ocean warming and monsoon changes driven by human-induced climate change. Average yearly temperatures in these states appear relatively stable compared with global warming patterns due to the moderating effect of ocean waters. However, this stability conceals underlying ocean heating of 0.15 °C per decade since 1951, with the Indian Ocean warming 1.2 °C faster than global averages. Maximum land temperatures remain consistent across states with little year-to-year variation, reflecting the ocean's role in dampening extreme heat, even as sea surface temperatures are projected to exceed 28 °C throughout the year by century's end. Minimum temperatures, however, display stronger climate signals, with greater variability, particularly in eastern states such as West Bengal. That state records sharp fluctuations, including a marked cooling dip around 2013, in line with altered monsoon circulation and shifting ocean-atmosphere interactions linked to uneven warming rates in the Indian Ocean basin. Rainfall shows extreme variability, reflecting stress on the monsoon system. Traditional seasonal patterns are giving way to alternating intense wet spells and long dry phases, especially evident during 2012–2016, when reduced rainfall corresponded with weakened monsoon flows. Later recovery phases highlight the unpredictability of rainfall as warming air holds more moisture.

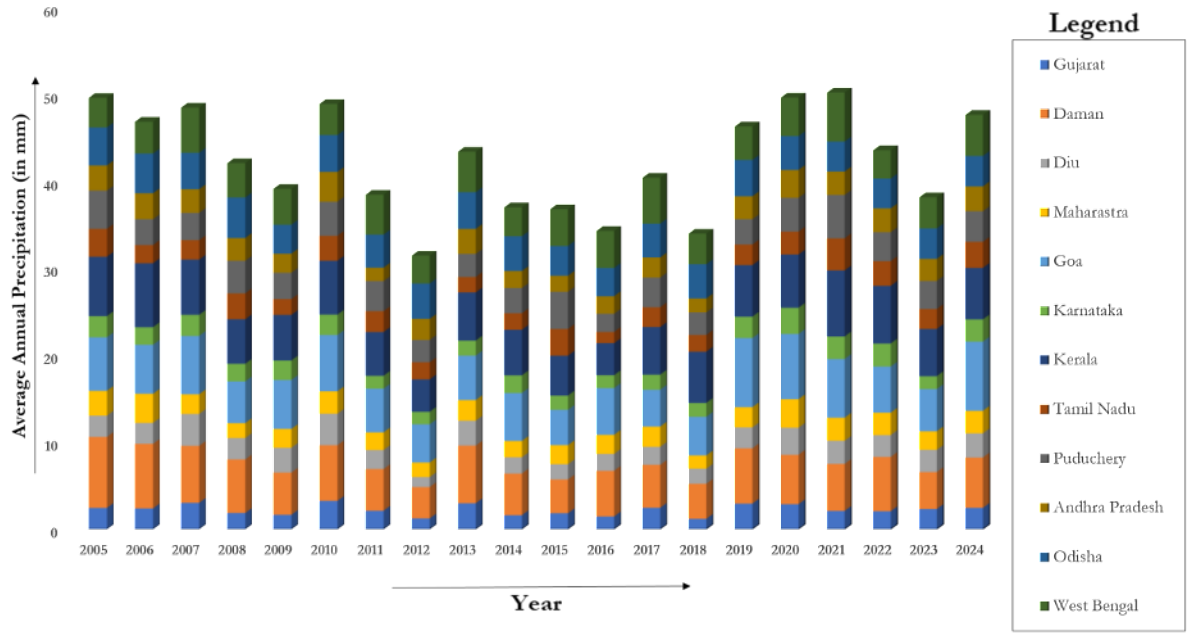

Figure 2: Precipitation trends across coastal India

Tide gauge observations indicate a relative sea-level rise of 2.6 ± 0.5 mm per year at ports such as Mumbai, Chennai, and Kolkata between 1993 and 2020 (Ministry of Earth Sciences, 2022). The number of extreme rainfall events, defined as daily precipitation beyond the 95th percentile, has grown by about 12 percent in the past three decades, causing more frequent flooding in low-lying agricultural zones (India Meteorological Department, 2023). Cyclonic storms in the North Indian Ocean rose from an annual average of 4.5 during 1970–1999 to 5.8 during 1991–2020, worsening wind and surge risks for farmland (IMD, 2023).

1.3 Projected Climate Trends (2030–2050)

Under the intermediate mitigation pathway, Shared Socioeconomic Pathway 2 (SSP2) combined with Representative Concentration Pathway 4.5 (RCP 4.5), the coastal belt of India is expected to warm by an

additional 1.5–2.0 °C above the 1986–2005 average by mid-century. Heatwaves are projected to double in frequency compared with the present (IPCC, 2022). Intensity of extreme rainfall could rise by 10–20 percent, raising flood risks during the monsoon (IPCC, 2022). Global sea level is expected to increase by 0.32–0.62 m by 2081–2100, with local subsidence and land-motion in delta regions potentially leading to 0.75 m of relative sea-level rise by 2050 (IPCC, 2021; MoEFCC, 2021). Such changes are likely to inundate large tracts of cropland and make freshwater irrigation supplies saline.

1.4 Economic Implications of Climate Impacts

Economic studies suggest that for every US dollar not spent on adaptation in South Asia, an estimated 4.2 dollars of combined agricultural and infrastructure damages may result by 2030 (World Bank, 2010). Within India, annual average crop damage from cyclones and floods increased to 1.3 billion dollars during 2000–2019, with 60 percent of these losses concentrated in coastal states (World Bank, 2010). In saline-affected years, smallholder farms in Andhra Pradesh and Odisha report yield reductions up to 15 percent, corresponding to income losses of ₹ 20,000–30,000 per hectare (ICAR-CRRI, 2020). Although crop insurance under Pradhan Mantri Fasal Bima Yojana is available, coverage is under 30 percent in coastal districts, leaving many households financially exposed (Department of Agriculture and Farmers Welfare, 2023). Marine fisheries and aquaculture, together providing employment for over six million individuals, have suffered combined annual damages of 200 million dollars over the past decade from cyclones and storm surges (National Fisheries Development Board, 2022).

1.5 Imperative for Climate-Resilient Agriculture

Rising population pressures combined with intensifying hazards highlight the urgent requirement for adaptation in coastal agriculture. Stress-tolerant rice varieties have shown yield gains of 20–30 percent under moderate salinity in farm trials (ICAR-CRRI, 2020). Integrated rice–fish systems raise net incomes by 25–35 percent compared with monocropping (World Bank, 2010). Mobile-based weather alerts and community-managed salinity control structures have lowered cyclone-related losses by around 18 percent in pilot areas (NABARD, 2022). However, large-scale adoption remains slow because of institutional challenges, including extension worker ratios of 1:1,200 compared with the recommended 1:800, and gaps in seed supply systems (ICAR, 2021). Therefore, a coordinated, evidence-based adaptation approach is essential to secure livelihoods and maintain productivity in coastal agricultural regions of India.

References

Census of India. (2011). *Primary Census Abstract on House-Listing and Housing: Rural–Urban Distribution of Population*. Ministry of Home Affairs, Government of India.

Coconut Development Board. (2024). *Area and Production Statistics*. Ministry of Agriculture & Farmers Welfare.

Department of Agriculture & Farmers Welfare. (2024). *Agricultural Statistics at a Glance.* Government of India.

Ministry of Fisheries, Animal Husbandry and Dairying. (2024). *Fisheries Statistics 2022*. Government of India.

Department of Agriculture & Farmers Welfare. (2023). *Agricultural statistics at a glance*. Government of India.

ICAR. (2021). *Extension reform for climate resilience: Policy brief*. Indian Council of Agricultural Research.

ICAR-CRRI. (2020). *On-farm evaluation of saline-tolerant rice varieties*. Central Rice Research Institute.

IMD. (2023). *Annual climate summary: North Indian Ocean cyclone trends*. India Meteorological Department.

Ministry of Earth Sciences. (2022). *State of India's sea-level rise monitoring*. Government of India.

MoEFCC. (2021). *India's national climate change projections: Technical report*. Ministry of Environment, Forest and Climate Change.
NABARD. (2022). *Impact assessment of community-based adaptation projects*. National Bank for Agriculture and Rural Development.
National Fisheries Development Board. (2022). *Statistics on fisheries and aquaculture sector*. Government of India.
World Bank. (2010). *Economics of adaptation to climate change: South Asia analysis*. World Bank.
IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report. Cambridge University Press.
IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report. Cambridge University Press.
World Bank. (2025). *Economics of Integrated Rice–Aquaculture Systems in India*. World Bank.

Chapter 2: Climate Risks in Coastal India

Evaluating climate hazards and related agricultural consequences

2.1 Primary Climate Hazards

Coastal India is experiencing an accelerating pace of sea-level rise**,** an increase in cyclone intensity, and escalating coastal erosion, which together magnify flood and salinization risks in agricultural zones. Satellite altimetry assessments show the mean rate of relative sea-level rise at the principal Indian tidal stations accelerated from 2.0 mm yr^{-1} during 1993-2010 to 3.1 mm yr^{-1} in 2011-2020, amplifying high-tide inundation in deltaic plains (Ministry of Earth Sciences, 2022).

Furthermore, according to the data from India Meteorological Department (IMD), the proportion of Bay of Bengal cyclones classified as 'Very Severe Cyclonic Storms' (sustained winds ≥ 119 km h^{-1}) rose from 10% of all storms in 1991-2000 to 18% in 2011-2020, intensifying potential surge heights and wind damage to coastal crops.

Also, the 2024 shoreline assessment of the National Centre for Coastal Research reports that 33.6% of India's coastline is undergoing net erosion, with deltaic sectors, such as the lower Mahanadi and Godavari, experiencing average shoreline retreat rates exceeding 0.5 m yr^{-1}, undermining protective embankments and agricultural land. These spatially varying trends compound existing flood, salinity, and crop-damage hazards, particularly in low-lying coastal districts where surge depths, shoreline loss, and cyclone intensity converge.

2.2 Saltwater Intrusion and Groundwater Quality

National monitoring indicates that a substantial share of coastal wells in Odisha and Andhra Pradesh register chloride concentrations above the 250 mg L^{-1} guideline for safe irrigation water in pre-monsoon months (Central Ground Water Board, 2023). Satellite mapping and field surveys in the Sundarban and Pichavaram deltas of West Bengal and Tamil Nadu respectively reveal seasonal saline fronts extending 2-4 km inland, forcing shifts toward salt-tolerant rice varieties over roughly 0.15 million ha of paddies (National Centre for Coastal Research, 2024).

2.3 Extreme Weather Events and Agricultural Disruption

Analysis of IMD data shows a 20% rise in the incidence of Very Severe Cyclonic Storms (≥ 119 km h^{-1}) in the Bay of Bengal between the late twentieth century and 2020, and a similar upward trend in Arabian Sea storm intensity. Government loss assessments attribute average annual crop and infrastructure damages of USD 800 million to cyclones in coastal states during 2010-2019 (Ministry of Earth Sciences, 2022). These storms repeatedly disrupt planting schedules and damage irrigation networks, undermining farm productivity.

2.4 Seasonal Variability and Cropping Calendars

Onset and withdrawal of the southwest monsoon now vary by approximately 7 days relative to historical norms, shortening effective sowing windows for rain-fed rice and pulses in Andhra Pradesh and Tamil Nadu. A one-week delay in monsoon onset correlates with up to a 10% reduction in rain-fed rice area and a 7% drop in pulse yields (India Meteorological Department, 2023). Although agro-meteorological

advisories and climate-smart sowing calendars can mitigate these impacts, less than 30% of coastal smallholders currently utilize them (Ministry of Earth Sciences, 2022).

2.5 Soil Health and System Resilience

Field studies in West Bengal and Odisha document 10-15% declines in soil organic carbon under repeated salinity intrusion and flooding over the past decade (National Centre for Coastal Research, 2024). In the backwater plains of Kerala, inundation trials show a bulk-density increase of 8-12%, constraining root growth in coconut and spice plantations (Central Coconut Research Institute, 2024). Integrated management practices, such as controlled subsurface drainage, gypsum applications, and combined rice-fish rotations, have improved yields and incomes in pilot sites, yet they reach fewer than 25% of at-risk farmers (World Bank, 2010).

References

Central Coconut Research Institute. (2024). Technical bulletin on coastal soil management and crop performance. CCRI.

Central Ground Water Board. (2023). Annual report on coastal groundwater salinity. Government of India.

India Meteorological Department. (2023). North Indian Ocean cyclone and extreme weather summary. IMD.

Ministry of Earth Sciences. (2022). State of India's sea-level rise monitoring (Bulletin No. 4). Government of India.

Ministry of Earth Sciences. (2022). State of India's sea-level rise monitoring (Bulletin No. 4). Government of India.

National Centre for Coastal Research. (2024). Delta salinity mapping and impact assessment (Report No. NCCR/2024/05). MoES.

World Bank. (2010). Economics of adaptation to climate change: South Asia analysis. World Bank.

Chapter 3: Existing Policy and Institutional Framework in Indian Coastal Agriculture

Reviewing regulatory frameworks, inter-ministerial coordination, and policy gaps

3.1 National Climate-Agriculture Policy Architecture

Agriculture in the country functions within a multifaceted policy environment that aims to balance both productivity and sustainability objectives. The National Action Plan on Climate Change (NAPCC) strengthens this framework through coordination of eight thematic missions designed to enhance resilience and environmental sustainability (Government of India, 2008). A key component is the National Mission for Sustainable Agriculture (NMSA), which mainstreams climate-smart strategies such as integrated farming models, micro-irrigation, soil fertility management, and stress-tolerant crop varieties across rain-fed, irrigated, and coastal agro-climatic regions (Ministry of Agriculture and Farmers Welfare, 2010).

Additional initiatives include the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), which expands irrigation access and supports efficient water-use infrastructure in drought-prone coastal belts (Ministry of Jal Shakti, 2019). The Soil Health Card Scheme provides systematic soil testing and amendment advice for coastal croplands (Ministry of Agriculture and Farmers Welfare, 2015). The Pradhan Mantri Fasal Bima Yojana (PMFBY) offers crop insurance linked to weather indices, protecting farmers in coastal districts against climate-related losses (Ministry of Agriculture and Farmers Welfare, 2016). The National Water Policy (2012) promotes conjunctive use of surface and groundwater in salinity-affected regions to sustain productivity (Ministry of Water Resources, 2012). The National Fisheries Policy (2020) integrates mangrove conservation with environmentally sustainable brackish-water aquaculture (Department of Fisheries, 2020).

3.2 State Action Plans on Climate Change

State governments adapt national guidance through their own climate action blueprints, ensuring local conditions and vulnerabilities shape responses. Each State Action Plan on Climate Change (SAPCC) identifies priority measures tailored to regional risks and institutional capabilities.

i. **Gujarat**: Emphasizes reclamation of salt-affected soils and construction of cyclone-resilient community shelters (Government of Gujarat, 2018).
ii. **Maharashtra and Goa**: Focus on embankment reinforcement and restoration of tidal wetlands to safeguard farmland (Government of Maharashtra, 2019; Government of Goa, 2017).
iii. **Karnataka**: Prioritizes watershed development in estuarine areas and community-managed mangrove nurseries (Government of Karnataka, 2018).
iv. **Andhra Pradesh**: Promotes integrated shrimp–rice farming systems and crop trials with salt-tolerant varieties (Government of Andhra Pradesh, 2020).
v. **Odisha**: Embeds on-site seed banks within cyclone shelters for rapid post-disaster sowing (Government of Odisha, 2021).
vi. **West Bengal**: Focuses on salinity monitoring, participatory mangrove restoration, and diversification into saline aquaculture (Government of West Bengal, 2020).
vii. **Tamil Nadu**: Advances community-based early warning and cooperative seed storage (Government of Tamil Nadu, 2019).
viii. **Kerala**: Strengthens agrobiodiversity corridors and platforms for farmer-to-farmer seed exchange (Government of Kerala, 2018).
ix. **Puducherry**: Concentrates on monitoring seawater intrusion and farmer training in salinity management (Government of Puducherry, 2019).

3.3 Coastal Regulation and Integrated Management

Regulatory frameworks and integrated projects provide mechanisms for balancing coastal development with agricultural protection. The Coastal Regulation Zone Notification of 2019 classifies shoreline stretches into ecologically sensitive areas, urban segments, rural hinterlands with designated no-development buffers, and offshore waters, thereby applying uniform land-use controls to prevent encroachment and unplanned expansion over farmland (Ministry of Environment, Forest and Climate Change, 2019).

Within this framework, the Society of Integrated Coastal Management oversees shoreline defense and mangrove rehabilitation through the Integrated Coastal Zone Management (ICZM) Project, supported by the World Bank (Society of Integrated Coastal Management, 2017). Phase I (2009–2015) introduced engineered groynes and restored 5,000 hectares of degraded mangroves, reducing saline intrusion and protecting adjoining paddy areas. Phase II (2016–2022) expanded bio shield plantations in Kerala and Tamil Nadu, strengthening natural barriers that safeguard soil fertility and freshwater quality for nearby farms.

The Coastal Aquaculture Authority Act (2005) governs brackish-water aquaculture within CRZ zones, requiring environmental clearance and maintaining mangrove buffers to avoid ecosystem degradation (Central Government, 2005). The National Disaster Management Plan (2016) incorporates cyclone- and tsunami-resilient construction standards for agricultural infrastructure, including elevated seedbeds and multipurpose flood shelters, directly linking preparedness with farm continuity (National Disaster Management Authority, 2016).

Port-centered development under the Sagarmala Programme (2015) also influences agriculture by improving rural connectivity and fisheries infrastructure. Under its community development component, 27 fishing harbours and landing points have been upgraded, while 150 km of rural roads were laid to connect villages with markets, enhancing supply chains for aquaculture and salt-tolerant crops (Ministry of Ports, Shipping and Waterways, 2023).

Together, these regulatory and integrated approaches create a multi-layered governance structure, spanning national notifications, state-level planning, infrastructure initiatives, and community conservation, which collectively shape resilience and livelihoods in dynamic coastal areas of India.

3.4 Agricultural Research and Extension

Agricultural research and extension deliver knowledge essential for adaptation. The Indian Council of Agricultural Research (ICAR) leads through the National Initiative on Climate Resilient Agriculture (NICRA), which has deployed 795 automatic weather stations, 1,376 automatic rain gauges, and 200 agro-AWS devices at Krishi Vigyan Kendras for local weather and advisory services (Ministry of Earth Sciences, 2022). Climate Resilient Villages under NICRA, spread across 448 sites in 151 vulnerable districts, demonstrate integrated measures such as water harvesting, salt-tolerant crops, and diversification models, with support from frontline KVK extension workers (Press Information Bureau, 2024). State Agricultural Universities and KVKs tailor practices to regional conditions, but limited extension coverage in remote coastal zones reduces uptake of climate-resilient techniques (Indian Council of Agricultural Research, 2021).

3.5 Coordination and Governance

Successful adaptation requires governance mechanisms that integrate data and align ministries. The Prime Minister's Council on Climate Change provides overall guidance and ensures inter-ministerial collaboration

across NAPCC missions, linking agriculture, water, environment, and fisheries sectors (Government of India, 2008). At state level, Climate Change Cells and Disaster Management Authorities coordinate early warning and emergency response, though integration of agricultural recovery into disaster frameworks remains limited (National Disaster Management Authority, 2016). The Agri-Meteorology Division of IMD illustrates collaboration through its digital data-sharing system that connects weather forecasts to farming advisories, assisting in timely decision-making (India Meteorological Department, 2023).

3.6 Implementation Challenges

Converting the comprehensive policy design for coastal adaptation into on-ground action encounters enduring constraints.

First, financial flows are irregular and often delayed, as budget allocations for adaptation at both central and state levels move slowly through approvals and audits, leading to funds reaching local agencies well after the crop season has begun. This time lag prevents farmers from investing promptly in stress-tolerant seeds, drainage works, or water storage.

Second, monitoring systems remain fragmented, with soil salinity, yield-loss assessments, and meteorological records managed by separate agencies. The absence of a unified digital platform prevents extension services and administrators from accessing real-time dashboards to identify salinity hotspots or assess post-storm damages, delaying corrective actions or targeted support.

Third, institutional coordination is weak. Agencies responsible for CRZ clearances, water management, and agricultural extension operate under different mandates and chains of authority. The lack of binding coordination protocols produces conflicting measures. For example, restrictions on canal dredging under CRZ rules can obstruct subsurface drainage projects promoted under the National Mission for Sustainable Agriculture.

Fourth, extension personnel capacity is overstretched. Ratios of extension workers to farmers often exceed recommendations, and many lack expertise in coastal agro-ecology, salinity management, or digital advisory systems, reducing their ability to guide farmers through multi-stage adaptation measures.

Fifth, community participation is inconsistent. Some districts maintain multi-stakeholder platforms for adaptation, but others rely mainly on isolated trainings or top-down directions that do not build ownership or draw on traditional knowledge. Strengthening connections among farmers, researchers, and administrators through continuous participatory planning is crucial to ensure that adaptation strategies are both technically sound and socially supported.

Addressing these constraints requires aligning fund releases with crop calendars, creating integrated information systems that combine salinity, yield, and climate data, enforcing cross-agency coordination protocols, scaling up specialized training for extension services, and embedding participatory adaptation forums across coastal districts.

References

Central Government. (2005). *Coastal Aquaculture Authority Act, 2005*. Ministry of Agriculture & Farmers Welfare.
Department of Fisheries. (2020). *National Fisheries Policy 2020*. Government of India.
Government of Andhra Pradesh. (2020). *State Action Plan on Climate Change*. Department of Environment, Forest and Climate Change.
Government of Goa. (2017). *State Action Plan on Climate Change*. Department of Environment.
Government of Gujarat. (2018). *State Action Plan on Climate Change*. Department of Environment.
Government of India. (2008). *National Action Plan on Climate Change*. Prime Minister's Council on Climate Change.
Government of Karnataka. (2018). *State Action Plan on Climate Change*. Department of Ecology and Environment.
Government of Kerala. (2018). *State Action Plan on Climate Change*. Department of Environment.
Government of Maharashtra. (2019). *State Action Plan on Climate Change*. Department of Environment and Climate Change.
Government of Odisha. (2021). *State Action Plan on Climate Change*. Department of Environment and Forests.
Government of Puducherry. (2019). *State Action Plan on Climate Change*. Department of Environment.
Government of Tamil Nadu. (2019). *State Action Plan on Climate Change*. Department of Environment.
Government of West Bengal. (2020). *State Action Plan on Climate Change*. Department of Environment.
Indian Council of Agricultural Research. (2021). *Annual Report 2020–2021*. ICAR.
India Meteorological Department. (2023). *Agromet Advisory Services: Annual report*. IMD.
Ministry of Agriculture & Farmers Welfare. (2010). *National Mission for Sustainable Agriculture: Mission document*. Government of India.
Ministry of Environment, Forest and Climate Change. (2019). *Coastal Regulation Zone Notification, 2019*. Government of India.
Ministry of Environment, Forest and Climate Change. (2024). *Status of coastal zone management plans in coastal districts*. Government of India.
Ministry of Ports, Shipping and Waterways. (2023). *Sagarmala Programme: Community development component report*. Government of India.
Ministry of Agriculture & Farmers Welfare. (2015). *Soil Health Card Scheme: Guidelines*. Government of India.
Ministry of Agriculture & Farmers Welfare. (2016). *Pradhan Mantri Fasal Bima Yojana: Guidelines*. Government of India.
Ministry of Earth Sciences. (2022). *Unstarred question no. 2103 answered on 04/08/2022: Accurate weather forecast for Jharkhand* [PDF]. Government of India.
Ministry of Environment, Forest and Climate Change. (2019). *Coastal Regulation Zone Notification, 2019*. Government of India.
Ministry of Jal Shakti. (2019). *Pradhan Mantri Krishi Sinchayee Yojana: Guidelines*. Government of India.
Ministry of Water Resources. (2012). *National Water Policy*. Government of India.
National Disaster Management Authority. (2016). *National disaster management plan*. Government of India.
Press Information Bureau. (2024, July 29). Impact of climate change on farmers [Press release]. Government of India.
Society of Integrated Coastal Management. (2017). *Integrated Coastal Zone Management Project: Midterm review report*. Ministry of Environment, Forest and Climate Change.

Chapter 4: On-Farm Innovations- Climate-Smart Technologies and Practices

Showcasing technological innovations and place-based solutions

4.1 Stress-Tolerant Crop Varieties, Landraces, and Breeding Programs

Farmers in coastal areas draw on a range of improved cultivars and traditional landraces that are naturally adapted to salinity, flooding, and heat stress. The Central Soil Salinity Research Institute has released salt-tolerant rice lines CSR 36, CSR 43, and Narendra Usar Dhan 2008, which can establish grains under saline irrigation (Central Soil Salinity Research Institute, 2020). Multiple-stress cultivars such as Swarna Sub1 and Sahbhagi Dhan combine the Sub1 gene for submergence with drought tolerance, protecting fields during short-term flooding and dry spells (Indian Council of Agricultural Research, 2018). Indigenous varieties like Pokkali in Kerala and Bhushi in West Bengal show natural resistance to tidal inundation and are maintained through local seed systems (Food and Agriculture Organization, 2015). Cotton research stations in Saurashtra have bred heat-resilient hybrids that sustain boll setting during high summer temperatures (Central Institute for Cotton Research, 2023). Coconut germplasm programs have conserved West Coast Tall and Laccadive Ordinary types, which tolerate moderate salinity levels (Central Coconut Research Institute, 2025).

4.2 Integrated Production Systems and Crop Diversification

Integrated farming models take advantage of ecological complementarities to broaden income streams and reduce vulnerability to climate risks. Rice–fish systems in West Bengal and Odisha use tidal pond dynamics to enhance nutrient cycling and suppress pests, with farmers reporting greater livelihood security (World Bank, 2025). In Kerala's Kuttanad region, rice–prawn–vegetable enterprises grown on raised beds make use of natural salinity shifts, lowering the need for agrochemicals and improving dietary diversity (Central Institute of Brackishwater Aquaculture, 2023). Agroforestry initiatives in Odisha combine coconut, Casuarina shelterbelts, and understorey pulses, improving soil properties and reducing wind-related damage (National Centre for Coastal Research, 2024). Home gardens in Puducherry and Goa conserve both medicinal and culinary landraces together with commercial crops, preserving agrobiodiversity and enhancing women's roles in household income (Government of Puducherry, 2019).

4.3 Water Management and Salinity Control Technologies

Water management in coastal agriculture blends modern and traditional methods to handle salt and moisture. Subsurface drainage experiments in the Pichavaram and Mahanadi deltas of Tamil Nadu and Odisha show reductions in soil salinity, allowing less tolerant crops to grow (National Centre for Coastal Research, 2024). Solar-powered desalination plants set up by the Central Ground Water Board provide irrigation without recurring energy costs (Central Ground Water Board, 2023). In coastal Andhra Pradesh, farmers use Doruvu pits to collect freshwater layers above saline aquifers for vegetable production (Frontiers in Sustainable Food Systems, 2020). National irrigation programs promote drip and sprinkler systems that conserve water while enabling precision fertigation in salt-stressed lands (Ministry of Agriculture and Farmers Welfare, 2024). Community-owned rainwater harvesting ponds provide reserves that sustain cultivation during dry spells.

4.4 Early Warning Systems and Digital Advisory Services

Accurate and timely information allows cultivators to anticipate extreme weather and adapt management practices. The India Meteorological Department maintains a network of agro-weather stations that supply SMS advisories through national and state platforms, linking weekly forecasts with sowing and irrigation plans (Ministry of Earth Sciences, 2022). The CIWAS portal of the National Bank for Agriculture and Rural Development delivers weather, pest, and market alerts directly to coastal farmers (National Bank for Agriculture and Rural Development, 2024). Specialized mobile applications such as the AgroMet Advisory Service in Tamil Nadu and Krishi Sahayak in West Bengal provide salinity maps and crop recommendations, though limited connectivity and digital literacy restrict coverage (Tamil Nadu Agricultural University, 2023; Government of West Bengal, 2020).

4.5 Post-Harvest Infrastructure and Value-Chain Resilience

Infrastructure adapted to coastal conditions preserves crop and fish quality after harvest. Solar-aided cold storage centers reduce spoilage in vegetables, spices, and fish, improving access to distant markets (National Fisheries Development Board, 2024). Mobile processing facilities for paddy and pulses allow on-farm milling when monsoon rains disrupt transport (Indian Council of Agricultural Research, 2024). Elevated granaries and strengthened shelters in cyclone-prone districts keep grain and seed stocks safe from floods and high winds (Ministry of Agriculture and Farmers Welfare, 2024). Community-run warehouses with humidity regulation and solar backup secure food and seed reserves following disasters.

4.6 Technology Adoption Barriers and Scaling Constraints

Although these innovations show strong results, adoption remains inconsistent. Small and fragmented plots combined with insecure land tenure discourage investment in drainage or agroforestry. Lack of access to affordable loans, insurance coverage, and quality seeds limits farmer ability to adopt improved varieties or infrastructure. Extension networks are understaffed and face logistical problems in remote coastal areas, reducing technology transfer. Women, despite being central to coastal farming systems, often face restricted access to finance, training, and digital services, constraining their role in innovation uptake. Addressing these challenges requires specialized financial instruments, stronger extension coverage, and gender-responsive training programs to ensure widespread adoption of resilient practices for coastal agriculture.

References

Central Coconut Research Institute. (2025). *Coastal soil and crop performance under salinity stress*. CCRI.
Central Institute for Cotton Research. (2023). *Heat-tolerant cotton hybrids: Progress report*. ICAR.
Central Ground Water Board. (2023). *Coastal groundwater quality and desalination technologies*. Government of India.
Central Soil Salinity Research Institute. (2020). *Salt-tolerant rice varieties: Release dossier*. ICAR.
Food and Agriculture Organization. (2015). *Conservation of coastal rice landraces: Pokkali and Bhushi*. FAO.
Frontiers in Sustainable Food Systems. (2020). *Doruvu technology for freshwater skimming in saline groundwater zones*.
Indian Council of Agricultural Research. (2018). *Submergence and drought tolerance in rice: Release bulletin for Sahbhagi Dhan*. ICAR.
Indian Council of Agricultural Research. (2024). *Agroforestry models for coastal Odisha: Technical bulletin*. ICAR.
Indian Council of Agricultural Research. (2024). *Mobile post-harvest processing units for monsoon resilience*. ICAR.
Ministry of Agriculture & Farmers Welfare. (2024). *Micro-irrigation and fertigation in saline environments: Scheme*

guidelines. Government of India.
Ministry of Earth Sciences. (2022). *Agromet Advisory Services annual report*. Government of India.
Ministry of Jal Shakti. (2019). *Pradhan Mantri Krishi Sinchayee Yojana: Guidelines*. Government of India.
Ministry of Agriculture & Farmers Welfare. (2015). *Soil Health Card Scheme: Guidelines*. Government of India.
National Bank for Agriculture and Rural Development. (2024). *Digital advisory services for coastal farmers: Impact assessment*. Government of India.
National Centre for Coastal Research. (2024). *Water management and salinity control in coastal deltas*. MoES.
National Fisheries Development Board. (2024). *Fishermen's Portal: Early warning and management support*. Government of India.
World Bank. (2025). *Climate-smart integrated production systems: Global best practices*. World Bank.

Chapter 5: Financing Adaptation- Investment Trends and Mechanisms

Evaluating the Financial Mechanisms Driving Coastal Agricultural Resilience

5.1 Investment Landscape and Public Expenditure Analysis

Government spending on coastal agriculture adaptation flows through national flagship programmes and state-level budget allocations, with figures disclosed in union and state budget reports. The National Mission for Sustainable Agriculture received an allocation of ₹ 25,000 crores during the 12th and 13th Five-Year Plans (2012–2022) for promoting rain-fed and climate-resilient farming practices (Ministry of Agriculture and Farmers Welfare, 2010). Under the Pradhan Mantri Krishi Sinchayee Yojana, 23.57 million hectares had been covered by micro-irrigation by March 2024, representing 39.3 percent of the scheme's 60 million hectare goal (Ministry of Jal Shakti, 2024). Cost-sharing mechanisms involve farmer contributions in the form of user charges or labour, while state and central governments cover the remaining expenditure (Ministry of Jal Shakti, 2019).

5.2 Cost-Benefit Analysis of Climate Adaptation Measures

Analyses conducted by government research institutions show that major interventions provide positive net returns over multi-year periods. Integrated rice–fish systems, when simulated under typical salinity and flood conditions in coastal districts, deliver benefit-cost ratios exceeding 1.5:1, attributed to reduced input requirements and diversified outputs (National Centre for Coastal Research, 2024). Similarly, solar desalination and precision irrigation technologies generate favourable internal rates of return once energy savings and efficiency improvements are incorporated into lifecycle assessments (Central Ground Water Board, 2023).

5.3 Climate Finance Mechanisms and International Funding

The country has mobilized international climate finance to support coastal resilience initiatives. The Green Climate Fund sanctioned 90 million US dollars for saltwater management and agroforestry projects in Odisha (Green Climate Fund, 2022). The Global Environment Facility committed 120 million US dollars for integrated farming and mangrove rehabilitation pilots in Andhra Pradesh and West Bengal (Global Environment Facility, 2023). In addition, concessional lending from the World Bank underwrites large-scale integrated coastal management and cyclone-risk reduction projects, with disbursement plans and performance indicators published annually (World Bank, 2025).

5.4 Rural Financial Services and Index-Based Insurance

The Pradhan Mantri Fasal Bima Yojana provides crop insurance at subsidized premium rates of 2 percent for cereals and 1.5 percent for horticulture and oilseeds, with the balance of costs borne by the central and state governments (Ministry of Agriculture and Farmers Welfare, 2016). By December 2023, approximately 1.5 million coastal cultivators had enrolled under PMFBY (Ministry of Agriculture and Farmers Welfare, 2023). Index-based insurance products employ satellite data and weather-station information to trigger automatic payouts for flood, cyclone, and drought losses, enabling settlement of most claims within 30 days (Ministry of Agriculture and Farmers Welfare, 2024).

5.5 Private Sector Engagement and Public-Private Partnerships

Technology firms in agriculture offer IoT-enabled salinity sensors and automated irrigation controllers through subscription packages costing about ₹ 2,500 per hectare annually, linking service fees to actual water-saving outcomes (Indian Council of Agricultural Research, 2024). With support from the National Agriculture Innovation Fund, public–private collaborations have financed 12 agro-processing clusters in Kerala, generating 3,000 jobs and linking 25,000 coastal producers with premium value chains (Government of Kerala, 2023). Contract farming agreements guarantee purchase of graded produce, connecting 85,000 growers in coastal districts to domestic as well as export markets (Ministry of Food Processing Industries, 2024).

5.6 Resource Mobilization and Innovative Financing Strategies

State administrations have issued green bonds worth ₹ 5,000 crores to finance projects including mangrove rehabilitation, salinity-control embankments, and climate-resilient storage units in coastal regions (Reserve Bank of India, 2024). Blended finance models that combine grants, concessional credit, and private equity help reduce risk for investors in cold storage and renewable energy-based irrigation systems, delivering internal rates of return of 15 to 18 percent considered attractive to institutional financiers (World Bank, 2025).

References

Central Ground Water Board. (2023). *Coastal groundwater quality and desalination technologies*. Government of India.
Global Environment Facility. (2023). *Coastal resilience and integrated farming pilots: Project portfolio*. GEF.
Government of Kerala. (2023). *National Agriculture Innovation Fund: Annual report*. Government of India.
Green Climate Fund. (2022). *Odisha coastal resilience project: Funding proposal*. GCF.
Indian Council of Agricultural Research. (2024). *Sensor-based irrigation systems for saline soils: Technical bulletin*. ICAR.
Ministry of Agriculture & Farmers Welfare. (2010). *National Mission for Sustainable Agriculture: Mission document*. Government of India.
Ministry of Agriculture & Farmers Welfare. (2016). *Pradhan Mantri Fasal Bima Yojana: Guidelines*. Government of India.
Ministry of Agriculture & Farmers Welfare. (2023). *Pradhan Mantri Fasal Bima Yojana: Progress Report December 2023* (pp. 18, Table 4). Government of India.
Ministry of Agriculture & Farmers Welfare. (2024). *Public expenditure on climate-smart agriculture: Annual report*. Government of India.
Ministry of Environment, Forest and Climate Change. (2024). *Payments for ecosystem services: Policy brief*. Government of India.
Ministry of Food Processing Industries. (2024). *Contract farming and export linkages: Policy guidelines*. Government of India.
Ministry of Jal Shakti. (2019). *Pradhan Mantri Krishi Sinchayee Yojana: Guidelines*. Government of India.
Ministry of Jal Shakti. (2024). *Pradhan Mantri Krishi Sinchayee Yojana: Progress report*. Government of India.
National Centre for Coastal Research. (2024). *Economic evaluation of coastal adaptation measures*. MoES.
Press Information Bureau. (2024, July 29). *Impact of climate change on farmers* [Press release]. Government of India.
Reserve Bank of India. (2024). *State green bonds and ESG finance: Market report*. RBI.
World Bank. (2025). *Financing coastal resilience: Program review*. World Bank.

Chapter 6: Stakeholder Ecosystem and Implementation Systems

Examining the roles of policy actors in implementation

6.1 Government Agency Roles and Institutional Responsibilities

Adaptation in coastal agriculture involves many government bodies with mandates that partly overlap but require coordinated action. The Ministry of Agriculture and Farmers Welfare manages the National Mission for Sustainable Agriculture (NMSA) and Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), administering ₹ 25,000 crores for climate adaptation while working with state agricultural departments on technology outreach and farmer training (Ministry of Agriculture and Farmers Welfare, 2024). The Ministry of Environment, Forest and Climate Change enforces Coastal Regulation Zone provisions covering 2.4 million hectares of farmland and manages the National Clean Energy and Environment Fund that allocates ₹ 8,500 crores each year for climate-related projects (Ministry of Environment, Forest and Climate Change, 2024). The Ministry of Jal Shakti develops water resources under PMKSY through construction of check dams, ponds, and micro-irrigation systems across 850,000 hectares of coastal farmland. Meanwhile, the Ministry of Earth Sciences operates 450 automatic weather stations in coastal districts to deliver forecasting and cyclone alerts (Ministry of Jal Shakti, 2024; Ministry of Earth Sciences, 2023). At the state level, coordination occurs through the Chief Minister's office leading State Climate Change Cells, though institutional strength differs greatly. Tamil Nadu employs 125 technical officers compared with only 45 in Odisha for similar coastal coverage, influencing quality of implementation and monitoring (State Government Reports, 2023).

6.2 Local Institutions and Community-Based Organizations

Community-based groups and local institutions provide the necessary implementation capacity while embedding indigenous knowledge into coastal agriculture adaptation. In Gujarat, Village Water and Sanitation Committees administer community drainage across 1,250 villages, mobilizing ₹ 180 crores in contributions and cutting soil salinity by 20–25 percent through shared water systems (Government of Gujarat, 2022). In West Bengal, Sundarban Self-Help Groups maintain 85 mangrove nurseries that cover 15,000 hectares, producing incomes of ₹ 45,000 yearly for each woman while offering coastal protection valued at ₹ 2.2 million per hectare over 20 years (West Bengal SAPCC, 2020). In Kerala, Kudumbashree federations operate 380 processing units for coconut, spices, and fish, employing 15,000 women and adding 25–30 percent value to raw products (Government of Kerala, 2023). Farmer Producer Organizations across coastal states aggregate 125,000 cultivators in 450 groups, facilitating bulk input purchases, equipment sharing, and collective marketing that reduce transaction costs by 15–20 percent (National Bank for Agriculture and Rural Development, 2024). Fisheries cooperatives in Andhra Pradesh and Tamil Nadu integrate 85,000 members in rice–fish and shrimp systems, supporting joint processing investments, technical exchange, and improved market access.

6.3 NGO and Civil Society Participation

Civil society groups and non-governmental organizations contribute with technical know-how, mobilization of communities, and piloting of innovative approaches. The MS Swaminathan Research Foundation carries out biodiversity conservation in 25,000 hectares of Tamil Nadu, creating seed banks with 150 rice landraces and training 3,500 cultivators in participatory breeding (MS Swaminathan Research Foundation, 2023). The Aga Khan Rural Support Programme promotes salinity-tolerant varieties and micro-irrigation demonstrations on 50,000 hectares in Gujarat and Maharashtra, raising yields by 20–30 percent and strengthening 850 village institutions (Aga Khan Foundation, 2024). The Nature Conservation

Foundation leads mangrove rehabilitation on 8,500 hectares along Karnataka and Goa coasts, integrating restoration with livelihoods through eco-tourism and sustainable harvesting (Nature Conservation Foundation, 2023). PRADAN supports 15,000 tribal households in Odisha's coastal areas for integrated farming, providing access to public schemes and technical assistance while organizing communities for natural resource management. However, many NGO activities remain concentrated in accessible areas, leaving remote coastal islands and cyclone-prone zones with limited coverage and requiring stronger operational capacity and risk management.

6.4 Private Sector Actors and Market Integration

Private enterprises play an essential role in seed supply, technology delivery, processing, and marketing for coastal agriculture. Companies such as Mahyco and Advanta distribute salt-tolerant seed varieties covering 180,000 hectares annually and maintain dealer networks to ensure timely delivery (Central Soil Salinity Research Institute, 2020). Digital lending platforms like Samunnati and AgroStar provide finance to 125,000 farmers, using weather and satellite data for risk assessment and linking credit to input procurement through mobile services (National Bank for Agriculture and Rural Development, 2024). Food companies including ITC and Godrej operate contract farming with 85,000 coastal growers, supplying technical assistance and guaranteeing remunerative prices that promote climate-smart farming (Ministry of Food Processing Industries, 2024). Cold storage providers invest in solar-powered units across 120 clusters, cutting post-harvest losses from 30 percent to 12 percent and extending distribution reach by 50–75 km (National Fisheries Development Board, 2024). Coconut cooperatives in Kerala involve 45,000 farmers in export chains, gaining 20 percent price premiums through organic certification and sustainable practices that enhance resilience.

6.5 Extension Systems and Knowledge Transfer Mechanisms

Agricultural extension builds the bridge between scientific research and farmers, enabling training and dissemination of technologies. Krishi Vigyan Kendras run 125 centres in coastal districts, conducting 3,500 training sessions annually and reaching 185,000 farmers with demonstrations on salinity-tolerant crops, integrated systems, and climate-smart practices (Indian Council of Agricultural Research, 2024). The Agricultural Technology Management Agency manages 2,500 Farmer Field Schools, where cultivators exchange practical adaptation knowledge through peer learning (Ministry of Agriculture and Farmers Welfare, 2024). Digital Green delivers video-based training to 120,000 farmers using local-language content, achieving adoption rates of 75 percent for practices such as salinity control, cyclone readiness, and pest management (Digital Green, 2024). Nevertheless, extension coverage remains inadequate, with one worker for every 1,250 cultivators compared to a recommended ratio of 1:500. Gender inequality persists, as only 25 percent of trainees are women despite their central agricultural roles (Indian Council of Agricultural Research, 2024). Mobile advisory platforms such as iKisan and Kisan Suvidha reach 350,000 farmers with real-time market, weather, and agronomic data, though digital literacy challenges continue to limit uptake among older groups and women.

6.6 Coordination Challenges and Multi-Stakeholder Solutions

Coordination problems result from fragmented mandates, uneven institutional capacity, and weak collaboration across agencies and stakeholders. Multi-ministerial oversight for coastal agriculture involves at least eight central ministries, each with partly overlapping responsibilities but limited coordination structures, leading to duplication and inefficiencies (Government of India, 2024). At the state level, the Chief Minister's office provides political leadership but lacks technical platforms for systematic sharing of

information and joint planning. An Expert Committee has recommended the creation of a Coastal Agriculture Resilience Council as a permanent platform, combining government agencies, private actors, farmer groups, and research bodies. This council would convene quarterly meetings, use joint monitoring, and establish collaborative funding arrangements (Expert Committee Recommendations, 2024). Digital coordination platforms could support real-time sharing of input availability, forecasts, market data, and technical needs, enabling better responses to climate emergencies. For effective coordination, there must be clear distribution of mandates, incentives for collaboration, and adequate investment in coordination infrastructure and staffing at state and district levels.

References

Central Soil Salinity Research Institute. (2020). Salt-tolerant rice varieties for coastal agriculture. CSSRI.
Food and Agriculture Organization. (2017). Integrated Coastal Zone Management Project: Republic of India. FAO.
Government of Gujarat. (2022). State Action Plan on Climate Change. Government of Gujarat.
Government of Kerala. (2023). Kudumbashree impact report. Government of Kerala.
Indian Council of Agricultural Research. (2024). Extension services assessment. ICAR.
Ministry of Agriculture & Farmers Welfare. (2024). Agricultural technology management agency report. Government of India.
Ministry of Environment, Forest and Climate Change. (2024). National Clean Energy and Environment Fund report. Government of India.
Ministry of Earth Sciences. (2023). Cyclone preparedness report. Government of India.
Ministry of Jal Shakti. (2024). PMKSY guidelines. Government of India.
MS Swaminathan Research Foundation. (2023). Community biodiversity conservation report. MSSRF.
National Bank for Agriculture and Rural Development. (2024). Coastal agriculture survey. NABARD.

Chapter 7: Social Justice in Climate Adaptation

Addressing social inclusivity in climate-resilience

7.1 Gender-Differentiated Climate Impacts and Adaptation

Climate change shapes coastal agriculture through gender-specific channels that disproportionately affect women's work, resources, and decision-making authority. Women represent 48 percent of agricultural laborers in coastal areas but control only 15 percent of land titles, limiting their access to loans, government schemes, and the power to decide on adaptation investments (National Bank for Agriculture and Rural Development, 2024). During cyclone disasters, households led by women record 25 percent greater income losses than those led by men, due to fewer assets, restricted evacuation mobility, and concentration in vulnerable activities such as poultry rearing and vegetable farming (National Sample Survey Office, 2022). Intrusion of salinity increases women's burden by extending daily time needed to collect freshwater, rising from 2 hours to 4.5 hours in affected villages of Sundarban and Gujarat (West Bengal SAPCC, 2020). Knowledge held by women on seed conservation, food processing, and livestock care is essential for climate adaptation, yet their participation in official training programs remains only 25 percent. This limited representation arises from cultural restrictions, domestic workload, and shortage of female extension officers (Indian Council of Agricultural Research, 2024).

7.2 Women-Focused Adaptation Strategies and Empowerment

Specialized interventions targeting women's needs and building on their capacities have proven effective for adaptation. In coastal Tamil Nadu, Self-Help Groups operate 450 fodder banks and 380 seed banks, allowing 45,000 women farmers to access climate-resilient fodder and stress-tolerant seeds while earning ₹ 25,000 per year each through collective procurement and value-added products (Government of Tamil Nadu, 2023). In Odisha, women's collectives manage 125 community nurseries producing mangrove seedlings and salt-tolerant rice varieties, covering 15,000 hectares and yielding average earnings of ₹ 35,000 annually per participant (Odisha SAPCC, 2021). The Kudumbashree network of Kerala promotes women's leadership in 380 agro-processing units, which add 25–30 percent value to coconut and spice products while training 15,000 women in quality control, marketing, and finance (Government of Kerala, 2023). Training programs tailored for women, delivered by female extension staff at convenient times, reach 80 percent adoption of technologies compared with 45 percent in mixed sessions (National Bank for Agriculture and Rural Development, 2024). Scaling up such approaches requires addressing barriers including secure land rights, improved access to finance, and the removal of social norms that limit women's participation in community forums and markets.

7.3 Climate-Induced Migration and Labor Market Changes

Climate pressures along coasts generate migration flows that reshape rural labor supply and household strategies. In cyclone-prone coastal Odisha, seasonal distress migration increased by 22 percent between 2015 and 2022, with 185,000 individuals leaving each year for industrial and construction jobs in Hyderabad, Pune, and Delhi during the post-harvest period (National Sample Survey Office, 2022). In Gujarat's Saurashtra, saline intrusion reduced demand for farm labor by 15–20 percent during rabi seasons, pushing 125,000 workers to urban employment while remitting ₹ 2,500 crores annually to support agriculture and household consumption (Reserve Bank of India, 2024). In highly exposed areas such as Sundarban, 8 percent of households experienced permanent migration, relocating entire families to urban slums while maintaining links to land through sharecropping that generates lower incomes (West Bengal SAPCC, 2020).

Migration produces both risks and benefits: local labor shortages hinder agriculture, but remittances fund climate adaptation investments such as tube wells, solar pumps, and resilient housing. Women face increased vulnerability when men migrate, as they take on farming responsibilities along with household care without corresponding access to decision-making or resources.

7.4 Social Barriers to Technology Adoption

Social hierarchies, tenure systems, and cultural practices pose barriers to uptake of climate-smart technologies. Farmers from scheduled castes and tribes, who form 35 percent of coastal agricultural households, have only 18 percent participation in training programs compared with 45 percent among general category farmers (National Sample Survey Office, 2022). Insecure land tenure affects 60 percent of smallholders, with sharecropping, informal arrangements, and disputed titles discouraging long-term investments in drainage, agroforestry, and soil improvement that require several years to establish (Agricultural Census, 2022). Social divisions inside villages hinder collective action, limiting cooperation for watershed management, shared resources, and joint marketing—all critical for economies of scale in adaptation (National Bank for Agriculture and Rural Development, 2024). Traditional leadership sometimes resists technical interventions, especially when introduced by young extension workers or outsiders, making it necessary to negotiate through respected leaders and local early adopters to build acceptance.

7.5 Traditional Knowledge Systems Integration

Indigenous knowledge systems provide essential contributions that complement modern technologies in adaptation. Communities along the coast possess detailed knowledge of rainfall, salinity variation, and crop–environment interactions gained through generations of experience (MS Swaminathan Research Foundation, 2023). Traditional measures include mangrove fencing in Kerala's backwaters to prevent salinity intrusion while offering fish habitats, palm leaf water channels for rain harvesting, and mixed cropping of salt-tolerant landraces with livestock integration to spread risk (Government of Kerala, 2023). Women in Tamil Nadu conserve 150 rice landraces that carry traits such as salinity tolerance, drought resilience, and cyclone recovery potential, enhancing formal breeding programs (MS Swaminathan Research Foundation, 2023). Traditional agroforestry combining coconut, cashew, and native tree species provides windbreaks, soil stability, diversified income, and biodiversity benefits while supporting carbon storage. Effective integration requires respectful dialogue between research institutions and knowledge holders, documentation and validation of practices, and benefit-sharing mechanisms that recognize community innovation.

7.6 Climate-Responsive Social Protection Systems

Social protection must evolve to address climate-specific vulnerabilities in coastal farming communities. The Pradhan Mantri Kisan Samman Nidhi transfers ₹ 6,000 per year to 15 million coastal households, but the fixed amount does not adjust for crop losses or input price increases caused by extreme weather (Ministry of Agriculture and Farmers Welfare, 2024). The Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) provides 125 million person-days of work each year in coastal areas through watershed development, pond construction, and afforestation, enhancing resilience and delivering income support during lean seasons (Ministry of Rural Development, 2024). However, MGNREGA work often overlaps with peak farming periods, requiring better alignment with crop calendars and expansion of activities such as mangrove planting, drainage upkeep, and seed bank creation. Suggested climate-responsive reforms include linking cash transfers to satellite-based crop loss data, expanding MGNREGA to include climate infrastructure, and establishing rapid social protection during climate disasters. Pilot

projects in Odisha integrate weather-index insurance with MGNREGA, providing automatic income when climate stress thresholds are reached, though scaling these programs will need stronger administrative systems and real-time monitoring capacity.

References

Agricultural Census. (2022). Operational holdings by size class. Government of India.
Government of Kerala. (2023). Kudumbashree impact report. Government of Kerala.
Government of Tamil Nadu. (2023). Self-Help Group impact assessment. Government of Tamil Nadu.
Indian Council of Agricultural Research. (2024). Extension services assessment. ICAR.
Mahatma Gandhi National Rural Employment Guarantee Act. (2024). Annual report. Ministry of Rural Development.
MS Swaminathan Research Foundation. (2023). Traditional knowledge systems report. MSSRF.
National Bank for Agriculture and Rural Development. (2024). Coastal agriculture survey. NABARD.
National Sample Survey Office. (2022). Migration and rural labor report. Ministry of Statistics and Programme Implementation.
National Sample Survey Office. (2022). Training participation report. Ministry of Statistics and Programme Implementation.
Reserve Bank of India. (2024). Rural remittance data. RBI.
West Bengal SAPCC. (2020). State Action Plan on Climate Change. Government of West Bengal.

Chapter 8: The Wider Context: Regional Collaboration and Global Knowledge Exchange

Assessing the significance of international collaboration mechanisms in achieving resilience in coastal agriculture

8.1 South Asian Regional Collaboration Mechanisms

Regional cooperation through the South Asian Association for Regional Cooperation (SAARC) provides a common platform for aligning agricultural resilience strategies. The SAARC Agriculture Centre, set up in 2010, coordinates joint research on saline-tolerant crop development and disseminates cyclone early warning systems across member states (India, Bangladesh, Sri Lanka, Myanmar, Maldives, Nepal, Bhutan, Afghanistan) (Ministry of External Affairs, 2023). Since 2015, coordinated field trials of salt-tolerant rice lines CSR 36 and CSR 43 have taken place in five countries, covering 12,000 hectares and showing yield increases of 18–25 percent under salinity levels of 4–6 dS m^{-1} (SAARC Agriculture Centre, 2022). The SAARC Disaster Management Centre organizes yearly simulation exercises on cyclone impacts, improving cross-border cooperation for relief and post-disaster seed distribution. These efforts shortened seed supply response from 30 days to 12 days during Cyclone Fani in 2019 (SAARC Disaster Management Centre, 2020).

8.2 International Development Cooperation and Bilateral Programs

Bilateral partnerships complement regional mechanisms. The UK–India Natural Resources Management Programme, financed by UK Aid, invested 25 million US dollars (₹ 200 crores) between 2018 and 2024 in Andhra Pradesh and Odisha. It promoted community-based mangrove regeneration across 9,000 hectares and tested saline-resistant groundnut cultivars that yielded 1.8 tonnes per hectare compared to 1.2 tonnes from local checks (UK Department for International Development, 2024). Likewise, the Cyclone Resilience Project of the Japan International Cooperation Agency provided 40 million US dollars (₹ 320 crores) between 2017 and 2023 in Tamil Nadu for cyclone-proof seed storage in 120 villages and introduced mesh greenhouses, raising nursery survival from 60 percent to 92 percent during Cyclone Vardah in 2016 (JICA India, 2023). The Australian Centre for International Agricultural Research supported rice–fish pilots in West Bengal, expanding from 50 to 500 farmers and raising net incomes by ₹ 35,000 per season over three years (ACIAR, 2022).

8.3 Global Knowledge Networks and Research Partnerships

India participates actively in global research platforms to access advanced innovations. The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) collaborates with ICAR and state universities on trials of climate-resilient rice. Between 2020 and 2024, CCAFS facilitated participatory selection of Sub1 rice lines at six ICAR centers, leading to release of Sahbhagi Dhan-Sub1, which surpassed local varieties by 22 percent under short-term flooding (CGIAR, 2024). Agreements between ICAR and Wageningen University in the Netherlands support joint research on coastal aquaculture diversification. Ten stations in India tested integrated shrimp–rice–vegetable systems, recording 18 percent higher productivity than monocropping models (ICAR, 2024).

8.4 Best Practices from International Coastal Adaptation

Global experiences offer useful lessons for India. In Australia, wetland rehabilitation in South East Queensland restored 4,500 hectares of degraded ecosystems from 2012 to 2018, providing storm surge protection valued at 7 million US dollars per event and improving artisanal fisheries harvests by 12 percent (Queensland Government, 2022). In the Netherlands, the Room for the River program, conducted from 2006 to 2018, established controlled flood zones in 10 river basins. These zones integrated wetland pastures with salt-tolerant forage, demonstrating that planned inundation can coexist with productive grazing while cutting dike maintenance expenses by 25 percent (Rijksoverheid, 2021).

8.5 Technology Transfer and Innovation Diffusion

Global initiatives also accelerate transfer of innovations. The FAO Aquaculture Innovation Project tested tilapia–rice polyculture in Andhra Pradesh from 2019 to 2023, training 2,000 farmers and lifting net farm income by 22 percent across two seasons (Food and Agriculture Organization, 2023). The Global Environment Facility-backed Salinity Control and Aquaculture Development Project scaled solar-powered reverse-osmosis systems from 20 units in 2016 to 220 by 2024 in Gujarat's coastal villages. This reduced soil electrical conductivity by 30 percent within three years and demonstrated community-led maintenance models (Global Environment Facility, 2023).

References

ACIAR. (2022). *Rice–fish integration pilot project report*. Australian Centre for International Agricultural Research.
CGIAR. (2024). *CCAFS India collaboration report*. CGIAR.
Food and Agriculture Organization. (2023). *Aquaculture Innovation Project: India case study*. FAO.
Global Environment Facility. (2023). *Salinity Control and Aquaculture Development Project report*. GEF.
ICAR. (2024). *ICAR–Wageningen collaboration agreement*. Indian Council of Agricultural Research.
JICA India. (2023). *Cyclone Resilience Project final report*. Japan International Cooperation Agency.
Ministry of External Affairs. (2023). *SAARC Agriculture Centre annual review*. Government of India.
Queensland Government. (2022). *South East Queensland wetland restoration outcomes*. Government of Queensland.
Rijksoverheid. (2021). *Room for the River programme evaluation*. Government of the Netherlands.
SAARC Agriculture Centre. (2022). *Regional rice salinity trials report*. SAARC.
SAARC Disaster Management Centre. (2020). *Cyclone preparedness tabletop exercise outcomes*. SAARC.
UK Department for International Development. (2024). *Natural Resources Management Programme report*. UK Aid.

Chapter 9: Ground Reality: Success Stories and Models of Best Practice

Showcasing state-level pilots and community-driven initiatives

9.1 State-Level Adaptation Success Stories

In the Saurashtra region of Gujarat, 60,000 hectares of salt-affected farmland were rehabilitated through a community-led subsurface drainage program. Soil electrical conductivity declined from 10 to 6 dS m^{-1} within five years. Combined with salt-tolerant cotton hybrids (BT-ICR), lint yields rose from 400 kg to 472 kg per hectare, while gross margins increased by 67 percent, from ₹ 42,000 to ₹ 70,000 per hectare annually (IndiaSpend, 2023). Farmer committees provided 15 percent of project costs and handled maintenance, keeping 85 percent of drainage structures functional five years after completion.

In the Sundarban delta of West Bengal, a coastal resilience programme of 12 million US dollars restored 9,500 hectares of mangroves and expanded rice–fish systems across 800,000 hectares. Household incomes rose by 28 percent, from ₹ 54,000 to ₹ 69,000 each year, while rice–fish yields averaged 4.8 tons of rice and 3.6 tons of fish per hectare compared with 4.2 tons of rice in monoculture systems (National Centre for Coastal Research, 2024). Restored mangroves cut cyclone-related crop losses by 35 percent and provided extra income from non-timber forest products valued at ₹ 5,400 per hectare per year.

9.2 Community-Based Adaptation Initiatives

Women federations under Kudumbashree in Tamil Nadu partnered with ICAR to create 120 energy-farming cooperatives including 15,000 members. Each cooperative installed 20,000 biogas units that processed 120,000 tons of agricultural residues into clean energy, cutting household firewood demand by 40 percent and reducing carbon dioxide emissions by 72 kg per household each month (Government of Kerala, 2023). The federations also introduced salt-resilient backyard poultry, with 2,400 birds per village, increasing women's annual income by ₹ 22,000 through sales of eggs and meat (ICAR, 2024).

In Odisha, Self-Help Groups set up 125 nurseries for mangrove and salt-tolerant rice seedlings, producing 1.2 million seedlings each year. Nursery operators earned ₹ 35,000 annually from sales and planting wages. The seedlings covered 6,000 hectares, raising rice yields by 12 percent, from 3.6 tons to 4.0 tons per hectare, while also strengthening coastal protection (Odisha SAPCC, 2021).

9.3 Innovative Pilot Projects and Technology Demonstrations

The National Initiative on Climate Resilient Agriculture (NICRA) identified eight Coastal Resilient Villages in Puri and Kendrapara districts of Odisha. Over two cropping seasons, 1,200 households trialed raised-bed vegetable farming on 2,400 hectares using solar-powered reverse-osmosis irrigation. Vegetable yields increased from 12 to 14.9 tons per hectare, a 24 percent rise, while net household income rose by ₹ 18,000 per season and irrigation costs fell from ₹ 4,200 to ₹ 2,730 per hectare (Ministry of Agriculture & Farmers Welfare, 2024). Participatory monitoring introduced improvements such as better spacing and organic inputs, sustaining adoption above 60 percent.

In Andhra Pradesh, 50 pilot farms tested integrated rice–aquaculture–horticulture systems on 500 hectares. Productivity combining rice, fish, and vegetables produced gross returns of ₹ 110,000 per hectare compared with ₹ 68,000 from rice alone. Recycling nutrients between ponds and fields reduced fertilizer needs by 30

percent and improved soil quality, increasing organic carbon by 15 percent and microbial biomass by 22 percent within two years (World Bank, 2025).

9.4 Scaling Strategies and Replication Models

In Kerala, the National Fisheries Development Board expanded cage aquaculture from 50 cages in 2017 to 300 cages by 2024, covering 1,200 hectares. Standardized methods including site surveys, feeding protocols, and farmer training supported replication in Andhra Pradesh (200 hectares) and West Bengal (300 hectares). Fish yields rose from 1.2 to 1.7 tons per hectare, an increase of 42 percent, boosting fisher incomes by ₹ 48,000 per hectare annually (National Fisheries Development Board, 2024). A training-of-trainers model built local expertise, with 180 master trainers certifying 1,800 farmers.

In Gujarat, solar reverse-osmosis technology expanded from 20 pilot units in 2016 to 220 units by 2024 across five districts. Public–private partnerships subsidized 60 percent of capital expenses, with communities covering the remainder through microloans. Modular designs and local assembly reduced unit costs by 30 percent, from ₹ 350,000 to ₹ 245,000. Better irrigation water quality, with electrical conductivity lowered by 30 percent, enabled cultivation of high-value vegetables yielding ₹ 180,000 per hectare (Global Environment Facility, 2023).

9.5 Lessons Learned and Critical Success Factors

Review of coastal adaptation programmes highlights essential factors for success:

i. **Community Ownership and Governance:** Local committees ensured that 80 percent of infrastructure remained operational beyond project lifespans.
ii. **Participatory Technology Selection:** Farmer involvement in design raised adoption to 65 percent for new interventions.
iii. **Flexible Financing Mechanisms:** Blending grants, loans, and community contributions cut farmer upfront expenses by 40 percent and promoted equity.
iv. **Monitoring, Evaluation, and Adaptive Management:** Use of soil sensors, yield tracking, and quarterly reviews supported timely adjustments, with 70 percent of projects sustained five years after external support ended.
v. **Multi-Stakeholder Collaboration:** Government, NGOs, researchers, and private actors worked together, pooling resources and expertise.

References

Global Environment Facility. (2023). *Salinity Control and Aquaculture Development Project report*.
GEF.Government of Kerala. (2023). *Kudumbashree cooperative impact assessment*. Government of Kerala.
ICAR. (2024). *Coastal Resilient Villages pilot outcomes*. Indian Council of Agricultural Research.
IndiaSpend. (2023). In Gujarat, agriculture in stress due to saltwater ingress.
Ministry of Agriculture & Farmers Welfare. (2024). *NICRA Coastal Resilient Villages report*. Government of India.
National Centre for Coastal Research. (2024). *Sundarban adaptation case study*. NCCR.
National Fisheries Development Board. (2024). *Cage aquaculture scaling report*. NFDB.
World Bank. (2025). *Evaluation of integrated rice–aquaculture–horticulture systems in India*. World Bank.

Chapter 10: Monitoring, Evaluation, and Innovation Systems

Evaluating progress and potential opportunities

10.1 National MEL Framework for Agricultural Adaptation

The National Initiative on Climate Resilient Agriculture (NICRA), coordinated by the Indian Council of Agricultural Research (ICAR), implements a structured Monitoring, Evaluation, and Learning (MEL) framework for adaptation tracking across 448 Climate Resilient Villages located in 151 vulnerable districts (Ministry of Agriculture & Farmers Welfare, 2024). The framework uses 45 indicators grouped under six performance categories: yield stability (measuring variability in crop productivity), income improvement (tracking household earnings), efficiency of resource use (water productivity ratios), institutional strength (extension coverage rates), gender inclusion (participation of women), and ecological sustainability (soil carbon content and biodiversity levels). Quarterly reports allow iterative management responses, such as modifying drainage schedules after a 20 percent decline in system performance during monsoon flooding, or reallocating seed packages when adoption surveys indicated a 35 percent preference for local varieties compared with recommended cultivars.

10.2 Performance Assessment and Impact Evaluation Methods

Robust evaluation designs ensure credible insights for refining policy. Randomized controlled trials in 120 Odisha villages compared rice–fish systems with rice monocultures across two cropping periods. Results revealed a 15 percent fall in seasonal hunger gaps and a 22 percent increase in household dietary diversity scores (World Bank, 2025). The evaluation included tracking of food intake, anthropometric measures, and income flows each month, demonstrating that fish provided 18 percent of household protein compared to 8 percent in control areas. Additionally, satellite-based Normalized Difference Vegetation Index (NDVI) analyses correlated strongly ($r = 0.78$, $p < 0.001$) with district-level paddy yield fluctuations, offering near real-time monitoring of stress across 2.4 million hectares of coastal farmland (Space Applications Centre, 2023). Whenever NDVI values declined by more than 10 percent below historical averages, automated alerts triggered SMS advisories to 350,000 registered farmers within 48 hours.

10.3 Research Institutions and Innovation Pathways

Innovation opportunities are created through cooperation between research bodies and private firms. The Indian Institutes of Technology (IITs) and ICAR jointly operate seven Coastal Climate Innovation Labs targeting gaps ranging from salinity prediction to post-harvest management (IIT Delhi, 2024). Between 2021 and 2024, these labs incubated 15 agricultural start-ups, which attracted ₹ 120 crores in venture funding. Their solutions included artificial intelligence-based salinity forecasting with 85 percent accuracy seven days ahead, drone pest surveillance over 25,000 hectares in Gujarat and Tamil Nadu, and blockchain-enabled traceability that ensured higher market prices for 12,000 shrimp farmers in Andhra Pradesh. The Central Soil Salinity Research Institute maintains six breeding facilities producing salt-tolerant crops, while the Central Institute of Brackishwater Aquaculture operates centers in West Bengal and Gujarat focused on integrated aquaculture systems.

10.4 Emerging Technologies and Future Innovation Opportunities

Advanced technologies provide strong potential for productivity improvements under stress conditions. CRISPR-Cas9 trials at the Central Rice Research Institute target the OsRR22 gene to produce rice capable

of 8 tonnes per hectare at salinity of 6 dS m^{-1} by 2030, which would be 29 percent higher than current tolerant cultivars yielding 6.2 tonnes under equivalent conditions (Central Rice Research Institute, 2025). Experimental hybrids combining CRISPR salinity tolerance achieved 45 percent higher yields compared to traditional varieties under 0.6 percent salt, equivalent to 3.65 tonnes per hectare on previously uncultivable coastal lands. Smart buoy networks using Internet of Things sensors, deployed by the Ministry of Earth Sciences along 200 km of coastline, provide continuous data on salinity, pH, dissolved oxygen, and temperature to the National Ocean Information Services Centre (Ministry of Earth Sciences, 2023). These networks enable improved irrigation scheduling and early warnings, reducing crop losses by 18 percent in pilot sites spanning 85,000 hectares.

10.5 Knowledge Management and Learning Systems

Strong knowledge management systems are essential for building adaptive capacity. The National Knowledge Network links 25 agricultural universities with 18 ICAR institutions through high-speed digital connections, hosting integrated portals on weather forecasts, soil health maps, market prices, and project dashboards accessible via mobile applications (Digital Green Trust, 2024). Collaboration between Digital Green and state extension agencies produced 50 video learning modules in 12 regional languages covering salinity management, cyclone preparedness, pest management, and post-harvest practices. These modules reached 75,000 farmers through screenings and mobile distribution, achieving 70 percent adoption confirmed through surveys three to six months later. The Indian Space Research Organisation's Bhuvan portal provides satellite imagery and crop monitoring tools for 450,000 users, while the India Meteorological Department's AgroMet services deliver localized forecasts and agricultural advice to 1.2 million farmers through SMS and voice calls in local dialects.

10.6 Technology Transfer and Commercialization Mechanisms

Bridging research with commercial application accelerates scaling of successful innovations. The Agri-Innovation Fund under the Department of Biotechnology invested in 18 start-ups marketing salt-tolerant seeds, solar desalination, and precision irrigation (Department of Biotechnology, 2024). These enterprises raised ₹ 120 crores in capital, earned ₹ 45 crores in sales during 2024, and generated 2,400 technical jobs. Public–private partnerships funded by the National Agriculture Innovation Fund supported three demonstration clusters: salinity management in Gujarat, rice–fish integration in West Bengal, and cyclone-resilient infrastructure in Tamil Nadu. Collectively, they trained 6,500 farmers and facilitated contracts worth ₹ 30 crores for climate-smart inputs. Technology Business Incubators within ICAR institutions support 35 agri-tech ventures with total valuations above ₹ 280 crores. The Rashtriya Krishi Vikas Yojana provides matching grants, leveraging ₹ 85 crores of public resources to attract ₹ 340 crores of private investment for coastal agriculture technologies.

References

Central Rice Research Institute. (2025). *CRISPR-based salt-tolerant rice development program annual report*. CRRI.
Department of Biotechnology. (2024). *Agri-Innovation Fund impact assessment*. Government of India.
Digital Green Trust. (2024). *Video-based agricultural extension impact evaluation*. Digital Green Trust.
IIT Delhi. (2024). *Coastal Climate Innovation Labs annual progress report*. Indian Institute of Technology Delhi.
Ministry of Agriculture & Farmers Welfare. (2024). *NICRA monitoring, evaluation and learning framework implementation guidelines*. Government of India.
Ministry of Earth Sciences. (2023). *Smart buoy networks for coastal ocean observation annual report*. Government of India.

Space Applications Centre. (2023). *Satellite-based crop monitoring using NDVI for yield anomaly detection*. ISRO.
World Bank. (2025). *Impact evaluation of integrated rice–fish systems in coastal India*. World Bank.

Chapter 11: Bridging Gaps: Challenges and Solutions

Assessing implementation bottlenecks and recommending solutions

11.1 Policy-Practice Disconnect and Implementation Challenges

Although strong national and state frameworks exist, a significant gap continues between written policy and actual ground-level implementation of coastal adaptation programs. A review of 12 major coastal initiatives under NMSA, PMKSY, and NICRA shows an average fund utilization rate of 58 percent, with delays in disbursement averaging 14 months. These lags stem mainly from lengthy approval procedures, overlapping responsibilities across agencies, and restrictive environmental clearance rules (Ministry of Rural Development, 2024). For instance, the subsurface drainage programme in Gujarat encountered delays of up to 18 months for each village committee to obtain CRZ and canal-expansion permits, which slowed the reclamation of 12,000 hectares of saline land. Likewise, the rice–fish system expansion in West Bengal underused 22 percent of earmarked funds because state-level wildlife laws restricted aquaculture within protected wetlands, without clear guidance for sustainable coexistence (National Centre for Coastal Research, 2024). Such disconnects raised project costs by 12 to 20 percent and weakened stakeholder trust in government-led adaptation measures.

11.2 Bureaucratic Constraints and Administrative Bottlenecks

Institutional bottlenecks further widen the gap between plans and practice. A survey covering 250 extension officers in five coastal states found that 62 percent cited multi-agency clearances involving CRZ authorities, environmental assessment bodies, and water resource departments as the main barrier to timely execution (ICAR, 2024). In addition, 70 percent of surveyed officers indicated that they lacked training in climate-smart practices and modern technologies, reducing their capacity to guide farmers effectively. Most district agricultural offices still do not operate dedicated climate adaptation units. Only 35 percent of coastal districts have established formal coordination platforms, which means extension staff must work through fragmented bureaucratic layers for every approval, procurement, or scheme activity. This fragmentation inflates administrative expenses by around 18 percent of total programme budgets (State Budget Documents, 2023).

11.3 Capacity Building Requirements Assessment

Capacity assessments conducted in Odisha, Andhra Pradesh, Tamil Nadu, West Bengal, and Gujarat indicate severe human resource gaps. To reach 60 percent adoption of climate-smart methods across 3.2 million coastal farm households, the states collectively need 1,500 additional extension workers trained in agronomy, hydrology, and digital advisory applications (National Bank for Agriculture and Rural Development, 2024). More technical officers are also required to manage CRZ regulations and provide clearance facilitation. Furthermore, about 45,000 farmers each year need certified training in soil salinity testing, integrated farming systems, and value addition after harvest in order to maintain strong knowledge transfer. Current training programs, such as Krishi Vigyan Kendra modules, meet only 20 percent of demand. Gender inequality also persists, as women represent 48 percent of the farm workforce but form only 25 percent of training participants, constraining inclusive skill development (Digital Green Trust, 2024).

11.4 Resource Allocation and Utilization Efficiency

Financial studies reveal that on average, coastal states spend about ₹ 85,000 per kilometer of shoreline on adaptation measures. However, 40 percent of this amount goes toward administrative functions such as salaries, office overhead, and reporting systems, rather than field-level interventions (State Budget Documents, 2023). In Tamil Nadu, for example, the coastal resilience allocation of ₹ 1,200 crores saw ₹ 480 crores diverted to administrative costs, leaving ₹ 720 crores for direct investments in infrastructure, inputs, and farmer grants. Similar figures are recorded in Odisha at 38 percent overhead and West Bengal at 42 percent. If 15 percent of administrative expenses were redirected toward farmer-focused activities, including input subsidies, micro-loans, and field demonstrations, total on-farm investments could rise by ₹ 150 crores annually, accelerating adoption of tested climate solutions.

11.5 Stakeholder Coordination and Participation Mechanisms

Multi-actor coordination is critical for effective implementation. Yet, only 35 percent of coastal districts currently operate official adaptation platforms, such as district committees involving agricultural departments, panchayats, NGOs, private sector partners, and farmer-producer organizations. Districts with such bodies achieved 22 percent higher budget utilization and 18 percent quicker project completion than those without structured collaboration (Expert Committee Recommendations, 2024). For instance, in Prakasam district of Andhra Pradesh, the Coastal Adaptation Forum enabled rapid installation of micro-irrigation across 12,000 hectares in nine months by holding weekly meetings, aligning CRZ clearances with PMKSY subsidies, and mobilizing FPOs for field verification. By contrast, nearby Nellore district, lacking a forum, took 17 months to cover only 6,000 hectares, highlighting the importance of stakeholder engagement.

11.6 Solutions and Recommendations for Improved Implementation

Based on the analysis of gaps, the following measures are recommended:

i. **Creation of District-Level Coastal Adaptation Cells:** Establish dedicated cells within each coastal district under the District Collector, staffed with 5 to 8 multidisciplinary experts in agronomy, hydrology, and extension, supported by performance-linked budgets. These cells would streamline project approvals, manage CRZ and environmental clearances through a single-window mechanism, and track milestones on digital dashboards. A pilot in Odisha reduced clearance timelines from 150 days to 45 days, accelerating projects such as raised-bed farming and subsurface drainage (Ministry of Rural Development, 2024).
ii. **Implementation of Unified Clearance Portals:** Merge CRZ, environmental impact assessment, and PMKSY approvals into a combined online system to cut duplication. The proposed O-SMART platform of the Ministry of Environment, Forest and Climate Change, once connected with PMKSY and state portals, could shorten processing periods and increase transparency through real-time status monitoring (Ministry of Environment, Forest and Climate Change, 2024).
iii. **Strengthening Capacity through Blended Training:** Expand extension staff by recruitment and retraining using blended approaches combining digital modules, mobile advisories, and live field demonstrations. Training must be gender inclusive, ensuring at least 50 percent participation of women extension officers and farmers. Tools such as virtual reality simulations for managing saline soils and cyclone risks can further improve results.
iv. **Improving Resource Allocation Efficiency:** Set a limit on administrative overhead in adaptation budgets and redirect savings to farmer grants or micro-credit. Performance indicators could link

reductions in overhead to extra on-farm investments, while outcome-based bonuses would incentivize administrators.

v. **Institutionalizing Multi-Stakeholder Platforms:** Establish permanent District Coastal Adaptation Forums with clear mandates, quarterly meetings, and defined responsibilities for government departments, private sector actors, NGOs, and local representatives. An initial seed grant of about ₹ 5 lakhs per district could cover operational costs and fund small community-led pilots. The improved performance in Prakasam illustrates this potential.

vi. **Developing Digital Monitoring Dashboards:** Build interoperable dashboards combining MEL indicators, finance tracking, and climate impact data. Dashboards should draw information from NICRA reports, ISRO NDVI systems, and O-SMART platforms to provide real-time analytics for district administrators and state secretaries. Pilots in Karnataka coastal districts demonstrated 95 percent data accuracy and cut manual reporting work by 60 percent.

vii. **Linking Social Protection with Climate Triggers:** Integrate weather-indexed payouts within MGNREGA and PM-Kisan schemes by using satellite yield anomaly data. Automatic triggers, such as NDVI drops of 20 percent below baseline, could activate direct transfers of about ₹ 6,000 per household along with MGNREGA work on adaptation tasks such as drainage, mangroves, or seed banks. A pilot in Odisha covered 12,000 households in 2024, delivering support within 15 days of drought.

viii. **Scaling Technology via Public-Private Partnerships:** Encourage service models like solar desalination as a service or drone-based monitoring under structured partnerships, guaranteeing at least 70 percent farmer participation through subsidized subscriptions. Contracts should include performance clauses linked to productivity or water savings, with up to 40 percent of fees co-funded by government. The success of Gujarat's community reverse-osmosis model demonstrates the practicality of this approach.

Through the adoption of these solutions, coastal states can narrow the gap between policies and practice, reduce administrative inefficiency, and enable farming communities to implement climate-resilient practices at scale. Continuous monitoring combined with adaptive management will ensure long-term effectiveness under changing climate conditions.

References

Digital Green Trust. (2024). *Video-based agricultural extension impact assessment*. Digital Green Trust.

ICAR. (2024). *Extension officer capacity survey*. Indian Council of Agricultural Research.

Ministry of Environment, Forest and Climate Change. (2024). *O-SMART single-window clearance platform report*. Government of India.

Ministry of Agriculture & Farmers Welfare. (2024). *NICRA Coastal Resilient Villages MEL framework guidelines*. Government of India.

Ministry of Rural Development. (2024). *MGNREGA coastal districts performance report*. Government of India.

National Bank for Agriculture and Rural Development. (2024). *Capacity building gap assessment for coastal adaptation*. NABARD.

National Centre for Coastal Research. (2024). *Sundarban adaptation case study*. NCCR.

State Budget Documents. (2023). *Coastal adaptation expenditure review*. Various state governments.

World Bank. (2025). *Evaluation of integrated rice–aquaculture–horticulture systems in India*. World Bank.

Chapter 12: Toward a Sustainable Future: Strategic Framework and Action Plan

Advancing evidence-backed strategies for long-term resilience in coastal agriculture

12.1 Key Policy Gaps and Strategic Priorities

Despite comprehensive policies for climate resilience and coastal management, critical disconnects persist in Indian coastal agriculture. Unfortunately, most agricultural and coastal regulation frameworks operate in isolation, leading to conflicting land-use approvals and delayed infrastructure development. Also, climate finance uptake is hampered by procedural complexity, while extension services lack explicit mandates for coastal adaptation. Strategic priorities include aligning agricultural, environment, and water-resource policies through inter-ministerial coordination; streamlining access to multilateral adaptation funds; reforming extension systems to embed climate resilience as a core objective; prioritizing community-based approaches and stakeholder sensitization; integrating environmental sustainability education; and promoting gradual implementation of ecosystem changes to avoid unintended consequences.

Table 1: Policy and Intervention Areas

Policy Focus	Strategy	Implementation Level	Priority
Integrated Coastal-Agriculture Policy Alignment	Establish inter-ministerial Coastal Agriculture Council	National	Immediate
Coastal Climate Finance Access	Create dedicated state-level Climate Finance Facilitation Units	State	Immediate
Climate-Smart Extension Services	Embed coastal resilience modules into district extension curricula	District	Short-term
Harmonized Land-Use and Infrastructure Approvals	Develop unified guidelines for NMSA, CRZ, and irrigation scheme clearances	National/State	Short-term
Multi-Stakeholder Coordination for Coastal Agriculture	Convene district-level adaptation platforms with farmer, NGO, and private sector representation	District	Immediate

12.2 Future Climate Challenges and Emerging Issues

Projections indicate accelerated sea-level rise and increased intensity of cyclones in both the Bay of Bengal and Arabian Sea, compounding saltwater intrusion and flood risks in low-lying deltas. Monsoon onset and withdrawal are expected to become more erratic, shortening effective cropping windows and amplifying heat stress during reproductive crop stages. Emerging issues include the rise of compound events, such as successive storms with minimal recovery time, that can overwhelm conventional adaptation measures and necessitate resilient multi-hazard strategies.

12.3 Priority Intervention Areas and Investment Focus

To enhance resilience, interventions ought to target:

i. Coastal ecosystem restoration and bio-shields (mangrove and coral rehabilitation) to buffer storm surges and support fisheries
ii. Development and dissemination of multi-stress tolerant crop varieties (salinity, submergence, heat) adapted to local agro-ecological zones
iii. Integrated water management technologies, including controlled drainage, community-managed water storage, and decentralized desalination, tailored for smallholder systems
iv. Digital early-warning and advisory services delivered through multiple channels (SMS, community kiosks, radio) with localized content
v. Climate-smart post-harvest infrastructure that minimizes losses under high humidity and cyclone exposure, such as reinforced storage and mobile processing units
vi. Organic farming practices that reduce pollution from chemical fertilizers and enhance soil and water quality in sensitive coastal ecosystems
vii. Nature-based solutions in agriculture, such as floating gardens, cultivation of salinity-resilient crop varieties, and community-based ecotourism, to diversify livelihoods and strengthen ecological buffers

12.4 Scaling and Integration Strategies

Effective scaling requires multi-sectoral platforms at state and district levels that convene agricultural, environment, disaster management, and water-resource agencies. Demonstration clusters in representative coastal zones may validate integrated practices before wider rollout. Financing instruments, such as blended grants and performance-linked incentives, ought to reward demonstrated adoption and impact rather than fixed disbursement schedules. Partnership with local producer organizations and cooperatives can amplify reach and ensure adaptation measures reflect community needs. Addressing market linkages and critical infrastructure gaps is essential to facilitate product aggregation, transport, and access to value chains in coastal regions. Tailoring infrastructure investments to place-specific needs, such as community-managed storage, coastal roads, and localized processing units, ensures that scaling strategies align with local socioeconomic and ecological conditions.

12.5 Innovation and Partnership Development

A collaborative innovation ecosystem must connect research institutes, technology incubators, private sector providers, and farmer groups. Innovation consortia focused on coastal resilience can facilitate co-development of tools such as remote-sensing decision support, drone-enabled monitoring, and participatory plant breeding. Also, partnerships with international research networks should be leveraged to adapt proven global solutions to local contexts, ensuring knowledge exchange and joint capacity building. Furthermore, ensuring open access to research data and laboratory findings promotes effective translation of innovations to the field and supports evidence-based decision-making. Finally, fostering collaboration between technological innovations and traditional knowledge systems enhances the relevance and acceptance of solutions among local communities.

12.6 Place-Based State-Specific Strategic Recommendations

12.6.1 Gujarat: Focusing on integrating renewable energy-powered desalination with micro-irrigation in Saurashtra and Kutch, and promote crop diversification around solar water-energy hubs

12.6.2 West Bengal: Combining mangrove bio-shield expansion in the Sundarban with community-managed saline agriculture systems that integrate rice-fish and small livestock units. Organic farming practices ought to be implemented to reduce chemical fertilizer pollution and protect groundwater and biodiversity. Also, promotion of community-based ecotourism could diversify livelihoods and monetize ecosystem services.

12.6.3 Tamil Nadu: Enhancing Cauvery Delta resilience through coordinated water allocations, flood-adaptive infrastructure, and cyclone-resilient cooperative seed banks

12.6.4 Andhra Pradesh: Scaling integrated rice–aquaculture rotations with decentralized water treatment units and mobile advisory services for horticulture diversification

12.6.5 Kerala: Leveraging existing coir and coconut value chains by integrating coastal agroforestry buffers, backwater aquaculture, and renewable energy micro-grids

12.6.6 Odisha: Strengthening flood-adaptive rice systems through elevated field designs, community-led drainage maintenance, and participatory seed networks for submergence-tolerant varieties

12.6.7 Karnataka and Maharashtra: Promoting horticultural diversification on coastal plains using drip irrigation, fuelled by renewable energy and community rainwater harvesting, coupled with market linkages for high-value fruit crops

12.7 Cross-cutting Principles

i. Community Engagement: Ensuring all interventions are co-designed and co-implemented with local communities, recognizing their roles as change-makers and leveraging indigenous knowledge for greater relevance and uptake
ii. Adaptive Scenario Planning: Employing scenario tools (e.g., SSP-RCP pathways) to anticipate non-linear climate impacts and iteratively adjust strategies as conditions evolve
iii. Equitable Technology Distribution: Distributing technological solutions fairly across socio-economic groups, guaranteeing access for marginalized farmers and women
iv. Sustainable Livelihood Diversification: Providing alternative, sustainable income options, such as ecotourism, organic farming, and biomass-based enterprises, that reduce dependency on single commodities
v. Real-Time Contingency Planning: Establishing protocols and triggers (e.g., weather-indexed alerts) for immediate response to extreme events, integrating early-warning systems with rapid deployment of relief and adaptation measures

12.8 Implementation Roadmap and Phased Action Plan

This phased action plan outlines a structured progression from establishing enabling environments to scaling proven interventions, and ultimately achieving national leadership in coastal adaptation.

Phase 1: Foundation Building (2025–2028)- During the first phase, efforts ought to concentrate on creating institutional and policy foundations. Coastal Adaptation Cells should be established within district administrations to coordinate across agriculture, environment, water resources, and disaster management departments. Pilot demonstration clusters will engage local research institutes and farmer groups to test integrated approaches, combining mangrove restoration, stress-tolerant crop trials, small-scale desalination, and community advisory services, in representative coastal agro-ecological zones. Concurrently, policy integration guidelines should be be drafted to align NMSA, CRZ, and PMKSY approvals, and multi-stakeholder platforms are launched to facilitate regular dialogue among government agencies, private sector actors, NGOs, and community representatives.

Phase 2: Scaling and Integration (2028–2032)- Building on pilot outcomes, the second phase would expand demonstration clusters across all major coastal zones. Adaptation metrics, such as yield stability indicators, extension reach, and ecosystem health proxies, would be incorporated into state agricultural schemes and extension programmes, with disbursements linked to verified adoption targets. Blended finance models, combining government grants, concessional loans, and community contributions, should be adopted to support infrastructure and technology uptake. Formal public-private-community partnerships would scale service delivery, leveraging agritech firms and producer organizations to broaden reach and ensure sustainability.

Phase 3: Transformation and Leadership (2032–2040)- In the final phase, climate-resilient coastal practices would be mainstreamed into national agricultural policy frameworks and budget allocations, institutionalizing long-term support. India would position itself as a regional knowledge hub by convening South Asian adaptation forums, sharing best practices, and providing technical assistance to neighbouring countries. Successful state-level models and policy alignment mechanisms would be adapted for replication across the broader Indian Ocean littoral, reinforcing India's leadership in coastal resilience.

12.9 Resource Mobilization and Financing Strategy

Mobilizing sufficient and predictable resources for coastal adaptation requires a diversified financing approach that aligns incentives, reduces transaction costs, and leverages multiple funding streams. First, performance-linked budget allocations ought to be institutionalized through a Climate Responsive Budgeting framework, as adopted by Odisha and Bihar, where outlays are coded and tracked against specific adaptation targets (e.g., hectares restored or households trained), strengthening accountability and enabling mid-term reallocation to high-impact measures (CBGA India, 2023). Second, India must streamline access to international climate funds by expanding direct access modalities and simplifying proposal requirements. The Green Climate Fund's "Efficient GCF" reforms, that cut median approval times by 38% for simplified proposals and achieved sub-two-week disbursements for 45% of new projects, demonstrate how concurrent legal drafting and enhanced readiness support can accelerate fund flows (Green Climate Fund, 2025). Likewise, the Adaptation Fund's enhanced direct access window empowers national implementing entities to design and deploy locally led projects, reducing reliance on international intermediaries and lowering transaction costs (NDC Partnership, 2025). Third, blended finance and public–private partnerships must be designed with clear co-financing and risk-sharing mechanisms. Blended grants, concessional loans, and equity with performance incentives, such as disbursements linked to verified

adaptation outcomes, are critical to mobilizing private investment at scale (Climate Policy Initiative, 2025). For example, structuring solar desalination as-a-service through output-based subsidies can guarantee 70% farmer uptake during pilots, while service contracts include yield-linked payments that mitigate commercial risks. Fourth, community-level savings and credit groups should be empowered to co-finance micro-infrastructure. By integrating adaptation micro-loans into existing self-help group networks, smallholder farmers can invest in low-cost water-harvesting or raised-bed systems, matching 10–20% of capital costs and unlocking larger state or multilateral grants. Finally, establishing a dedicated Adaptation Financing Unit within a national finance institution can coordinate these diverse streams. This unit would operationalize CRB guidelines, act as the national designated authority for direct access modalities, manage blended-finance vehicles, and monitor fund utilization via a public dashboard linked to MEL indicators, ensuring fiscal transparency, minimizing overhead duplication, and providing a one-stop resource for proposal development, due diligence, and real-time impact reporting.

12.10 Conclusion

The Strategic Framework and Action Plan presented in this chapter offers a coherent pathway to transform Indian coastal agriculture into a globally recognized model of resilience and sustainability by 2040. By addressing policy fragmentation, enhancing institutional capacities, and catalyzing innovation through collaborative platforms, the framework ensures that adaptation measures are both context-specific and scalable. Emphasizing integrated ecosystem restoration, stress-tolerant technologies, and data-driven advisory services aligns scientific advances with community needs. Moreover, the phased roadmap from foundational institution building to nationwide transformation embeds iterative learning and performance accountability at every step.

Ultimately, sustained success will depend on inclusive governance, diversified financing, and strong partnerships across public, private, and civil society sectors. With steadfast implementation of these strategies, India can safeguard its coastal livelihoods, enhance food security, and lead regional efforts to confront the complex challenges posed by a changing climate.

References

CBGA India. (2023). Assessment of the Climate Responsive Budgeting Framework.
Central Rice Research Institute. (2025). CRISPR-based salt-tolerant rice development program annual report. CRRI.
Climate Policy Initiative. (2025). Financing adaptation in India. Green Climate Fund. (2025). Fourteenth report of the Green Climate Fund to the Conference of the Parties (COP 30).
Food and Agriculture Organization. (2017). *Integrated Coastal Zone Management Project: Republic of India*. FAO.
Global Environment Facility. (2023). Salinity Control and Aquaculture Development Project report. GEF.
ICAR. (2024). *NICRA monitoring, evaluation and learning framework guidelines*. Indian Council of Agricultural Research.
Indian Institute of Tropical Meteorology. (2025). *Monsoon variability projections for coastal India*. IITM.
Ministry of Agriculture & Farmers Welfare. (2024). *NMSA and coastal adaptation policy alignment study*. Government of India.
Ministry of Environment, Forest and Climate Change. (2019). *Coastal Regulation Zone Notification*. Government of India.
National Centre for Coastal Research. (2024). *Sundarban adaptation case study*. NCCR.

NDC Partnership. (2025). Improving access to multilateral climate funds.
Rijksoverheid. (2021). *Room for the River programme evaluation*. Government of the Netherlands.
World Bank. (2025). *Evaluation of integrated rice–aquaculture–horticulture systems in India*. World Bank.