Do Adaptation Interventions Reduce Vulnerability and Disaster Risk and Strengthen Socio-Ecological Resilience?: Lessons from Coastal Odisha, India

Banerjee, Sumanta and Mohapatra, Souryabrata

Ravenshaw University, NCAER

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Do Adaptation Interventions Reduce Vulnerability and Disaster Risk and Strengthen Socio-Ecological Resilience? Lessons from Coastal Odisha, India

Sumanta Banerjee, Ravenshaw University, India
Souryabrata Mohapatra, NCAER, India

Abstract: Adaptation measures are crucial tools in combating the adverse effects of climate change. Assessing the progress of adaptation efforts in developing countries like India, particularly in disaster-prone states like Odisha, is of utmost importance. This study explores how adaptation initiatives help to reduce vulnerability, mitigate disaster risks, and enhance socio-ecological resilience. Utilizing insights from the Sustainable Livelihood Framework, Sendai Framework, and Millennium Ecosystem Assessment, we identify various adaptation strategies and compile an inventory. This inventory is derived from diverse sources, including peer-reviewed literature, gray literature, and documents from International Non-Governmental Organizations (INGOs) and state-level Non-Governmental Organizations (NGOs). The key results from the inventory indicate that the government is the leading adaptation provider, followed by the interventions of the INGOs and NGOs. It is observed from the qualitative data analysis that 35 percent of the adaptation reduces disaster risk, 45 percent of the activities/interventions help in reducing vulnerability, and 20 percent of the interventions promote and strengthen ecological resilience building. The research is limited by the fact that the adaptation inventory created is not a comprehensive list of adaptation interventions but rather an indicative one. It does not consider autonomous or household-level adaptations. Additionally, it offers for expanding successful adaptation interventions from local to regional or national levels, as demonstrated by experiences in Coastal Odisha, which can be applied to broader geographical areas.

Keywords: *Climate Adaptation, Disaster Risk Reduction, Socio-Ecological Resilience, Coastal India*

Introduction and Conceptualization

The state of Odisha is located on the east coast of India and is home to 42 million people (Ministry of Home Affairs 2011). Odisha witnesses the wrath of cyclones arising from the Bay of Bengal (Ray-Bennett 2016). Historically, many devastating cyclones have formed in the Bay of Bengal, and they have caused massive devastation in terms of damaging infrastructure and livelihood (Special Relief Commissioner, n.d.-a). Slow-onset events such as coastal erosion have also affected the state (Roy et al. 2018). From the review of literature, it has been observed that in developed countries, like the United Kingdom and the Netherlands, studies focusing on adaptation drivers, providers, beneficiaries, and types have been conducted to understand observed adaptation or adaptation practice in coastal and delta settings (Tompkins et al. 2009; Sánchez-Arcilla et al. 2016; PBL Netherlands Environmental Assessment Agency 2012).

However, in developing countries like India and particularly disaster hotspot states like Odisha, studies concerning observed adaptation are minimal. In order to cite, there is only one project, "Deltas, vulnerability climate change: migration and adaptation" (DECCMA), where the adaptation strategies undertaken in the Mahanadi delta (which is part of Coastal Odisha) have been studied. This research article was drawn from the DECCMA project's understanding and its working paper on observed adaptation in deltas (Tompkins et al. 2017).

The state of Odisha is acclaimed widely by the United Nations Disaster Risk Reduction (UNDRR) and other organizations globally for its disaster risk reduction efforts. The state has also reduced its vulnerability, which is aptly reflected in the Multidimensional Poverty Index conducted by India's premier policy think tank organization, the National Institute for Transforming India (NITI Aayog 2023). Thus, it becomes imperative to study the adaptation strategies undertaken by a vulnerable state like Odisha and how these strategies contribute to reducing disaster risk vulnerability and strengthening socio-ecological resilience. The objective of the article is to understand what drives adaptation in Coastal Odisha and how these adaptive strategies undertaken by different adaptation providers have contributed to the reduction of vulnerability and disaster risk and strengthened socio-ecological resilience. The article also sheds light on a catalog of adaptation strategies undertaken in Coastal Odisha.

Adaptation is one of the potent tools for reducing vulnerability to climate change impact, enhancing resilience, and safeguarding livelihoods, especially in vulnerable regions and communities (Intergovernmental Panel on Climate Change [IPCC] 2014). The implementation of adaptation policies at different levels of government is noticeable, as observed in developed nations (Remling 2018), as well as in Africa and Asia (Ford and Berrang-Ford 2015). The commitment to strengthen adaptation efforts has advanced through the different agreements of the United Nations Framework Convention on Climate Change, particularly the Paris Agreement. This agreement mandates both developed and developing nations to adapt to climate change while striving to limit the global temperature increase to below 2°C in the twenty-first century, with endeavors focused on constraining the rise to 1.5°C (UNFCCC 2016).

In order to understand adaptation and document it, there is no established approach to do it effectively. The limited availability of adaptation databases and conceptual complexities are marked by a lack of agreement on what constitutes adaptation (Ford and Berrang-Ford 2015). Consequently, data and information on observed adaptations are absent for regions highly vulnerable to climate impacts (Cochrane et al. 2017).

We suggest that for a better comprehension of the diverse types of adaptations, it is most advantageous to categorize adaptation according to its objectives, specifically reducing risk and strengthening resilience (see Figure 1). Based on extensive research in livelihoods, disaster risk, and ecosystem services spanning several decades, we argue that (1) in accordance with the Sustainable Livelihood Approach by the Department for International Development (DFID) 1999, reduction in vulnerability can be understood through assets base at individual and at the community level; (2) following the Sendai Framework on Disaster Risk Reduction (DRR)

approach; DRR can be evaluated by investments in preparedness, response, recovery, and prevention (3) aligned with the Millennium Ecosystem Assessment (MEA 2005), social–ecological resilience can be measured by alterations in ecosystem services, encompassing provisioning, regulating habitat, and cultural services. These components collectively cover a broad spectrum of adaptations.

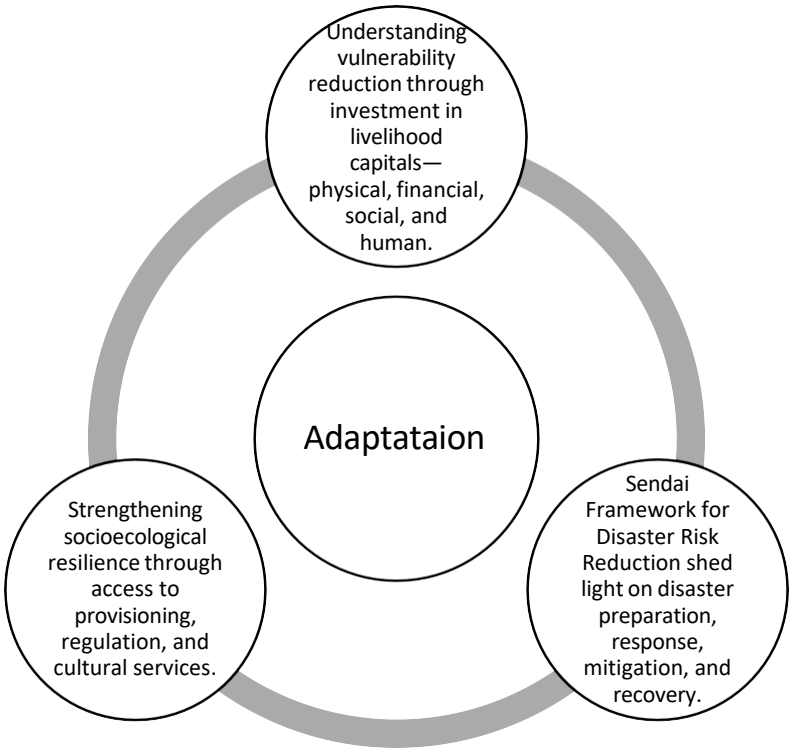

Figure 1: Key Elements of Adaptation
Source: Tompkins et al. 2018

International and national assessments have been conducted to comprehend the various adaptation efforts taking place in developed nations (Tompkins et al. 2010). These studies illuminate the nature and prevalence of adaptation initiatives. However, there is a scarcity of research focusing on developing countries, particularly in disaster-prone regions like Odisha, India. Limited attention has been given to studying adaptation interventions in these areas. The DECCMA project has attempted to explore the role of migration as a catalyst for adaptation in the Mahanadi delta of Coastal Odisha, India.

The gap in the literature is addressed by considering important questions raised by Smit et al. (2001) regarding who is adapting and how they are doing so. The authors addressed this gap by focusing on documented cases of observed adaptation in Odisha, particularly in Coastal Odisha. In this context, empirical evidence of adaptation is identified and classified.

To define "adaptation" for incorporation into the inventory, the authors adopted a comprehensive perspective, i.e., adaptation as encompassing any decisions or modifications made in response to climate change, whether in reaction to existing or anticipated climate-related challenges (IPCC 2022). This expansive definition enabled the inclusion of a diverse array of adaptations, which could also be classified as developmental efforts, risk management strategies, or resilience-building measures (Eakin et al. 2009).

The data in the inventory consists of documented instances of adaptation based on empirical evidence. It is crucial to recognize that this collection is not randomly chosen, nor does it provide a complete overview of all adaptation activities. Rather, it comprises interventions that are in the public domain or published. This method, previously employed in the UK (Tompkins et al. 2009), tends to prioritize reports from the government and NGOs, potentially neglecting adaptation initiatives from the private sector and individuals.

It is intriguing to explore the factors driving adaptation and discern whether it is primarily driven by climate change or other influences. A better understanding of these triggers enables governments to leverage them to promote the widespread adoption of adaptation strategies. By examining whether adaptations were prompted by sudden events (like cyclones and floods), or other factors, we investigated the underlying drivers of adaptation. While many examples in the inventory did not specify the driving forces behind adaptation, some insights can still be gleaned from the compiled information. Thus, this adaptation inventory focuses on one of India's hotspot disaster states, particularly Coastal Odisha. The inventory will help to understand the type of adaptation interventions that have helped communities adapt to the changing climate dynamics in this part of the world.

The structure of the article is as follows: the material and methods section outlines the data collection methods and analytical procedures, followed by the results and discussion section, which investigates the adaptation strategies, and finally, the last section provides the conclusion.

Material and Methods

Study Area

Odisha is located between 17°49′ to 22°34′ North Latitude and 81°27′ to 87°29′ East Longitude. It shares borders with West Bengal to the northeast, Bihar and Jharkhand to the north, Andhra Pradesh to the southeast, Chhattisgarh to the west, and is bounded by the Bay of Bengal to the east. The state has a coastline of approximately 480 km and covers a total area of 155,707 km^2, making up about 4.87 percent of India's total area. Odisha is divided into four main geographical regions: the Northern Plateau, Central River Basins, Eastern Hills, and Coastal Plains. The northern part of the state, above 20°N latitude, generally has elevations up to 500 m above sea level, while the southwestern districts have elevations reaching 1,500 to 1,600 m. The Eastern Hills are generally elevated around 900 m above sea level. The Odisha coastline, which is 480 km long and ranges from 10 to 100 km in width, is

part of India's east coast. Several rivers, including the Mahanadi, Brahmani, Baitarani, Devi, Budhabalanga, Subarnarekha, and Rushikulya, drain this coastal area. The coastline aligns obliquely with the global wind system, creating strong littoral currents and making it one of the world's largest littoral drift regions. Other significant coastal features of Odisha include mangroves, estuaries, and various sedimentary and sandy environments such as sand dunes.

Data Collection

The data collection approach is based on the work of Smit et al. (2001), and utilizing methodologies previously employed by Tompkins et al. (2009), an inventory of observed adaptations was created for Coastal Odisha. This approach, adapted from the DECCMA project (www.deccma.com), involved conducting a literature review to gather empirical evidence on adaptation. The review incorporated both journal articles and gray literature available online from government websites, research organizations, INGOs, and NGOs.

The data were gathered based on fundamental inquiries specified by Smit et al. (2001). The specific inquiries are as follows: (1) What are the triggers or drivers prompting adaptation? (2) Who is implementing and benefiting from the adaptation efforts? (3) What are the overarching objectives of the adaptation in terms of reducing risks, decreasing social vulnerability, and fostering socio-ecological resilience?

The information compiled represents empirical evidence of adaptation practices. It is not a randomly chosen selection of adaptations, nor does it aim to describe the entirety of adaptation efforts. The search for adaptation strategies was based on critical/key sectors identified by a document, Odisha Climate Change Action Plan (Forest, Environment and Climate Change Department, n.d.). This document helps identify sectoral interventions that key departments of the state undertake. The inventory generated using methods applied in the UK context (Tompkins et al. 2010) focuses solely on published works, thereby primarily capturing documented evidence of adaptation. This approach inherently limits the identification of private sector or individual adaptation efforts, which are often not available in publicly available resources.

The authors collected data on adaptation strategies from peer-reviewed literature, government department websites, INGOs, and NGOs. The collected data was collated in a spreadsheet template. The information on each adaptation activity/intervention was documented with respect to the central theme highlighted by Smit et al. (2001) on the provider/beneficiary and function/effects of adaptations.

The limitation of this approach is that the inventory does not represent a comprehensive sample of all data available on observed climate change adaptation in Odisha; rather, it consolidates interventions and published literature on adaptation in the region.

For analyzing adaptation interventions, the frameworks that help in analyzing the adaptation strategies are the Sustainable Livelihood Approach, Sendai Framework for Disaster Risk Reduction, and Millennium Ecosystem Assessment. From the review of the literature, it is well understood that adaptation helps reduce vulnerability and disaster risk. It also contributes

toward strengthening the ecosystem (Eakin et al. 2009; Ensor and Berger 2009). Understanding vulnerability and its interaction with different elements within it, such as shocks, trends, and seasonality, plays a critical role in defining the vulnerability context of the household and how different livelihood capital, such as physical, human, financial, and social capital, plays a role in strengthening the livelihood/adaptation strategies of household at the village level. Thus, the Sustainable Livelihood Framework forms the basis of adaptation as capitals help enhance income and strengthen livelihood systems (DFID 1999). The Sendai Framework for Disaster Risk Reduction framework (UNDRR 2015) is a guiding document that helps us understand various aspects of disasters and how they interact with vulnerabilities. It emphasizes how strengthening adaptation actions can reduce disaster risk and lessen vulnerability. The MEA (2005) addresses the third aim of adaptation, which is building social–ecological resilience. In analyzing the adaptation interventions, the review article has referred to the inventory of adaptation to climate change in the UK (Tompkins et al. 2009), the state of the adaptation in the context of the Paris Agreement (Tompkins et al. 2018), and observed adaptation in the deltas (Tompkins et al. 2017).

Results and Discussion

Adaptation Drivers in Coastal Odisha

The drivers of adaptation can be classified as climate-related or non-climate-related drivers. Climate-related drivers include cyclones, floods, drought, and heat waves, whereas non-climate-related drivers help build adaptive capacities. Non-climate drivers are generally indirect drivers, which is reflected in terms of sustainable development policies, regulations, and corporate social responsibility programs (Tompkins et al. 2009). Coastal Odisha is a hotspot for cyclones, floods, erosion, and drought (Kumar et al. 2010; Bahinipati and Sahu 2012; Das 2009; Chittibabu et al. 2004). The annual report of natural calamities data indicates that in the last twenty-three years, the state has faced as many as ten cyclones of high- to moderate- and low-intensity cyclones. The cyclonic storms have also led to storm surges in many parts of Coastal Odisha (Special Relief Commissioner, n.d.-a). The climate drivers concerning different sectors in Odisha have been identified. Table 1 indicates the sectors and climate drivers of cyclones followed by floods and coastal erosion drive adaptation by different adaptation providers.

Table 1: Drivers of Adaptation

Sectors	*Drivers*
Agriculture and Farmers' Empowerment	Increases in temperature, erratic rainfall, and dry spells lead to drought-like situations and crop loss due to cyclones and saline water intrusion in coastal regions (Special Relief Commissioner, n.d.-b)
Fisheries and Animal Husbandry	The rise in sea surface temperature results in the migration of many valuable species to lower layers, which leads to a drop in the catch of many species (Dineshbabu et al. 2020; Responsible Seafood Advocate 2023). The reduction in the number of available fishing days due to depressions and cyclonic disturbances, as well as loss of land-to-sea, affects the sector severely

Water Resource Management	Urbanization has led to the conversion of land into built-up spaces, directly impacting the hydrological set-up of a city area (Sahu et al. 2021). Some of the cities with critically low groundwater resources may lead to water scarcity (Pradhan 2016)
Health and Family Welfare	An increase in temperature, humidity, and erratic rainfall patterns leads to heat stress problems and may also result in vector-borne diseases (Thomson and Stanberry 2022)
Energy Sector	Extreme climate events like floods, storms, and cyclones destroy the transmission and distribution infrastructure (Special Relief Commissioner, n.d.-b)
Forests, Environment and Climate Change	Climate-induced dry spells and anthropogenic causes might exacerbate the existing stress on forest resources. Forest fire affects the flora, fauna, and biodiversity of the forest ecosystem (Mohanty 2023)

Adaptation Interventions Catalog

In the material and methods section, we have discussed the climate drivers that affect Coastal Odisha. In this section, we have addressed the adaptation intervention undertaken to counter the impact of those drivers. The following table presents a catalog of the adaptation measures with a brief description:

Table 2: Catalog of Adaptation Strategies with a Brief Description

Events	*Options*	*Strategies*	*Short Description*	*References*
Cyclones, Floods, and Storm Surges	Nature-based Solutions (NbS) like Mangrove and Casuarina Plantations	The plantation of mangroves and casuarina near the coastline protects from cyclonic storms and tidal surges and provides a host of ecosystem services that include livelihood aspects	Mangroves are known for storm surge protection and help local communities augment their livelihood portfolio by providing a breeding ground for fishery resources, which ultimately help the marine fishing communities in their increased catch and other ecosystem services	Das (2022); Barnes (2022); Chow (2018); UNDP (n.d.)
	Housing under the Odisha Disaster Recovery Project	The concrete houses were constructed near the coastline to withstand high wind speeds	Under the Odisha Disaster Recovery Project, concrete houses were constructed in the vulnerable districts of Odisha to protect communities from extremely severe cyclonic storms	Gram Vikas (2013)
	Structural Interventions	Construction of multi-purpose cyclone and flood shelters	The multi-purpose cyclone/Flood Shelters protect communities residing near the coast in case of cyclones and floods, as they are equipped with all basic amenities. These shelters are managed by Cyclone/Flood Shelter Maintenance and Management Committees, which provide cooked food and other basic facilities	Dash and Walia (2020)

Saline Water Intrusion	Livelihood Diversification/Alternative Livelihood	Climate-tolerant crops	Saline and stress-tolerant paddy varieties that can withstand floods, saline water intrusion, and pest attacks. Climate-smart practices help increase productivity and can withstand extreme and slow-onset disasters	International Rice Research Institute (IRRI and DA&FE 2022); Mitra et al. (2021)
		Fattening of mud crabs and other Women's Self Help Groups (WSHGs) driven activities (such as promotion of microenterprises, poultry farming, and coir-based products)	Fattening of mud crabs through various processes to increase local market value. The Government of Odisha has taken giant strides in the empowerment of women through the promotion of WSHGs and SHGs-driven enterprises. The WSHGs were supported by capacity building, financial inclusion, livelihood, and market linkage	Lalramchhani et al. (2019); Department of Mission Shakti, Government of Odisha (n.d.)
	Food Security/ Diversified Livelihood	Floating garden	Floating farming is a method utilized for food production in regions prone to prolonged waterlogging. Its primary objective is to adjust farming practices to accommodate rising or prolonged flood occurrences. This approach involves utilizing floating platforms made from decomposing vegetation, serving as a nutrient-rich base for cultivating crops. These floating platforms are designed to remain buoyant on the water's surface, effectively transforming waterlogged areas into viable agricultural land	Council on Energy, Environment, and Water (CEEW 2023)
Coastal Erosion/ Sea-Level Rise	Structural Interventions	Resettlement	The Government of Odisha has built a model colony for the communities affected by coastal erosion. It is a clear case of a managed retreat where communities are resettled in a safe location (from Satabhaya in Kendrapara District of Odisha to Bagapatia) with all the facilities and amenities. They were also compensated for the loss of agricultural land	Down to Earth (2023)

Crop Loss due to Climate-Induced Disasters	Soft Interventions	Financial incentives for farmers, particularly focusing on small and marginal farmers	The main goal of crop insurance is to promote sustainable agricultural production and offer financial assistance to farmers who experience crop losses or damage as a result of unexpected events	Department of Agriculture & Farmers' Empowerment (DA&FE, n.d.)

Table 2 highlights the catalog of adaptation strategies, but when we emphasize these strategies in terms of their relevance from the perspective of saving lives and livelihood, three strategies stand out. The three strategies are as follows:

1. The state of Odisha is frequently affected by cyclones; the most important strategies in terms of reducing disaster risk and vulnerability are the construction of multi-purpose cyclone and flood shelters (Dash and Walia 2020; Jena and Kouame 2023), concrete houses, and resorting to NbS such as mangrove and casuarina plantations.
2. Due to the impact of climate-induced natural disasters, the Government of Odisha, in collaboration with the IRRI, promoted climate-resilient rice varieties, such as Sahbhagi Dhan, Swarna Shreya, Bin Adhan 11, and Swarna Sub 1. These climate-resilient rice varieties helped better to adapt to changing climate dynamics. The solution holistically addressed the problem by providing quality seeds, capacity building, and climate-smart management practices to improve the overall productivity of crops. Around 60,000 farmers benefited, and half of them were women farmers (IRRI and DA&FE 2022).
3. The resettlement of people of Satabhaya (a village affected by coastal erosion and cyclones, and a major part of the village has been engulfed by sea) has been shifted to a safer place named Bagapatia in Kendrapara district of Odisha (Down to Earth 2023)

A detailed analysis of the strategies mentioned above is discussed below with instances and examples in the context of Odisha. From the literature review, we classify the data from the inventory of Coastal Odisha into different sectors, such as DRR, water resource management, agriculture-based livelihood, coastal zone management, education, research, and others.

The state of Odisha is known across the world for its adaptive governance model and DRR efforts (Walch 2018; Banerjee and Mohapatra 2023). To reduce the impact of disaster and strengthen adaptation efforts, a considerable proportion of disaster risk management initiatives range from long-term risk reduction, like infrastructural interventions like cyclone shelters, to medium-term preparedness in terms of warming systems, capacity building, and training. During the last fifty years, it has been observed that food production has decreased

by 40 percent in the state (Planning and Convergence Department 2010, 2012). The agricultural adaptation initiatives were undertaken as a large chunk of the coastal population is still dependent on climate-sensitive sectors, i.e., agriculture and allied sectors. The activities undertaken for strengthening the agricultural livelihood are crop diversification (from mono-cropped paddy to vegetables and fruits), climate-smart agricultural practices (Swarna sub-1 and Lunashree varieties), contingency planning, awareness building on climate change, integrated watershed management have strengthened the adaptive capacity of the sector (Department of Forest, Environment and Climate Change [DoF, E & CC], Government of Odisha 2018). The promotion of organic farming as a production system that supports the use of green manure, bio-fertilizers, vermicompost, and other traditional cropping methods (Government of Odisha 2018). The crop insurance schemes, especially the weather-based crop insurance schemes, have performed well, and it is observed from the adaptation inventory that they have helped communities adapt to climate change (Swain and Patnaik 2018). Further, initiatives in the water resources and coastal zone management sector, such as the construction of embankments, highlight the adaptation measures undertaken by the state to counter the multiple forms of hazard faced by the state. The capacity-building activities and livelihood diversification activities in the form of providing training to adopt alternative livelihood practices (women-led microenterprises, poultry farming, culture fisheries, and coir-based products) have helped the communities diversify and adapt to climate variability and change (www.iczmpodisha.org). The impact of cyclones and flooding has led to a host of preparedness activities (mock drills, capacity building, training, etc.). Thus, multi-purpose cyclone shelters were constructed on a large scale in Coastal Odisha to adapt. At the same time, the Department of Water Resources, Government of Odisha, has undertaken various initiatives such as renovation of canals and construction of saline embankments as a part of strengthening the infrastructure base. Significant developments have been made in the form of non-structural interventions, such as flood forecasting systems.

In the context of providing safe shelters and reducing vulnerability, the Odisha State Disaster Management Authority has constructed over 800 multi-purpose cyclone shelters and evacuation roads along the entire coastline of the state. Embankments are being erected to shield seaside villages from sea intrusion, and numerous vulnerable families have been relocated from straw huts to new multi-hazard, disaster-resistant houses (Jena and Kouame 2023).

Significantly, Odisha is the first Indian state to establish an early warning system for conveying crucial disaster-related information to the most remote areas. Approximately 1,200 villages in all the coastal districts now receive cyclone or tsunami alerts through sirens and mass messaging. This early warning system, supported by watchtowers in over 120 coastal locations, is the foundation of Odisha's disaster preparedness and response (Jena and Kouame 2023).

The Integrated Coastal Zone Management Plan (ICZMP) comprehensively addresses the issues with respect to multi-coastal impacts through institutional, structural, and livelihood

interventions.[1] The construction of a geo-tube to prevent coastal erosion in Pentha (Kendrapara district of Coastal Odisha) is an example in the above context. The management of coastal habitat through community-led mangrove plantations has helped the communities against the storm surge (Das 2022). The Ministry of Forest, Environment, and Climate Change, along with the Government of Odisha, UNDP, and the Green Climate Fund, has undertaken initiatives to strengthen the climate resilience of the communities of the coastal regions of Odisha through a host of programs such as strengthening the ecosystem services, climate adaptive livelihoods, and NbS initiatives such as mangrove conservation and plantation (UNDP, n.d.).

In the context of coastal erosion and impacts such as the sea-level rise, the Satabhaya gram panchayat within Kendrapara district of Odisha has lost eleven villages to the sea. The geomorphologic change of Coastal Odisha and Satabhaya village has been significant (Roy et al. 2018). From the analysis of time-series satellite images, the shoreline shifting from a landward direction from 1929 to 2015 is 436 m. Thus, the Government of Odisha decided to resettle around 818 households to a safer place in the village of Bagapatia under Gupti gram panchayat in the Kendrapara district of Odisha. The government has provided land and other basic amenities in the resettled location. This is an example of a managed retreat in the context of adaptation to climate change in Coastal Odisha, India.

In terms of strengthening socio-ecological resilience, regulating services such as climate regulation and erosion control are important. The state of Odisha has strengthened its approach by following the State Action Plan on Climate Change and through its important elements such as renewable energy policy and low carbon development policy in the transportation sector by offering services such as Capital Region Urban Transport Services (CGBA and Shakti Sustainable Energy Foundations 2020). The erosion control measures such as geo-synthetic tubes (Hindu 2016) and the planting of mangrove trees that prevent erosion have helped the communities residing near the coast.

Community-Level Initiatives

The saltwater intrusion has affected agriculture, thereby limiting livelihood options. Thus, as a part of climate change adaptation, farming mud crabs in small bamboo cages was undertaken by the communities residing in the coastline of Rajnagar block of Kendrapara district of Odisha with support from IGSSS and local NGO under the sustainable options for livelihood program. It started with a few marginal fishermen and farmers in the saline water bodies close to their homestead land. The model is found to be replicable and locally appropriate for the community as there are instances of low pressure, which has significantly reduced the fish catch and contributed to their additional income. The impact of saltwater intrusion has led to diversifying livelihood and adopting salt-tolerant crop cultivation of different varieties.

[1] www.iczmpodisha.org

The floating garden provided the scope to farm on water using the water hyacinth that has become a threat to water bodies and the waterlogged areas in the region. Thus, their vegetable needs are met, and the water bodies are cleared of water hyacinths, leading to better sanitation and availability of water (*CEEW* 2023). The Integrated Rice-Fish Culture practice, an alternative livelihood option introduced by the Regional Centre for Development Cooperation (RCDC, a state-level NGO) in the Rajnagar block of Kendrapara in Odisha, is another example of a climate-smart agriculture option that diversifies risk by combining paddy and vegetable cultivation with pisciculture and protects the units from floods and winds by raising bunds and planting horticultural tress on them (RCDC 2016).

Adaptation Providers and Beneficiaries

From the adaptation inventory, it is observed that the government is the main provider of adaptation, followed by International and National NGOs (Tompkins et al. 2017). The ways of categorizing adaptation are in accordance with the framework of Eakin et al. (2009). It is observed from the qualitative data analysis that 35 percent of the adaptation reduces disaster risk, 45 percent of the activities/interventions help in reducing vulnerability, and 20 percent of the interventions promote and strengthen ecological resilience building. The specific findings from the adaptation inventory indicate how some of the initiatives listed in Table 3 have reduced disaster risk. DRR measures are generally categorized as long-term, medium-term, immediate response, and post-disaster recovery and reconstruction and rehabilitation (UNDRR 2015). The types of DRR measures are as follows:

Table 3: Disaster Risk Reduction Measures

Aspects of DRR	*Examples from Coastal Odisha*
Long Term	Construction of multi-purpose cyclone and flood shelters (MCS/MFS), Strengthening of Early Warning System and Impact-based Forecasting, and creation of coastal infrastructure and water resource management initiatives
Medium Term	Maintain existing infrastructure (embankments and drainage systems), active stakeholder engagement in the design and delivery of DRR, Education, and training at village and school level for DRR Management (Evacuation training, for example, Mock Drills for Cyclone Management and Tsunami Evacuation), Capacity Building of community volunteers
Immediate Response	Temporary shelter, food, and hygiene services
Post-Disaster recovery	Rebuilding infrastructure (homes, saline embankments) under state and central projects

Another key finding of the adaptation inventory is how the vulnerability reduction measures in terms of strengthening the livelihood capitals in accordance with the Sustainable Livelihood Approach have reduced the vulnerability. Some of the key aspects of vulnerability reduction measures are listed in Tables 4 and 5.

Table 4: Aspects of Vulnerability Reduction

Aspects of Vulnerability Reduction (Livelihood Capitals)	*Examples from Coastal Odisha*
Natural Capital	Potential Fishing Zones (PEZ) and Livelihood Diversification activities in the form of training and capacity building in ICZMP for small-scale fisheries
Human Capital	Climate-resilient farming practices, use of climate-tolerant and indigenous crop varieties, promotion of off-farm livelihood activities, training, and capacity building of community to improve farm productivity
Social Capital	Promotion of farmer co-operatives, organizations, and women SHGs that strengthen collective bargaining power and overall adaptive capacity and community-based disaster risk reduction initiatives
Physical Capital	Create climate-resilient infrastructure as a part of the National Cyclone Risk Mitigation Project and climate-resilient housing schemes of the state and central government
Financial Capital	Weather-based insurance schemes, credit, subsidies for development, and strengthening of agriculture and its subsector

The adaptation inventory also sheds light in accordance with MEA 2005 and provides us with an understanding of how ecosystem services are being supported, created, or affected by adaptation activities. In Coastal Odisha, there is documentary evidence on different aspects of ecosystem services, such as provisioning services and regulating and cultural services.

Table 5: Aspects of Creation of Ecological Resilience

Aspects of the Creation of Ecological Resilience	*Examples from Coastal Odisha*
Provisioning	Mixed land use (e.g., Integrated Rice-Fish Culture, Seed bank for crop diversification at the community level, and water management initiatives)
Regulating	Enforcement of regulations, Protection of Biodiversity and Forests, Incentives and rewards for community-based organizations and individuals for plantation and tree crops
Cultural	Conservation of wildlife and biodiversity in natural heritage sites (e.g., Bhatarkanika Wildlife Division)

Conclusion and Inferences

The article highlights the types of adaptations occurring across Coastal Odisha and how these adaptations have reduced the vulnerability of disaster risk and strengthened socio-ecological resilience. Agriculture, water resource management, disaster management, and coastal zone management are the top three sectors where a maximum number of adaptations are being undertaken. The government is the top adaptation provider, followed by national and international organizations. The community is the main beneficiary in the context of adaptation intervention. Around 35 percent of the interventions fall in the category of DRR, 45 percent of the interventions under vulnerability measures, and only 20 percent of measures fall in the category of ecosystem resilience to deliver adaptation. Ecosystem resilience is

reflected in terms of provisioning, regulating services, and cultural services adaptation activities undertaken in Coastal Odisha, which have undoubtedly strengthened ecological resilience and reduced vulnerability. However, the state government's efforts have been commendable in managing the disaster and providing relief services. To support the argument, data from the Special Relief Commissioner reveals that fatalities numbered around ten thousand in the 1999 super cyclone but decreased to 45 in 2013 Cyclone Phailin in 2013 and nearly reached 'Zero Casualty' in subsequent cyclones. Most of the adaptation activities cater to DRR and vulnerability reduction because Coastal Odisha is a major disaster-prone area. From the adaptation inventory, it has been observed that shocks triggered by cyclones, followed by heavy rain and saltwater intrusion were driving the adaptations. However, the stress and seasonal impact of climate change were evident. Thus, it is clear that most shocks contribute to drive adaptation in Coastal Odisha.

The research undertaken is just an indicative list and not exhaustive documentation of all the adaptations that are being undertaken in the state of Odisha. The research broadly identifies the key areas of intervention in terms of adaptation to climate change. The limitation of the research is that the adaptation inventory prepared is not an exhaustive list of adaptation interventions. It is just an indicative list. It does not take into account the autonomous or household adaptation that is taking place at the household level.

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The authors declare that generative AI or AI-assisted technologies were not used in any way to prepare, write, or complete essential authoring tasks in this manuscript.

Informed Consent

The authors have obtained informed consent from all participants.

Conflict of Interest

The authors declare that there is no conflict of interest.

Data Availability

Data compiled and collated in an Excel template is available upon reasonable request.

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ABOUT THE AUTHORS

Sumanta Banerjee: Research Scholar, Department of Economics, Ravenshaw University, Cuttack, Odisha, India
Corresponding Author's Email: sumantabanerjee005@gmail.com

Souryabrata Mohapatra: Associate Fellow, NCAER, New Delhi, Delhi, India; Affiliate, University of Auckland, Auckland, New Zealand
Email: smoh876@aucklanduni.ac.nz