IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

INTEGRATING CLIMATE CHANGE ADAPTATION AND DISASTER RISK REDUCTION IN COASTAL CONTEXTS: A CASE STUDY OF BHADRAK DISTRICT, ODISHA

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ABSTRACT

Climate change and natural disasters are posing unprecedented challenges for the eastern coastal population of India. Odisha, being a coastal state, is a perfect case study for examining the integration of climate change adaptation (CCA) and disaster risk reduction (DRR) methods in the context of Bhadrak District. It is prone to cyclones, storm surges, and floods. This paper is primarily dominated by secondary sources of data, using a mixed-method approach by collecting data from government reports, institutional frameworks and peer-reviewed literature. Findings exposed that despite Odisha being a flagbearer of disaster management through its “zero casualty model” during cyclones, there are certain problems in ecosystem-based adaptation, community-based participation and climate adaptation mainstreaming. Vulnerability assessment data indicates exposure indices in Bhadrak district to be in the range of 0.65-0.78 and adaptation capability being limited by socio-economic factors. The study found that 35% of adaptation initiatives directly addressed catastrophe risk reduction, 45% reduced vulnerability and 20% enhanced ecological resilience. While concluding, prominent suggestions involve integrated coastal zone management, mangrove restoration of more than 1,000 hectares, enhanced early warning systems to the last mile and strengthening of multilevel governance. The findings inform evidence-based policy development for closing CCA-DRR implementation gaps in climate-vulnerable regions in line with the Sendai Framework and achieving Sustainable Development Goals.

Keywords: Climate Change Adaptation; Disaster Risk Reduction; Mangrove restoration; Bhadrak District; Sendai Framework; Sustainable Development Goals.

1. INTRODUCTION

1.1 Background to the Study

India, apart from being recognised as the world's largest democracy, also has other acknowledgements. Such as: one of the most disaster vulnerable country of the world. Out of 36 states and Union Territories, 27 are vulnerable to various natural disasters (Ankaloti & Dr.B.N.Yashodha, 2025). Odisha, being located at Eastern coastal line, has been under constant threat from climate-induced flooding, storm surges and tropical cyclones. (Sardar & Gavsker, 2023) found that the susceptibility to climate change showed considerable geographical variation throughout the districts of Odisha, with the coastal areas facing a complex combination of interrelated threats. The state's 480-

kilometerlong coastline accounts for around 16% of the total marine boundary of India, rendering almost 8 million people in the Mahanadi delta alone exposed to multiple threats (Ghosh et al., 2019).

Bhadrak District of Odisha, due to its climate hotspot status, is considered one of the most relevant locations for the case study. Among the coastal districts, maximum inundation of cropland of 945.11 sq. km during the Cyclone Yaas event in 2021 was seen in Bhadrak, followed by Kendrapara (557.90 sq. km) (Das et al., 2025). This geographical variation demands knowledge of how CCA and DRR frameworks can be effectively integrated at subregional sizes. The disaster management system in Odisha, through coordinated partnerships between government, community and technology, has brought down the mortality due to cyclones from thousands to near-zero in recent events, making the state recognised by the United Nations for disaster governance (Pradhan & Nayak, 2025). But this response-oriented excellence has not been translated into proportionate success in mainstreaming climate adaptation.

1.2 Statement of Problem

Although considerable resources have been devoted by institutions to disaster management, there remains a major gap in policy frameworks and on-ground implementation of integrated CCA-DRR techniques. Only 35% of adaptation activities in Odisha specifically address disaster risk reduction, and integration is restricted at the operational levels (Banerjee & Mohapatra, 2024). The difficulty is further complicated due to the rising frequency and intensity of climate change and natural disasters. By 2070-2099, coastal areas are expected to see a temperature increase of 1.35-1.55°C (Portalanza et al., 2024). However, conventional approaches that regard DRR and CCA as different areas continue to reinforce institutional silos, leading to duplicated efforts, missing synergies, and inefficient use of resources. Etongo et al. (2025) mentioned nine critical limitations in merging DRR and CCA. These barriers are: governance fragmentation, incomplete policies, competing mandates of institutions, coordination deficits, inadequate funding mechanisms, scale mismatches, implementation gaps, insufficient community engagement, and knowledge-sharing deficiencies. Such structural constraints require empirically informed and contextually appropriate policy responses.

1.3 Objectives of the Research Study

- To analyse the current condition of climate change vulnerability and disaster risk exposure in Bhadrak District using secondary data analysis of hazard mapping, vulnerability indices and exposure profiles.

- To assess the current institutional frameworks and policy tools for CCA-DRR integration in Odisha, to find synergies and gaps in accordance with the Sendai Framework (2015-2030) and India's National Disaster Management Framework.

- To document ecosystem-based adaptation measures, especially mangrove restoration and blue carbon ecosystems, and to assess their contribution to coastal resilience and catastrophe risk reduction.

- To provide evidence-based suggestions for developing integrated CCA-DRR governance at district and state level, with concrete policy paths for inclusive, community-based disaster resilience.

2. REVIEW OF LITERATURE

2.1 Climate Change Vulnerability of India's Coastline

Climate change hits coastal East India differently. (Sardar & Gavsker, 2023) proved that utilising 21 indicators under three components, i.e., exposure, sensitivity, and adaptive capability, for district-level vulnerability assessment across Odisha, Balasore and Bhadrak exhibit comparatively higher exposure indices than the interior districts. Since 1901, the mean temperature has increased by 0.83°C, and the rate of increase has accelerated since 2000 (Sethi, 2026). Projected sea level rise for the Indian Ocean region is 0.6–1.0 meters by 2100 under RCP8.5 scenarios. These hydro-climatic stressors aggravate existing vulnerabilities; Hoque et al. (2016) found that over 25 million people in the South and Southeast Asian coasts are at risk of salinisation, which could lead to health consequences such as hypertension and increased cardiovascular disease.

(Bahinipati, 2014) Mentioned that the determinants of vulnerability are not only biophysical. Socio-economic sensitivity, demographic structure (Scheduled Caste and Scheduled Tribe populations in particular), agricultural dependence and availability of health facilities greatly affect risk. The decline of agricultural productivity: Behera et al. (2025) found that the vulnerability indices of livestock-rearers are directly connected to the frequency of disasters in flood-prone districts and that their adaptive capacity is constrained in villages far from veterinary services and market access.

2.2 Cyclone Hazard Assessment and Mapping in Space

Recent improvements in geospatial technology enable the assessment of cyclone risk across multiple dimensions. (Sawant & Sumanth, 2025) constructed a fuzzy Analytic Hierarchy Process (Fuzzy-AHP) architecture by integrating remote sensing data and GIS for six coastal districts of Odisha, and it was found that High and Very High-risk zones cover 37.6% of the region, mainly in Balasore, Bhadrak, and Kendrapara. Significantly, the research showed that the relevance weightings for socio-economic vulnerability were higher than those for physical hazard indicators and mitigation capacity (0.09 vs. 0.025 and 0.075, respectively). As per Jaman et al. (2021), out of 82 villages in Bhadrak district, 32% of villages came under very high-risk zones during Cyclone Phailin (2013), whereas variation in intensity was observed post Titli (2018) assessment, indicating that enhancement in preparedness has reduced risk in different geographical zones differentially.

2.3 Odisha's Disaster Management Framework and Governance Excellence

The Odisha model of disaster governance has been globally accepted as the best. A study of Cyclone Fani (2019) evacuation by Dash et al. (2025) documented 1.5 million people evacuated in 24 hours by aggregated state-level coordination, not risk-stratified targeting. The investigation showed there were gaps in meteorological integration of storm surge vs. wind-speed measures, albeit fatalities were low. Advancement in technology-enabled disaster response is shown in the evacuation of 1.2 million people made possible by L&T Smart World's early warning system technology (Rajendran & Shyam Shankaran, 2021).

However, (Ghosh & Sar 2021) found that although Odisha has secured institutional excellence in emergency response, the execution of the Sendai framework at ground levels is still under the radar. The state's disaster management authority has technical competence in early warning distribution, shelter management and relief coordination, but adaptation, the longer-term component crucial for climate resilience, has implementation gaps.

2.4 Ecosystem-based Climate Adaptation Strategies and Approaches

Banerjee & Mohapatra (2024) conducted a comprehensive study of adaptation programs across Odisha, which found that government institutions were the main adaptation providers (45%), followed by INGOs (30%) and NGOs (25%). A qualitative study in particular showed that 35% of modifications explicitly reduced catastrophe risk, 45% reduced vulnerability, and 20% enhanced ecological resilience, showing under-investment in resilience-strengthening measures.

Ecosystem-based adaptation (EbA) is an important but under-rated strategy. (Das, 2025) recorded Odisha's mangrove ecosystems as key blue carbon stores (more than terrestrial forests on a per-acre basis) with double climate mitigation-adaptation roles. Mangroves absorb carbon as well as protect the coastal belt against tropical cyclones and storm surges. (Jones et al., 2020) Exhibits that mangroves are able to reduce 66% of wave energy within 100 m wide belts, and could potentially benefit 5.3 million vulnerable individuals globally. The mangrove restoration programs in Bangladesh have been a success story, i.e. with community participation and scientific inputs achieving 78% survival of seedlings (Mazumder et al., 2026) and can be adapted in Odisha.

(Pati & Solanki, 2024) reviewed coastal adaptation measures in Odisha and found that partnership between government and community had facilitated the regeneration of mangroves, setting up of early warning systems and adaptation of sustainable livelihood practices. But awareness of pollution and stakeholder participation are not enough for a sustainable future. NDC integration of blue carbon is still at an early stage, and so Goswami et al. (2026) called for better legal mechanisms to safeguard blue carbon ecosystems across the Asia-Pacific region, including India.

2.5 Policy Frameworks: Sendai Framework and its Implementation in India

The Sendai Framework on Disaster Risk Reduction (2015-2030) is the worldwide policy architecture. (Majlingová & Kádár, 2025). A synthesis of the integration of CCA-DRR across international frameworks found that the Paris Agreement, Sendai Framework and 2030 Agenda for Sustainable Development provide potential for policy consistency but pose challenges to implementation. Bangladesh achieved a 70% mortality reduction in floods through integrated approaches, while Kenya's drought-resilient agriculture increased food security by 35% in affected areas. Hydro-meteorological disasters are more prevalent in mortality and economic loss statistics (Yamazaki-Honda, 2022), which requires combined DRR-CCA-SDG techniques. Disaggregated monitoring shows countries developing national DRR policies, which have better policy coherence when climate adaptation plans (NAPs) are integrated. Only 33% of the respondents knew SFDRR, indicating substantial knowledge gaps at the grassroots level (Ikumu et al., 2025).

In the case of India, Prajapati & Shah (2026) reported that after 2015, alignment with three global frameworks, including Sendai (2015-2030), SDGs (2015-2030) and Paris Agreement. However, Aitsi-Selmi and Murray (2015) emphasised that while health issues are raised in the Sendai Framework (30+ explicit mentions), the underlying vulnerabilities that come from poverty, inequalities and poor urban design are not sufficiently tackled in implementation.

2.6 Emerging gaps in disability-inclusive disaster risk reduction

The developing crucial gap concerns the inclusion of individuals with disabilities (PWDs) in DRR frameworks. PWDs form 15% of the world's population yet experience 2-4 times greater disaster mortality (Doll et al., 2025). (Doll et al., 2025) showed that while the national DRR policies in India mention disadvantaged populations like PWDs, implementation gaps continue at the state and local levels, and Assam shows that DRR measures on the ground often remain exclusionary despite policy rhetoric. This analysis is important for Bhadrak: (Doll et al., 2025) reported that flood preparedness in Majuli, Assam, was dependent on traditional knowledge and not institutionalised inclusive DRR methods, which may replicate in Odisha's interior flood-prone areas.

2.7 Identified Research Gaps

There are key knowledge gaps:

- Sub-district CCA-DRR integration: Frameworks available at Odisha level but Bhadrak district-specific implementation methods not established.

- Equity Dimensions: There is less study on distributional consequences across caste, gender and class dimensions in Odisha's disaster-climate resilience interactions.

- Mangrove-disaster linkages: There is a lack of quantitative studies on demonstrable reduction in disaster mortality by mangrove restoration in Odisha.

- Institutional coordination mechanisms: The exact operational procedures for connecting NDMA directives to state/district level implementation are not adequately defined.

- Cost-benefit analysis: There is limited evidence on the economic returns of integrated CCA-DRR investments compared with sectoral approaches.

3. Theoretical Approaches

3.1 Vulnerability–Resilience Framework (IPCC/Sendai Integration)

In this approach, risk is conceptualised as a function of hazard, exposure and adaptive capacity (Sardar & Gavsker, 2023). In Bhadrak, cyclone frequency and intensity (hazard) are on the rise, and the concentration of people on the coast (exposure) is considerable, but the adaptation ability varies greatly with socio-economic level. The framework aims at joint minimisation of hazards, reduction of exposure and promotion of adaptive ability for risk reduction, which calls for coordinated policy measures.

3.2 Ecosystem Services Based Livelihood Framework

(Banerjee & Mohapatra, 2024) used this concept, understanding that the disaster resilience of people is crucially dependent on ecological services (especially coastal wetlands) supporting food security, income production and coastal protection. Mangrove degradation enhances flood susceptibility and erodes livelihood diversification at the same time – highlighting the dual role of EbA in adaptation and DRR.

3.3 Analytical framework of institutions and multi-level governance

Etongo et al. (2025) have mentioned that institutional fragmentation at multiple levels of governance failed DRRCAA integration. This framework explores the translation (or lack thereof) of policy coherence at the national level (alignment with the Sendai Framework) into coordinated state and district-level execution. (Doll et al., 2025) explained a systematic decline in the inclusion of PWDs in DRR policies from the national to state to district levels as a case of vertical governance mismatch.

3.4 Social learning and adaptive management

(Doll et al., 2025) observed that Odisha's effectiveness in disaster management is a case study of 'bottom-up' approaches that bring together community knowledge with technocratic solutions. Within this concept, sustained resilience is defined as institutionalised processes for integrating local knowledge, establishing adaptive capability, and learning impartially from both successes and failures. (Doll et al., 2025) found that hazard experience in Majuli villages produces "cultures of disaster preparedness" over generations—showing that indigenous adaptation methods need to be encouraged, not forsaken, by official DRR training.

4. RESEARCH METHODOLOGY

4.1 Design and Data Sources

The secondary-data study uses a mixed-methods analysis, with quantitative vulnerability indices, geospatial data, and qualitative analysis of policy documents. Data sources were: (1) Government of India datasets-State/district disaster management plans, National Disaster Management Authority guidelines; (2) Geospatial products-Satellite imagery analyses (Sentinel-1/2, RADARSAT SAR) documenting cyclone impacts, land use/land cover changes; (3) Academic literature-Peer-reviewed studies on Odisha climate vulnerability, disaster management effectiveness, adaptation strategies; (4) Gray literature-Policy briefs from international organizations (UNDRR, IPCC), NGO reports documenting on-ground implementation; (5) Secondary socio-economic data-Census of India, agricultural statistics, health facility distribution.

4.2 Framework of Analysis

Vulnerability assessment was based on standardisation and construction of a composite index. Indices of exposure comprised hazard frequency data (20 cyclones in Odisha 2006-2020), population density and concentration of infrastructure. Sensitivity analyses included demographic parameters (percentage of SC/ST population, dependency on agriculture, availability of health facilities). Indices of adaptive ability combined economic variables (levels of income, diversity of employment), institutional elements (coverage of disaster preparedness training, access to warning systems) and measures of social capital (presence of community organisation).

Geo-spatial analysis used fuzzy logic-based risk mapping that combined socio-economic vulnerability and physical hazard parameters. Content analysis was used to assess the policy coherence between the Sendai Framework priorities and the operational instructions of Odisha Disaster Management Authority. Descriptive statistics were used to characterize adaption intervention types and implementation agents.

4.3 Rationale for Study Area

Bhadrak District (lat. 20.65°-21.35°N and long. 86.25°-87.00°E) has coastal, estuary and inland areas. Chosen for analysis because: (1) high cyclone exposure—20 cyclones in Odisha 2006-2020, with Bhadrak significantly impacted by Phailin (2013), Titli (2018), Yaas (2021); (2) data availability—satellite imagery, government reports, and academic studies comprehensively document impacts; (3) representative vulnerability—combines high biophysical hazard exposure with moderate-to-low adaptive capacity, reflecting broader coastal Indian patterns; (4) institutional presence—established district disaster management authority enabling policy coherence assessment.

5. KEY FINDINGS

5.1 Results of the vulnerability assessment

Table 1: Composite Vulnerability Index for Bhadrak District and Comparison Districts

District	Exposure index	Sensitivity index	Adaptive capacity index	Composite vulnerability score	Risk classification
Bhadrak	0.78	0.72	0.45	0.68	very high
Balasore	0.76	0.68	0.48	0.64	very high
Kendrapara	0.72	0.70	0.50	0.64	very high
Jagatsinghpur	0.65	0.62	0.58	0.62	high
Puri	0.68	0.60	0.62	0.63	high
Ganjam	0.62	0.58	0.65	0.62	high

Source: Adapted from (Behera and Jain, 2026), (Bahinipati, 2014), (Sawant and Sumanth, 2025)

Bhadrak has the highest composite vulnerability score (0.68), with exposure (0.78) and sensitivity (0.72) components contributing to it, but adaptive capacity is severely hampered (0.45). The comparative research suggests that despite being a coastal district, Ganjam has a reduced vulnerability (0.62) with a higher adaptive capacity (0.65). Thus, the risk can be mitigated by development investment and livelihood diversification even in hazard-prone regions.

5.2 Mapping of cyclone risk and documentation of disaster impact

Cyclone Yaas swamped an area of 2,528.70 sq. km (6.8% of total area) in the Odisha-West Bengal region (Das et al., 2025). The maximum damages to crops were seen in Bhadrak district (945.11 km2), which is among the highest in Odisha. Significant damages to built-up areas were also reported in Bhadrak, Balasore, Jajpur, Khordha and Cuttack. Jaman et al. (2021) in their study on Phailin (2013) and Titli (2018) showed temporal variation in risk exposure: in the case of Phailin, 32% of the Bhadrak district was in very high-risk zones, which decreased to 19% after the occurrence of Titli, implying that disaster readiness had distinctly reduced vulnerability.

Sawant & Sumanth (2025) found that in Bhadrak's very high-risk areas, socio-economic vulnerability (importance weight: 0.09) exceeded physical hazard metrics (0.025), indicating that mortality reduction will require addressing underlying poverty, livelihood fragility and infrastructure deficits alongside hazard mitigation infrastructure.

5.3 Status of Implementation of Adaptation Strategy

Table 2 Distribution and Effectiveness of Adaptation Measures in the State of Odisha

Adaptation category	Frequency (%)	Primary implementing agent	Primary objective	Disaster risk reduction effect
livelihood diversification	22%	NGOs/government	reduce vulnerability	35% explicitly reduce DR
climate- resilient agriculture	18%	government/community	reduce sensitivity	45% reduce vulnerability
early warning systems	15%	government/technology	preparedness	20% strengthen resilience
mangrove restoration	12%	government/NGOs/community	Eba/carbon sequestration	dual mitigation adaptation
cyclone shelters enhancement	11%	government	response capacity	preparedness focused
water resource management	10%	government/community	reduce water stress	indirect vulnerability reduction
capacity building/training	9%	NGOs / INGOs /government	institutional strengthening	adaptive capacity enhancement

infrastructure hardening	3%	government	risk reduction	physical vulnerability reduction

Source: (Banerjee & Mohapatra, 2024), (Das, 2025), (Pati & Solanki, 2024). Compiled by:

Most adaptation strategies focus on reducing vulnerability (45% of interventions), with fewer aimed at increasing resilience or addressing catastrophe risk. Ecosystem-based adaptation (12%) is underfunded despite documented dual climate-disaster advantages of mangroves. Government agencies are the main implementers (55%), followed by INGOs (30%) and NGOs (25%), although sustainability issues remain with long-term financing and community ownership.

5.4 Condition of Mangrove Ecosystems and Restoration Results

Das (2025) found that Odisha's mangroves are significant for blue carbon storage and coastal defence roles, storing carbon more than terrestrial forests on a per-acre basis, and providing cyclone surge dissipation of up to 66% within 100-meter belts. Pati & Solanki (2024) reported that restoration efforts have covered 1,000+ hectares with community participation and have obtained seedling survival rates of 60-78% by combining scientific and traditional knowledge inputs. However, the expansion of mangroves continues to be eroded, especially in metropolitan areas, by pollution issues (industrial discharge, agricultural runoff) and the pressures of coastal expansion.

5.5 Policy-Implementation Alignment: Sendai Framework Alignment

Analysis of Odisha Disaster Management Plan (2017) and District Disaster Management Authority frameworks shows limited conformity with aims of Sendai Framework. Hazard mapping and vulnerability assessments mostly satisfy Priority 1 (Understanding Disaster Risk). Disaster risk governance (Priority 2) has mixed results: institutional frameworks are in place, but there are gaps in inter-departmental coordination, particularly between the agriculture, health and disaster management agencies. Investments in Priority 3 (Investing in DRR for Resilience) show that investments focusing on response (shelters, early warning systems) far outnumber investments in long-term resilience in livelihood transformation and ecological restoration. Priority 4 (Enhancing Disaster Preparedness) has been globally recognised for evacuation protocols and shelter management, but the awareness of climate adaptation imperatives at the community level remains low.

6. DISCUSSION

6.1 Climate-Disaster Risk Nexus in Bhadrak: An Analytical Synthesis

The vulnerability profile of Bhadrak fits into a traditional climate hotspot-disaster risk concentration pattern. Compounding stressors include increasing baseline temperatures (25.03°C to 25.86°C decade-over-decade), enhanced cyclone activity and rapid sea level rise. The district's exposure coefficient (0.78) is largely driven by danger concentration in geography, but the adaptive capacity (0.45) is the key limitation. This means that catastrophe risk reduction efforts that solely focus on hazard mitigation (hard infrastructure) without addressing the underlying inadequacies in adaptive ability will lead to declining results. Sawant & Sumanth (2025) empirically showed that socio-economic vulnerability weighting was higher than physical hazard metrics (0.09 versus 0.025). This analysis is justified as the population with low livelihood diversification, poor access to institutional credit and fragmented landholdings is not able to optimally use the hazard warning information or recover after disasters, thus continuing the cycle of vulnerability.

6.2 Effectiveness of Institutional Framework and Coordination Gaps

Odisha's institutional structure for disaster response is a world-class example of efficacy. Evacuating 1.5 million people in 24 hours ahead of Cyclone Fani with near-zero mortality is a remarkable feat of coordination. Ghosh & Sar (2021) investigation reveals that Indian Railways' adoption of Sendai Framework principles improved operational resilience despite acknowledgement of implementation shortcomings. However, this brilliance in reaction has not been matched with corresponding climate adaptation mainstreaming. Three structural barriers arise:

First, temporal misalignment: DRR institutions (NDMA, State Disaster Management Authority) give priority to emergency preparedness-response timeframes; CCA institutions (Ministry of Earth Sciences, Agricultural Department) are concerned about longer-term planning cycles. This results in coordination gaps as short-term disaster preparedness eclipses longer-term adaptive imperatives.

Second, sectoral fragmentation: a lack of coordination was noted as a major hurdle to the integration of DRR and CCA (Etongo et al., 2025). Odisha's structure is a case in point where the disaster management authority organises cyclone response, the agriculture department is responsible for livelihood adaptation, the forest/wildlife department works towards ecosystem protection and the health department deals with heat-related hazards. In the absence of established inter-sectoral coordination structures, duplication of efforts proliferates, and chances for synergy remain unmet.

Third, vertical misalignment of governance: (Doll et al., 2025) found systematic declines in policy inclusion of vulnerable populations (PWDs, marginalised groups) throughout administrative levels (national → state → district). The district disaster management plan of Bhadrak is in line with the state criteria but reflects little district-specific adaptation in targeting, suggesting that national policy frameworks do not immediately translate into local implementation.

6.3 Opportunities and Constraints for Ecosystem-Based Adaptation

Mangrove restoration is a high-potential, low-implementation adaptation strategy. (Das, 2025) Mangroves have multiple benefits simultaneously: (1) carbon sequestration (climate mitigation), (2) absorption of coastal surge (disaster risk reduction), (3) livelihood support through fisheries and honey production (vulnerability reduction). But ecosystem-based adaptation makes up only 12% of the recorded actions in Odisha. Barriers are:

- **Capital intensity:** Restoration of mangroves involves persistent capital investment (estimated at ₹2-3 lakhs per hectare across the establishment, monitoring and community livelihood support periods). Government funding limits prevent expansion beyond trial sites. Temporal dynamics. It takes 5-10 years to fully realise the benefits of mangrove ecosystem services, which is not aligned with political cycles that focus on visible outcomes in the short term.
- **Livelihood transition challenges:** Communities relying on aquaculture historically endure revenue reduction during mangrove restoration phases and require compensatory livelihood options that are rarely included in implementation.

- **Institutional Coordination:** Mangrove restoration needs to be taken up simultaneously by the Forest Department (stewardship), Agriculture/Fisheries Department (livelihood integration), Disaster Management Authority (DRR narrative integration) and Coastal Zone Management Authorities (developmental constraints).

Despite these challenges, (Mazumder et al. 2026) showed the cost-effectiveness and resilience benefits of hybrid green-grey infrastructure, combining mangrove restoration and strengthening of embankments in Bangladesh, where 78% of seedlings survived under community-integrated models – a sign that scaled implementation in Bhadrak is possible with the right institutional design.

6.4 Community Engagement and Adaptive Governance

Unlike the top-down approach prevalent in many Indian states, Odisha was reported by Doll et al. (2025) as an example of bottom-up DRR initiatives that combine local wisdom with technocratic solutions. The adaptive governance model indicates that catastrophe resilience is successful when local communities have ownership and agency. Communities in similar flood-prone areas (Majuli, Assam) develop "cultures of disaster preparedness" over multiple generations of hazard experience (Doll et al., 2025), indicating that formal institutional capacity building should be an addition to indigenous knowledge systems, not a replacement.

The implications for Bhadrak are: (1) formalized integration of community-based organizations in district disaster management planning; (2) documentation and validation of indigenous flood/cyclone response practices along with scientific knowledge; (3) revenue allocation for enabling community organizations to carry forward preparedness activities beyond project cycles; (4) gender-sensitive mechanisms to ensure that women's differential vulnerabilities and adaptive capacities are explicitly addressed.

7. POLICY SUGGESTIONS

7.1 Mechanisms for Institutional Integration

Recommendation 1: Set up an Inter-Sectoral Climate-Disaster Risk Coordination Committee at the district level, with a mandate for formal collaborative quarterly planning between the Disaster Management Authority, Agricultural Department, Forest/Wildlife Department, Health Department and municipality. Terms of reference must include:

(a) collaborative annual updates of vulnerability assessments; (b) coordinated budget planning to avoid duplication;
(c) integration of climate forecasts into sector-specific long-term plans; (d) methods for community representation to ensure accountability at the grass-roots level.

Recommendation 2: Develop a Bhadrak District CCA-DRR Integration Framework operationalising the commitments made under the national Sendai Framework. Framework to have: (a) quantitative targets, e.g. reduce mortality from disasters 50% by 2030, increase mangrove area 20%, strengthen adaptive capacity of 80% of vulnerable population; (b) sectoral actions, defining integration obligations of each department; (c) financing mechanisms, defining allocation of National Disaster Mitigation Fund accordingly to adaptation-resilience investments; (d) monitoring-evaluation protocols, to monitor integration effectiveness.

7.2 Scaling Up Ecosystem-Based Adaptation

Recommendation 3: Scaling up mangrove restoration to 5,000 hectares by 2030 through: (a) "Green Buffer Zones" along the coast combining mangrove and beach forest establishment with community livelihood enterprises (honey, ecotourism); (b) compensatory livelihood mechanisms supporting community transition from aquaculture where environmentally appropriate; (c) payment for ecosystem services schemes institutionalising long-term funding; (d) integration into coastal zone management regulations mandating green infrastructure in development projects.

Recommendation 4: incorporate blue carbon accounting into climate change mitigation plans. Specifically: (a) Conduct baseline blue carbon stock assessment across Bhadrak's 1,244 sq. (b) develop monitoring protocols to monitor carbon sequestration from restoration activities; (c) investigate incorporation into carbon credit markets when the national blue carbon framework develops; (d) convey climate mitigation benefits as an adaptation co benefit to justify government investments.km coastal area;

7.3 Livelihood Diversification and Adaptive Capacity

Recommendation 5: Set up Bhadrak Coastal Livelihood Resilience Program to reach 50,000 vulnerable households through: (a) training in climate-resilient agriculture (salt-tolerant crop varieties, water-efficient technologies); (b) support for diversification into micro-enterprises outside of agriculture-fisheries (value-added processing, eco-tourism, renewable energy installation); (c) improve access to institutional credit through dedicated lending schemes with partial government guarantee; (d) social safety nets (employment guarantee schemes) to provide income smoothing during disaster recovery periods.

Recommendation 6: Systematically integrate disability-inclusive disaster risk reduction. Implementation pathways:
(a) participatory vulnerability assessments disaggregated by disability status; (b) accessibility standards for all cyclone shelters; (c) persons with disabilities included in testing of early warning dissemination; (d) targeted capacity building for caregivers and families of persons with disabilities on adaptive support; (e) proportional allocation of dedicated disaster relief to persons with disabilities.

7.4 Early warning and forecasting based on science

Recommendation 7: Improve early warning systems that integrate storm surge models and wind speed forecasts. Existing systems focus on meteorological hazard metrics. Improved systems should incorporate: (a) inundation modelling integrating surge, rainfall, and fresh water runoff; (b) dissemination with 72 -hour lead-time via multiple channels (SMS, radio, WhatsApp, loudspeaker networks); (c) community-specific warning products (e.g., inundation probability at the village level); and (d) evacuation route guidance tailored to accessibility requirements.

7.5 Monitoring, Evaluation and Adaptive Management

Recommendation 8: Develop a Bhadrak Climate-Disaster Risk Information Portal, a publicly accessible platform that includes: (a) real-time hazard monitoring (satellite-based flood detection, forecasting of the weather); (b) community-level vulnerability indicators updated annually; (c) tracking and assessing the effectiveness of adaptation interventions; (d) citizen feedback systems that allow for community input on preparedness effectiveness; and (e) an open-source design that can be scaled to other districts.

8. CONTRIBUTION TO KNOWLEDGE

This paper is part of the scholarship on catastrophe risk reduction-climate change adaptation by:

(1) Empirical evidence of CCA-DRR integration issues in the specific setting of Indian coastal districts, contributing to the literature beyond national-level policy analysis to district-scale implementation realities.

(2) Quantitative vulnerability profiling showing socio-economic vulnerability dimensions are more important than physical hazard measurements in importance weightings, evidence supporting a policy shift towards building adaptive capability.

(3) Quantification of ecosystem services from dual climate-disaster advantages of Odisha's mangroves to provide economic justification for scaling up restoration spending beyond existing pilot levels.

(4) Institutional examination of the processes of vertical policy misalignments whereby the commitments of the Sendai Framework at the national level are attenuated at the level of implementation at the state-district level.

(5) Intersectionality insights on disability-inclusive disaster risk reduction: developing gaps in research connecting DRR frameworks with PWDs' diverse vulnerabilities.

9. CONCLUSION AND THE WAY FORWARD

Bhadrak District is an important case study for integrating climate change adaptation and catastrophe risk reduction in coastal India. The district's outstanding disaster response capacity (e.g. quick cyclone evacuation) is a sign of institutional quality, but there are serious gaps in climate adaptation mainstreaming, ecosystem-based approaches, building adaptive capacity and cross-sectoral coordination.

The way forward includes: (1) Institutional integration beyond sectoral silos through formal int er-departmental coordination and joint financing mechanisms; (2) Scaling up ecosystem-based adaptation, particularly mangrove restoration, due to the dual climate-disaster benefits; (3) Livelihood diversification and strengthening adaptive capacity by addressing underlying drivers of vulnerability, rather than only proximal hazard exposure; (4) Community participation and adaptive governance recognizing that disaster resilience is a product of hybrid integration of indigenous knowledge and scientific expertise; (5) Disability-inclusive frameworks that ensure DRR benefits reach all community members; (6) Monitoring-evaluation systems that enable adaptive management and evidence-based policy refinement.

Achieving these goals successfully requires the mobilisation of resources, institutional transformation and continuous political commitment that goes beyond selfish political interests. But the global experience from Bangladesh (70% reduction in flood mortality with integrated approaches) and Kenya (35% improvement in food security in drought regions) suggests it is feasible. Bhadrak has the institutional foundations, geographic data richness and community adaptive capacity required for transformative integration. If successful, Odisha will act as a global model for climate-resilient disaster governance, taking the state's existing excellence in response to the realms of long-term adaptation and sustainable development in line with the Sendai Framework and Sustainable Development Goals.

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