



RESEARCH ARTICLE

Barriers to effective cyclone adaptation strategies among paddy growers: Insights from cyclone-prone coastal regions of Odisha, India

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Abstract

Cyclones pose recurrent and escalating threats to agrarian livelihoods in coastal Odisha. Rice cultivation forms the backbone of rural employment, food security and household income in this state. The present study assessed the constraints that affect the adaptation behaviour of rice farmers in cyclone prone areas of Odisha. A multistage sampling design combining purposive and random techniques was adopted and about 120 paddy growers from Chaumukh and Dagara villages of the Baliapal block in Balasore district, one of the most cyclone-affected regions of the state were assessed. Primary data were collected through structured interviews using a five-point severity continuum that included highly severe to least or no constraint criteria. Constraint scores were aggregated and ranked based on mean severity to identify the most critical barriers across multiple dimensions of adaptation. The results revealed that each dimension including financial, institutional, technological, social, knowledge, psychological and environment was affected. Limited access to institutional credit emerged as the most severe constraint under the financial dimension. Bureaucratic delays in the disbursement of relief and subsidies were identified as the major impediment within the institutional dimension. Poor accessibility to climate-resilient rice cultivars was identified as the most critical constraint under the technological dimension. Social constraints were dominated by the migration of youth to towns and cities, reducing the availability of farm labour. In the environmental dimension, frequent flooding and waterlogging disrupting field operations was the major limitation. Poor understanding of climate adaptation strategies was the main constraint in terms of knowledge. The psychological dimension was primarily affected by trauma arising from past cyclonic experiences, while the market dimension was hindered by the lack of regulated markets for produce sale. Absence or lack of adequate cyclone shelters and safe storage facilities for harvested paddy emerged as the most severe constraint in the infrastructure dimension. The findings underscore the multidimensional nature of adaptation challenges faced by farmers and emphasise the need for integrated policy and institutional interventions to enhance climate resilience among coastal rice-farming communities.

Keywords: coastal agriculture; constraints; institution; resilience; technology

Introduction

Agriculture remains vital to Odisha's economy, employing 49 % of the workforce and supporting over 60 % of its population. Despite a declining gross state domestic product (GSDP) share, it remains key for rural employment and food security. Among the different sectors, the crop sector still enjoys the dominance of over 61 % of contribution towards agricultural gross state value added (GSVA). With food grain production of 143 lakh MT, Odisha ranks fifth among all states in rice production. This accounts for 8 % share in the nation's total production. Rice is cultivated in about 45 % of total cropped area (1). Agriculture is the major source of livelihood of countryside and plays a major role in shaping state's economy, Rice is the primary crop cultivated and produced in the state (2, 3). Even though Odisha as a state has shown advancements in farm

production, the issues concerned with significant socio-economic disparities still prevail in different parts of the state (4). These issues get further exacerbated by natural calamities like floods and cyclones (5–7) and livelihood sustainability and progress of the rural community get affected (8).

Owing to the ongoing climate change occurring around the globe, the damage to ecosystem has increased. This has happened due to increase in intensity as well as frequency of extreme weather events. Rise in vertical levels and temperatures of ocean waters has resulted in increased occurrences of tropical cyclones (9). Cyclones from the Bay of Bengal frequently hit Odisha, wreaking havoc on the state's agriculture, infrastructure and way of life. Variations in rainfall patterns have resulted in problems related to flooding and scarcity of water (10). The disastrous happenings like cyclonic storms,

earthquakes, floods and landslides have noted an increase throughout the year, which has led to prominent loss of life and assets. Cyclones have been considered the most devastating effect that have created an impact over large areas depending upon their intensity and duration (11). The degradation of coastal ecosystems, particularly the loss of mangrove buffers, has further increased farmers' problems as the natural protection against storm surges and wind impacts is reduced (12, 13). Farmers' cyclone adaptation decisions are significantly influenced by risk perception, emotional trauma and trust in institutional delivery mechanisms (14, 15).

Materials and Methods

The investigation was carried out in Balasore district, one of the coastal districts of Odisha. The district was selected based on secondary data obtained from the State Relief Commissioner's reports, which identify the districts most frequently affected by cyclones in the state. Among the highly cyclone-prone districts, Balasore was selected purposively for the present study. The district has been subjected to recurrent cyclonic disturbances originating from the Bay of Bengal, which have significantly affected agricultural activities, particularly the production of paddy in the region. A multistage purposive sampling technique was employed to select the blocks, panchayats and villages within the district for the investigation.

Selection of block

Baliapal was selected for the study as it is located near the coastal area and is one of the severely affected areas.

Selection of villages

Two villages, namely Chaumukh and Dagara, were randomly selected for the study.

Selection of respondents

The respondents were operationally defined as farmers involved in paddy cultivation. A complete list of all the farmers residing in the sample area was considered while getting information from departments of agriculture situated at district levels as well as block level. This information obtained was cross checked by resource personnel like teachers, sarpanches, religious leaders or any other local leaders. A total of 120 households were randomly selected for the study. An interview schedule was prepared with expert guidance and literature reviews tailored to the objectives of the investigation. The prepared schedule was pre-tested on 10 % of the sample size. The questionnaire was prepared in English language but, was read out to farmers in the local language Odia to get responses from them. Feedback was taken from them. The interview schedule was rechecked for relevancy and validity before preparing a final draft of it. Data was collected by interviewing farmers. Support of Kissan Saathi, local leaders, Sarpanch, Gram Panchayat members and Assistant Agricultural Officers of the respective region were given. The interviews were conducted at the respondents' homes and workplaces, ensuring that an informal environment is created and farmers give appropriate responses and honest answers without any external interference. It was studied with structured questions.

Structured questionnaire was given to the respondents and scores were obtained on different categories. The responses were obtained on a five-point continuum which ranged from very severe, most severe, moderately severe, least severe and not at all a constraint, with corresponding score of 5, 4, 3, 2 and 1. Later, scores of each problem were aggregated and mean score was calculated. Higher the mean value indicated the importance of the problem.

Results and Discussion

A broad array of factors was found to be restricting the adoption of strategies by the paddy growers in the coastal region of the state of Odisha. These factors were placed into separate dimensions and elaborated in the following sub-sections for better understanding.

Financial constraints

Those constraints that were of a financial nature are presented in Table 1. These issues limit the farmers' accessibility to resources in form of resilient seeds, infrastructure and monetary facilities which ultimately shape the cyclone adaptation strategies of farmers growing paddy in the region. The farmers opinionated the issue of 'Limited access to institutional credit' was the major constraint with the highest mean score of 4.92 followed by 'Shortage of investment in resilient structures (bunds, drainage, etc.)'. Other things such as 'High cost of farm inputs (seeds, fertilisers, pesticides, etc.)' showed response scores of 4.34 and 3.87. Following the trend of preference given by respondents, remaining issues were opined and ranked as per the decreasing order of mean score values.

The findings underscore the pivotal role of financial barriers in shaping farmers' adaptive responses to cyclonic disturbances, particularly among paddy growers in vulnerable regions. The top ranked constraint as limited access to institutional credit reflects a systemic bottleneck in formal financial inclusion. This may be attributed to stringent eligibility criteria, lack of collateral, bureaucratic delays and limited outreach of banking institutions in rural and cyclone-prone areas. Without timely and adequate credit, farmers are unable to invest in protective infrastructure or adopt resilient technologies, leaving them exposed to recurrent climatic shocks (16–19). The second highest concern was shortage of investment in resilient structures such as bunds and drainage systems. This suggested that farmers either lack capital or face institutional inertia in mobilising resources for long-term infrastructural safeguards. This could be linked to fragmented landholdings, unclear land tenure, or absence of targeted government schemes that incentivise climate-resilient infrastructure at the farm level (20). High costs of farm inputs further increase the financial stress, especially in post-cyclone recovery phases when input prices often surge due to disrupted supply chains. Farmers may resort to suboptimal practices or delay sowing, which adversely affects productivity and income stability. Lack of crop insurance limits financial recovery, deters investment in resilient practices, restricts access to credit and delays replanting ultimately weakening paddy farmers' ability to adapt effectively to cyclonic disruptions (21). High labour wage rates during peak seasons inflate production costs, limiting farmers' ability to invest in cyclone-resilient

Table 1. Constraints opined by farmers under financial dimension towards adaptation strategies

Sl. No.	Statements	Mean score	Rank
1.	High cost of farm inputs (seeds, fertilisers, pesticides, etc.)	3.87	III
2.	Limited access to institutional sources of credit	4.92	I
3.	Lack of crop insurance coverage	3.34	IV
4.	High labour wage rates during peak seasons	3.11	V
5.	Shortage of investment in resilient structures (bunds, drainage, etc.)	4.34	II

infrastructure, timely recovery measures and adaptive technologies essential for sustaining paddy cultivation.

Institutional constraints

Institutional constraints affecting farmers' cyclone adaptation strategies are highlighted in Table 2. The most critical issue, with a mean score of 4.58, is bureaucratic delays in disbursing relief funds and subsidies, reflecting slow and inefficient administrative processes. Poor coordination between state departments and stakeholders (mean score 4.24) ranks second, indicating fragmented governance and lack of integrated support. Limited support for community-based initiatives (mean score 3.92) is third constraint, suggesting weak grassroots mobilisation. The lack of extension and outreach programmes (mean score 3.35) reflects gaps in knowledge dissemination and farmer engagement. The lowest ranked constraint is limited access to government assistance and subsidies (mean score 3.14), which signals concern over inequitable or insufficient institutional support. Overall, the findings underscore the need for streamlined governance, timely financial delivery and inclusive institutional mechanisms to strengthen farmers' adaptive capacity in cyclone-prone regions.

The prominence of these institutional constraints reflects deeper governance challenges in disaster-prone agricultural systems. In cyclone-affected regions, timely institutional response is critical for restoring agricultural livelihoods; however, bureaucratic processes and procedural delays often reduce the effectiveness of post-disaster support mechanisms. Such delays can prolong recovery periods and discourage farmers from adopting proactive adaptation strategies, as uncertainty about institutional support increases risk perception among smallholder farmers. Similarly, weak coordination among government agencies and development stakeholders indicates a fragmented governance structure, where disaster management, agricultural extension and rural development programmes operate in isolation rather than through integrated response systems. This institutional fragmentation limits the effectiveness of adaptation planning and weakens the delivery of targeted support to vulnerable farming communities. The limited promotion of community-based initiatives further suggests that local institutions and farmer collectives remain underutilised despite their potential role in enhancing resilience through shared resources, collective learning and localised adaptation strategies. Moreover, gaps in extension outreach highlight the need for stronger knowledge and advisory systems that can bridge scientific innovations and farmers' adaptation practices (22). Strengthening institutional integration, decentralising disaster response mechanisms and promoting participatory and community-

driven adaptation approaches may therefore play a critical role in enhancing the resilience of cyclone-prone paddy-growing regions.

Technological constraints

The data presented in Table 3 reveals a prioritised set of technological constraints perceived by farmers in relation to climate adaptation strategies. The most critical issue, with the highest mean score of 4.96, is the lack of accessibility to climate-resilient cultivars, underscoring a significant gap in the availability of adaptive genetic resources. The second ranked constraint is lack of training on water management technologies (mean score 4.77) and reflects a need for capacity-building initiatives to enhance farmers' technical proficiency in resource conservation. Closely following is the poor dissemination of ICT-based advisories in local languages (mean score 3.83), indicating that language and communication barriers hinder the effective transfer of timely agricultural information. Meanwhile, the lack of maintenance and support systems in the post-cyclone phase (mean score 3.51) and the absence of decision support systems for risk management (mean score 3.08) are perceived as relatively lower-priority concerns, though they still represent important areas for institutional and technological strengthening. The findings underscore the urgent need to improve access to climate-resilient inputs, strengthen localised information dissemination and expand farmer-centric training programs to enhance adaptive capacity in vulnerable agricultural regions.

The findings highlight a layered set of technological barriers that shape farmers' adaptive responses to cyclonic stress, particularly in paddy-growing regions. The highest-ranked constraint lack of accessibility to climate-resilient cultivars suggests a critical disconnect between breeding innovations and last-mile delivery. This may be due to limited seed multiplication programs, weak extension linkages, or inadequate policy incentives for localised varietal deployment. Farmers' inability to access such cultivars directly undermines their capacity to withstand erratic weather patterns and soil stressors.

The lack of training on water management technologies, ranked two, reflects a broader need for capacity-building interventions. Efficient water management is crucial in both the pre- and post-cyclone phases; however, farmers often lack adequate exposure to technologies such as micro-irrigation, scientific drainage design and moisture conservation techniques. This gap significantly constrains their adaptive capacity, as effective drainage, water regulation and flood management are essential for minimising crop damage and ensuring rapid recovery in cyclone-prone paddy systems. This gap may

Table 2. Constraints opined by farmers under institutional dimension towards adaptation strategies

Sl. No.	Statements	Mean score	Rank
1.	Limited access to government assistance and subsidies	3.14	V
2.	Bureaucratic delays in disbursing relief funds or subsidies	4.58	I
3.	Poor coordination between state departments and stakeholders	4.24	II
4.	Lack of extension and outreach programmes	3.35	IV
5.	Limited support for community-based initiatives	3.92	III

Table 3. Constraints opined by farmers under technological dimension towards cyclone adaptation strategies

Sl. No.	Statements	Mean score	Rank
1.	Lack of accessibility to climate-resilient cultivars	4.96	I
2.	Lack of maintenance and support system in post-cyclone phase	3.51	IV
3.	Poor dissemination of ICT-based advisories in local languages	3.83	III
4.	Absence of decision support systems for risk management	3.08	V
5.	Lack of training on water management technologies	4.77	II

stem from under-resourced training institutions or the absence of farmer field schools focused on climate-smart practices (23).

The third ranked issue, poor dissemination of ICT-based advisories in local languages, points to a communication gap in digital agriculture. While mobile-based platforms and agro-advisory services have expanded, their effectiveness is curtailed when content is not linguistically or contextually tailored. This barrier is particularly acute in cyclone-prone regions, where timely, location-specific advisories can significantly influence preparedness and recovery. The lack of Odia-language ICT advisories reduces farmers' ability to interpret early warnings, farm contingency steps and post-cyclone recovery guidance, thereby restricting timely adaptation actions (24).

Inadequate post-cyclone maintenance systems and the absence of decision support tools though are perceived as less immediate and lower-ranked constraints. Their lower prioritisation may reflect limited awareness or exposure rather than reduced relevance. For instance, decision support systems if effectively introduced could enhance risk forecasting and resource allocation, but their uptake depends on digital literacy and institutional support. In sum, the results underscore the need for a multi-pronged technological strategy: improving access to resilient inputs, localising digital advisories, strengthening farmer training and institutionalising support systems that bridge technology with practice. Such interventions must be context-sensitive, inclusive and sustained to build long-term resilience in cyclone-affected agricultural landscapes (25).

Social constraints

A ranked overview of socio-cultural constraints perceived by farmers in the context of adaptation strategies is presented in Table 4. The highest-ranked constraint, with a mean score of 4.89, is the migration of youth to towns and cities, indicating a significant depletion of active agricultural labour and leadership in rural areas. This is closely followed by the lack of farmers' organisations for mobilisation (mean score 4.14), suggesting limited collective capacity to coordinate and implement adaptive measures. The third-ranked issue, strict adherence to traditional farming practices (mean score 3.77), reflects resistance to change and a preference for conventional methods, which may hinder the adoption of innovative technologies. Lower-ranked constraints include limited participation in training due to caste or communal issues (mean score 3.32), pointing to underlying social barriers that restrict inclusive capacity-building efforts. The least prioritised concern is the dominance of opinion leadership in segregated communities (mean score 2.95), which may influence decision-making but is perceived as less obstructive compared to other factors. Overall, the findings underscore the need for youth engagement, institutional

strengthening and socially inclusive extension approaches to enhance adaptive resilience in farming communities.

The findings reveal a nuanced landscape of socio-cultural barriers that shape farmers' adaptive capacity in cyclone-prone regions. The highest-ranked constraint migration of youth to urbanised settlements signals a critical demographic shift that weakens the agricultural labour force and erodes local leadership. This trend may be driven by limited livelihood opportunities, lack of recognition for farming as a viable career and the allure of urban employment, leaving behind an aging population less inclined to adopt new practices. The absence of robust farmer collectives or cooperatives weakens institutional support for adaptation. Without organised platforms, farmers struggle to access weather alerts, input subsidies, or training programs. Studies using Kendall's coefficient of concordance highlight those economic and social impediments such as poor mobilisation rank high among perceived constraints. Youth migration depletes rural human capital, especially the tech-savvy and adaptive segment of the farming population. Older farmers left behind are less likely to engage with mobile-based advisories, digital weather forecasts, or mechanised solutions. This demographic shift reduces the community's overall resilience and slows the diffusion of adaptive practices (26). In many villages, adaptation decisions are influenced by local elites or caste-based leaders. If these opinion leaders are skeptical of scientific advisories or resistant to change, their stance can discourage broader community participation. This gatekeeping effect reinforces social inertia and limits inclusive decision-making. Social exclusion based on caste or communal identity restricts access to extension services and training programs. Marginalised groups may be left out of capacity-building sessions, leading to uneven knowledge dissemination. This perpetuates vulnerability and undermines the equitable implementation of cyclone-resilient strategies (27).

Environmental constraints

The results in Table 5 highlight key environmental constraints perceived by farmers in relation to cyclone adaptation strategies. The most severe concern, ranked first with a mean score of 4.39, is frequent flooding and waterlogging, which significantly disrupt field operations and compromise crop productivity. Soil salinity and erosion due to storm surges (mean score 3.76) follow as the second major constraint, indicating long-term degradation of land quality in coastal and cyclone-prone areas. Unpredictable rainfall patterns affecting sowing and harvesting timelines (mean score 3.42) are ranked third, reflecting the challenges farmers face in aligning agricultural activities with erratic weather conditions. The loss of biodiversity and natural buffers such as mangroves (mean score 3.11) is perceived as a moderate concern, suggesting awareness of ecological degradation but lower immediacy in its impact. Post-

Table 4. Constraints opined by farmers under social dimension towards cyclone adaptation strategies

Sl. No.	Statements	Mean score	Rank
1.	Strict adherence to traditional farming practices	3.77	III
2.	Lack of farmer organizations for mobilisation	4.14	II
3.	Migration of youth to towns and cities	4.89	I
4.	Dominance of opinion leadership in segregated communities	2.95	V
5.	Limited participation in training due to caste or communal issues	3.32	IV

Table 5. Constraints opined by farmers under environmental dimension towards cyclone adaptation strategies

Sl. No.	Statements	Mean score	Rank
1.	Frequent flooding and waterlogging disrupting field operations	4.39	I
2.	Soil salinity and erosion due to storm surges	3.76	II
3.	Loss of biodiversity and natural buffers like mangroves	3.11	IV
4.	Unpredictable rainfall affecting sowing-cum-harvesting timelines	3.42	III
5.	Post cyclonic pest outbreaks	2.84	V

cyclonic pest outbreaks (mean score 2.84) are ranked lowest, possibly due to their episodic nature or limited visibility compared to more direct environmental disruptions. The findings highlight the need for integrated water management, strengthened coastal protection measures and climate-resilient planning to reduce environmental risks in cyclone-affected agricultural regions.

Cyclone-prone coastal regions in India, particularly Odisha, face overlapping ecological disruptions that constrain the adoption of climate-resilient agriculture. Frequent flooding and waterlogging delays sowing, transplanting and harvesting, misalign crop calendars and discourage investment in adaptive infrastructure. Storm surges cause soil salinity and erosion, reducing land productivity and forcing reliance on salt-tolerant varieties that may be unavailable or culturally unsuitable (28). The loss of natural buffers such as mangroves heightens exposure to wind and surge damage while disrupting essential ecosystem services. Unpredictable rainfall and post-cyclonic pest outbreaks further reduce crop stability and increase dependence on costly reactive inputs. Together, these stressors weaken adaptation efforts and erode farmer confidence in long-term resilience planning.

Knowledge dimension

The results presented in Table 6 reflect farmers' perceived constraints under the knowledge dimension in relation to cyclone adaptation strategies. The most critical barrier, with a mean score of 4.92, is poor comprehension of adaptational strategies, indicating a widespread gap in understanding the practical and technical aspects of climate resilience. Closely following is the lack of awareness about long-term climate change impacts (mean score 4.66), which suggests that many farmers may not fully grasp the broader implications of climatic shifts on agricultural systems. The absence of successful case studies and contemporary field experiences (mean score 3.66) ranks third, pointing to a need for locally relevant demonstrations and peer learning models. Inadequate training on interpreting weather forecasts and advisories (mean score 3.23) and low literacy levels hindering uptake of written or digital materials (mean score 3.04) are ranked lower, yet they still represent significant barriers to effective information access and utilisation. Overall, the findings underscore the importance of targeted knowledge interventions, including simplified training modules, experiential learning and context-sensitive communication strategies to strengthen farmers' adaptive capacity.

The adoption of cyclone-resilient strategies among paddy farmers in coastal India is significantly constrained by a hierarchy of cognitive and informational barriers. Foremost among these is poor comprehension of adaptational strategies, which reflects a critical disconnect between the dissemination of climate-resilient practices and farmers' ability to internalise and operationalise them. This gap often stems from overly technical advisories, lack of contextualisation and limited field-level demonstrations. Closely following poor comprehension of adaptation strategies is the pervasive lack of awareness about the long-term impacts of climate change, which scored a mean of 4.66, ranking second in terms of significance. This limited awareness often results in a reactive approach to cyclone events rather than a proactive stance. Many paddy farmers tend to perceive cyclones and extreme weather as isolated incidents rather

than as part of a broader pattern driven by climate change. Consequently, there is reduced motivation to engage in anticipatory measures such as crop diversification, climate insurance, or investing in resilient infrastructure. This short-term focus significantly undermines the sustainability of agricultural livelihoods, leaving farmers vulnerable to recurring damage and losses (29). Another critical barrier is the absence of successful case studies and contemporary field experience, with a mean score of 3.66 and ranked third. The lack of visible, proven examples within similar agro-ecological contexts leads to skepticism and hesitance in adopting new adaptation strategies. Farmers often rely on peer experiences to validate innovations and without documented local success stories or field demonstrations, the perceived risk associated with new practices remains high. This trust deficit inhibits the diffusion of adaptive technologies and practices across cyclone-prone communities. Compounding these issues is inadequate training on the interpretation of weather forecasts and advisories (mean score 3.23, rank IV). Although institutional and digital forecasting tools are increasingly available, many farmers struggle to understand or apply this information effectively. This gap results in misaligned farming operations, such as mistimed sowing or harvesting, reducing crop resilience to cyclone impacts. Furthermore, the complexity of weather data and lack of user-friendly communication formats hinder optimal utilisation of these critical resources (30). Finally, low literacy levels, scoring 3.04 and ranked fifth, present a significant obstacle in accessing written or digital adaptation materials. Many farmers face challenges in engaging with extension services that rely on print or digital content, especially when such materials are not in vernacular languages or are overly technical. This literacy barrier effectively excludes a substantial portion of the farming community from capacity-building programs, reducing overall adaptive capacity. Together, these interconnected barriers highlight the urgent need for extension models that are inclusive, contextually validated and sensitive to literacy levels. Only by addressing these issues can cyclone adaptation strategies achieve meaningful uptake and long-term resilience among vulnerable paddy farming populations.

Psychological dimension

The data in Table 7 outlines psychological constraints perceived by farmers in the context of cyclone adaptation strategies. The most prominent concern, with a mean score of 4.84, is trauma from past cyclonic experiences, indicating deep emotional distress that continues to influence farmers' readiness and response to future events. Ranked second is the lack of confidence in risk management approaches (mean score 4.48), suggesting that farmers may feel ill-equipped or uncertain about the effectiveness of available strategies. Fear of crop failure and financial losses (mean score 3.65) occupies the third position, reflecting anxiety over economic vulnerability during extreme weather events. Cognitive overload during crisis periods (mean score 3.31) and a fatalistic attitude that hinders proactive engagement (mean score 3.09) are ranked lower, yet they still represent significant psychological barriers that can impair decision-making and adaptive behaviour. The findings highlight the importance of psychosocial support, confidence-building

Table 6. Constraints opined by farmers under knowledge dimension towards cyclone adaptation strategies

Sl. No.	Statements	Mean score	Rank
1.	Lack of awareness about long-term climate change impacts	4.66	II
2.	Poor comprehension of adaptational strategies	4.92	I
3.	Lack of successful case studies and contemporary field experience	3.66	III
4.	Inadequate training on interpreting weather forecasts and advisories	3.23	IV
5.	Low literacy levels hindering uptake of written or digital materials	3.04	V

Table 7. Constraints opined by farmers under psychological dimension towards cyclone adaptation strategies

Sl. No.	Statements	Mean score	Rank
1.	Fear of crop failure and financial losses	3.65	III
2.	Trauma from past cyclonic experiences	4.84	I
3.	Fatalistic attitude hindering proactive approach	3.09	V
4.	Cognitive overload during crisis period	3.31	IV
5.	Lack of confidence in risk management approach	4.48	II

interventions and inclusive risk communication to enhance farmers' mental resilience and adaptive capacity in cyclone-prone regions.

Psychological factors deeply influence paddy farmers' willingness and ability to adopt cyclone adaptation strategies in vulnerable coastal regions. Topping the list is the trauma from past cyclonic experiences. Repeated exposure to devastating events such as crop destruction, loss of property and displacement, leaves farmers with lasting emotional scars. This trauma can manifest as avoidance behavior, where farmers disengage from adaptation initiatives due to associations with previous failures or ineffective relief efforts. Such psychological barriers significantly undermine trust in new interventions and institutional support, weakening resilience-building. Closely related is the lack of confidence in risk management approaches. Many farmers doubt the effectiveness of mechanisms like crop insurance, early warning systems, or climate-resilient infrastructure, often due to limited experience or previous disappointments. This skepticism reduces self-efficacy, making farmers reluctant to proactively adopt strategies that require investment or behavioural change. Instead, they may develop a dependency mindset, relying more on external aid than taking initiative to manage risks independently. Fear of crop failure and financial losses further reinforces risk aversion. Farming often represents a primary or sole livelihood source, so the prospect of experimenting with unfamiliar techniques carries high perceived financial risk. This fear discourages investment even in subsidised adaptation measures, perpetuating conservative farming practices that leave farmers exposed to cyclone impacts. During crisis periods, cognitive overload also impairs decision-making. The immediate pressures of protecting family, livestock and crops can overwhelm mental capacity, leading to delayed or missed opportunities to act on timely advisories. This short-term focus detracts from strategic, long-term adaptation planning. Finally, fatalistic attitudes as rooted in beliefs that cyclones are acts of fate or divine will, further dampen motivation to adopt preventive measures. Such cultural perspectives can override rational assessments, especially in more isolated or older populations. Together, these interlinked psychological constraints highlight the urgent need for trauma-informed, trust-building and culturally sensitive extension programs that empower farmers emotionally as well as technically embrace adaptive change.

Market dimension

The results in Table 8 highlight market-related constraints perceived by farmers in the context of cyclone adaptation strategies. The most pressing concern, ranked first with a mean score of 4.76, is the lack of regulated markets for sale, indicating that farmers face significant challenges in securing fair and stable outlets for their produce,

especially during post-disaster recovery. The second-ranked issue, lack of storage facilities (mean score 4.21), underscores the vulnerability of harvested crops to spoilage and loss, particularly when timely market access is disrupted. Reduced prices for cyclone-affected produce (mean score 3.97) are ranked third, reflecting the economic disadvantage farmers endure when quality and quantity are compromised by extreme weather events. Limited access to information systems for price and demand (mean score 3.52) suggests a gap in market intelligence, which hinders strategic selling and income optimisation. The lowest ranked constraint, dominance of middle-men cartels in the post-cyclone phase (mean score 3.18), points to exploitative practices that, while present, are perceived as less obstructive than infrastructural and institutional gaps. The findings emphasise the need for market reforms, improved infrastructure and digital access to empower farmers and enhance their resilience in cyclone-prone regions.

Market-related constraints play a critical role in shaping the adoption of cyclone adaptation strategies among paddy farmers in coastal regions. Foremost among these is the lack of regulated markets for sale, which exposes farmers to price volatility and weakens their bargaining power. In the aftermath of cyclones, when supply chains are disrupted and produce quality may be compromised. Moreover, the absence of institutional procurement mechanisms or minimum support prices discourages farmers from investing in adaptive practices. Even when farmers manage to salvage part of their crop through resilient strategies, the lack of assured market access reduces the perceived benefits of adaptation. The second most pressing issue is the lack of storage facilities. Cyclone-induced humidity and infrastructure damage make immediate post-harvest storage essential. Without access to drying yards, warehouses, or cold storage, farmers are forced into distress sales at low prices, nullifying the gains from any adaptive effort. Storage also enables staggered sales and better market timing, which are crucial for financial recovery and reinvestment in resilience-building measures. Reduced prices for cyclone-affected produce further compound the problem. Even partially damaged paddy fetches lower prices, creating an economic disincentive for farmers to adopt strategies aimed at partial recovery, such as staggered sowing or flood-tolerant varieties. This perception of futility undermines long-term planning and reinforces vulnerability. Limited access to information systems for price and demand restricts farmers' ability to make informed decisions. Without real-time market intelligence, farmers cannot align their production or sales with demand trends, leading to mistimed transactions and reduced profitability (31). Finally, the dominance of middle-men cartels in the post-cyclone recovery phase creates exploitative conditions. These

Table 8. Constraints opined by farmers under market dimensions towards cyclone adaptation strategies

Sl. No.	Statements	Mean score	Rank
1.	Reduced prices for cyclone-affected produce	3.97	III
2.	Lack of regulated markets for sale	4.76	I
3.	Lack of storage facilities	4.21	II
4.	Limited access to information systems for price and demand	3.52	IV
5.	Dominance of middle-men cartel in post-cyclone recovery phase	3.18	V

intermediaries often control logistics and pricing, preventing farmers from accessing formal markets or negotiating fair terms. This reduces autonomy and discourages engagement with institutional adaptation schemes (32). Together, these market constraints highlight the urgent need for regulated procurement systems, decentralised storage infrastructure and inclusive market intelligence platforms to enhance cyclone resilience in coastal paddy farming systems.

Infrastructure dimension

The results in Table 9 reflect farmers' perceptions of infrastructure-related constraints affecting cyclone adaptation strategies. The most critical concern, with a mean score of 4.95, is the lack of cyclone shelters and safe storage for harvest, indicating a severe gap in protective infrastructure that compromises both human safety and crop preservation during extreme weather events. Ranked second is the absence of cold chains and drying yards for post-harvest care (mean score 4.12), highlighting the vulnerability of produce to spoilage and quality loss due to inadequate post-harvest facilities. Poor networks of road connectivity for secured emergency transport (mean score 3.68) are the third-ranked constraint, suggesting logistical challenges in accessing relief, evacuation and market services during cyclone emergencies. Weak recovery of electricity supply and communication networks (mean score 3.44) and inadequate drainage systems leading to waterlogging (mean score 3.07) are ranked lower, yet they still represent significant barriers to timely recovery and field operability. These findings underscore the urgent need for resilient infrastructure investments, particularly in shelter systems, post-harvest logistics and transport connectivity, to enhance farmers' adaptive capacity in cyclone-prone regions.

Infrastructure-related constraints play a pivotal role in shaping the effectiveness and adoption of cyclone adaptation strategies among paddy growers in coastal regions. The most critical issue identified by farmers is the lack of cyclone shelters and safe storage for harvest. During cyclone events, the absence of secure shelters puts both human lives and harvested produce at risk. Farmers often prioritise family safety over crop protection and without safe storage facilities, even salvaged yields are vulnerable to spoilage, theft, or flooding. This undermines the perceived value of adaptation strategies, as efforts to protect crops become futile without post-harvest security (33). The second major constraint is the absence of cold chains and drying yards for post-harvest care. Cyclone-induced humidity and waterlogging accelerate grain deterioration. Without access to drying platforms or temperature-controlled storage, farmers cannot maintain the quality of their produce, leading to reduced market prices and economic losses. This discourages investment in resilient cropping systems, as the benefits are lost in the post-harvest phase. Poor road connectivity further hampers emergency transport and market access. Damaged or inaccessible roads delay evacuation, relief distribution and the movement of inputs along with yield harvests. It leads to the situation of farmers in remote areas struggling to reach markets or extension services, limiting their exposure to adaptive technologies

and institutional support. This isolation reduces the scalability of adaptation strategies across cyclone-prone regions (34). Weak recovery of electricity supply and communication networks disrupts access to early warnings, weather advisories and digital extension platforms for prepared against the menace of cyclone. In the absence of reliable power and mobile connectivity, farmers are unable to receive timely information or coordinate with support agencies, reducing preparedness and response efficiency. Finally, inadequate drainage systems lead to prolonged waterlogging, damaging root systems and delaying field operations. Even flood-tolerant varieties cannot perform optimally under stagnant water conditions. This discourages farmers from adopting such varieties, as infrastructural shortcomings negate their potential benefits and thus hampering their cyclone adaptation ventures. Collectively, these constraints highlight the urgent need for integrated infrastructure planning combining shelter, storage, connectivity and drainage to enable meaningful cyclone adaptation in coastal paddy farming systems.

Conclusion

Cyclone adaptation among paddy farmers in coastal Odisha is constrained by financial exclusion, delayed institutional support, limited access to climate-resilient seeds, labour shortages, ecological degradation and weak extension services. These interconnected barriers reduce farmers' capacity to adopt timely adaptation practices and increase livelihood vulnerability in cyclone-prone regions. Strengthening institutional coordination, improving last-mile delivery of support systems and promoting climate-resilient technologies are essential for enhancing adaptive capacity. Therefore, the government should design and implement integrated policies that address all the constraints, while also promoting public-private partnerships and coordinated institutional support to help farmers achieve better adaptation strategies. Future research should examine the long-term effectiveness of adaptation interventions, the role of digital advisory services and crop insurance and community-based resilience models in strengthening adaptation among coastal farming communities.

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Authors' contributions

JA drafted the manuscript. SD contributed to the design of the research methodology, data validation and revision of the manuscript. MPN and BM conceptualised the research framework and supervised the study. AD conducted the statistical analysis, interpreted the results and prepared the data visualisations. KKS

Table 9. Constraints opined by farmers under infrastructure dimension towards cyclone adaptation strategies

Sl. No.	Statements	Mean score	Rank
1.	Poor networks of road connectivity for secured emergency transport	3.68	III
2.	Inadequate drainage systems leading to waterlogging	3.07	V
3.	Lack of cyclone shelters and safe storage for harvest	4.95	I
4.	Weak recovery of electricity supply and communication networks	3.44	IV
5.	Absence of cold chains and drying yards for post-harvest care	4.12	II

coordinated the drafting process and ensured the manuscript's clarity. All authors read and approved the final manuscript.

Compliance with ethical standards

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