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Research Article

Impact and Adaptation of Cyclones on Major Crop Production for Smallholder Farmers in the South-central Coast of Bangladesh

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ABSTRACT

Climate change has increased the frequency and intensity of cyclones in Bangladesh's coastal regions, significantly affecting agricultural productivity. Therefore, implementing farm-level adaptation strategies against cyclones is essential to sustain and enhance crop productivity in these vulnerable areas. This study addresses this gap by examining farm-level vulnerabilities, cropping system impacts, and indigenous adaptation strategies across two highly cyclone-vulnerable districts (Patuakhali and Jhalokathi) in the south-central coastal region of Bangladesh. Utilizing a robust multi-stage random sampling design, primary empirical data were collected from 200 strictly screened smallholder households and systematically integrated with multi-decadal secondary meteorological data. The empirical results reveal severe, compounding seasonal disruptions, with Transplanted Aman (*T. Aman*) rice suffering the highest vulnerability, accounting for over 50% of aggregate cyclonic crop damage. Cyclonic storm surges trigger extensive economic losses averaging BDT 20,000-35,000 (163-285 USD) per household, primarily driven by secondary hazards such as rapid salinity intrusion, soil erosion, and prolonged waterlogging. While 79% to 80% of farmers perceive an accelerating frequency of cyclonic events, their current reactive adaptations (e.g., shifting planting timelines) are heavily constrained by indigenous knowledge and lack structural or technological scaling. Furthermore, 57% to 61% of smallholders identify the lack of institutional support and dedicated financial subsidies as the primary barriers to sustainable adaptation. These findings underscore an urgent need to transition from autonomous, experience-based coping mechanisms toward structural, zone-specific adaptation policies. This research provides a scalable framework for integrating empirical farmer perceptions with scientific weather analytics to engineer climate-resilient coastal agricultural systems globally.

Introduction

Climate change is widely recognized as one of the most pressing challenges of the 21st century, with far-reaching consequences for ecosystems, food security, and sustainable development (Lopez-Claros et al., 2020). Increasing global temperatures have intensified the frequency, magnitude, and unpredictability of extreme weather events, posing substantial risks to agricultural systems worldwide (Sarkar et al., 2024). Smallholder farmers are particularly vulnerable to these impacts due to their limited access to financial resources, advanced technologies, and institutional support mechanisms that could enhance adaptive capacity. Among climate-related hazards, tropical cyclones are of growing concern, as rising sea surface temperatures and changing atmospheric conditions have contributed to their increasing intensity and destructive potential (Mohammad et al., 2024). The consequences of cyclones are especially severe in developing countries, where inadequate infrastructure, resource constraints, and limited adaptation capacity exacerbate agricultural losses and threaten rural livelihoods (Siddik et al., 2024).

Bangladesh is recognized as one of the most climate-vulnerable nations, despite its negligible global emissions. Key threats include sea-level rise, salinity intrusion, intense cyclones, and flooding, which disrupt agriculture, threaten livelihoods, and cause massive displacement (Bhuyan et al., 2023a, b; Bhuyan et al., 2024). The coastal zone, covering approximately 32% of the country's land area and supporting more than 35 million people, is particularly exposed to these risks

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(Murshed et al., 2022). Its low-lying geography makes it highly vulnerable to cyclonic storm surges, saline water intrusion, and rising sea levels (Wahiduzzaman and Yeasmin, 2024). The increasing frequency and intensity of cyclones have caused substantial crop losses, generating both immediate economic damage and long-term threats to household food security (Ahmed, 2024). These impacts are further amplified by high population density, widespread poverty, and inadequate infrastructure.

Agriculture in the coastal region of Bangladesh is generally divided into three main seasons – Kharif-1 (mid-March-June), Kharif-2 (July-October), and Robi (October- mid-March)- based on climatic conditions, rainfall, and temperature, allowing for multiple crops on the same land. However, recurrent cyclones increasingly disrupt these production systems by damaging standing crops, delaying planting and harvesting operations, and causing salinity intrusion and prolonged waterlogging (Rahman and Uddin, 2021). Cyclones typically occur during the pre-monsoon (April–May) and post-monsoon (October–December) periods, coinciding with the critical growth and harvest stages of boro (dry-season) and aman (wet-season) rice, respectively. Rice, the country's staple food crop, is particularly vulnerable to wind damage, lodging, flooding, and salinity stress, resulting in substantial yield losses (Basu, 2025; Bhuyan et al., 2026; Chowdhuri and Pal, 2024). Other crops, including vegetables, pulses, oilseeds, and fruits, are also severely affected, especially in low-lying coastal districts (Ahsan et al., 2024). Major cyclones such as Sidr (2007), Aila (2009), and Amphan (2020) caused extensive agricultural damage, with crop losses in some coastal areas reaching 80–100% (Rashid et al., 2023). These recurrent shocks undermine agricultural productivity, threaten household food security, and exacerbate the vulnerability of smallholder farming communities (Ahmed, 2024).

In response, farmers in these coastal regions have developed a range of adaptation strategies to minimize losses and sustain production. These include the cultivation of salt-tolerant and short-duration rice varieties, adjustments to planting and harvesting times, the construction of raised seedbeds, the use of floating gardens for vegetable cultivation, and the adoption of mixed cropping or crop diversification practices (Rashid et al., 2023). Many farmers also employ soil and water management techniques, such as rainwater harvesting and canal re-excavation, to reduce the impacts of salinity and waterlogging caused by cyclones or storm surges. Some communities have formed local groups to share early warnings and coordinate collective adaptation activities (Roy et al., 2015).

Despite these efforts, the effectiveness of cyclone adaptation measures often depends on access to resources, institutional support, and accurate climate information. Understanding farmers' perceptions of cyclones is a critical component of effective policymaking, as it helps bridge the gap between scientific data and ground-level realities. So far, only a few studies (e.g., Arif et al., 2023; Sonet et al., 2024; Quader et al., 2017) have examined the impacts of climate change on cyclonic events and their effects on rural infrastructure and livelihoods in Bangladesh's coastal region. In addition, research on location-specific cyclone impacts and adaptation practices remains limited. Since adaptation measures that are effective in one location may not be suitable in another (Bhuyan et al., 2024), spatial information is essential for comprehensive adaptation planning in an area. In particular, there is limited research on the spatial impacts of climate change-induced cyclones on major crop production in the south-central coastal region. Given this context, the overall objective of this study is to examine the spatial impacts of cyclones on major crop production and to identify adaptation strategies adopted by smallholder farmers along Bangladesh's south-central coast, as they are among the most vulnerable groups to natural disasters. The specific objectives are to: i) evaluate farmers' perceptions of cyclones, ii) identify the impacts of cyclones on cropping seasons and economic loss in the study area, and iii) assess potential adaptation strategies and management policies for cyclone risk.

Materials and Methods

Study area

The study was conducted in two districts of the south-central coastal region of Bangladesh (Patuakhali and Jhalakathi) (Fig: 1). These districts were selected because historical records indicate substantial spatial variation in cyclone exposure and vulnerability across the coastal zone (Hossain et al., 2019). Therefore, they provide an appropriate basis for examining spatial differences in farmers' perceptions of cyclones, cyclone-induced crop damage, and adaptation strategies. Agriculture serves as the primary source of sustenance for the majority of people residing in rural areas. The principal crop in these regions is rice. Cyclone is a foremost hydrological problem in the projected area, mainly affecting winter season crops. Besides, the area is also susceptible to severe weather occurrences such as intense pre-monsoon storms, leading to subsequent issues such as water logging or flooding. Subsequently, in this study we interviewed farmers within these two coastal regions.

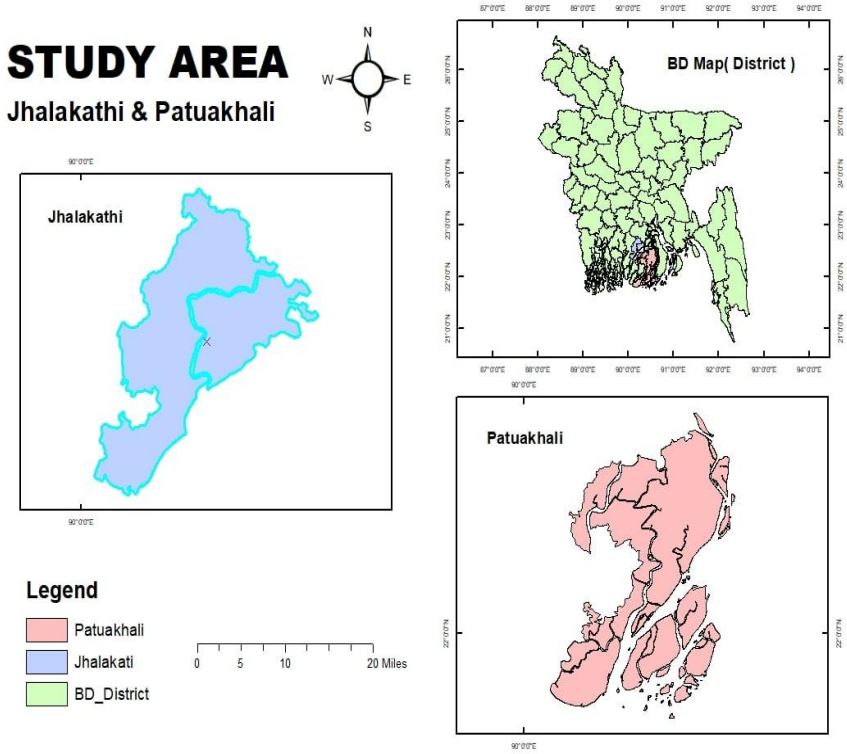

Fig. 1: Geographical locations of the study area

Data collection

Primary data were collected between June and August 2025 through a household questionnaire survey. A multi-stage sampling approach was employed to represent the highly cyclone-vulnerable south-central coastal zone of Bangladesh. First, the districts of Patuakhali and Jhalakathi were selected. Within these districts, cyclone-prone villages were identified and selected for field interviews. Similar sampling procedures have been adopted in previous studies (Bhuyan et al., 2024; Islam et al., 2020). The study calculated the minimum required sample size using Cochran's formula (Eq. 1):

$$\text{Sample Size, } n_o = \frac{(Z^2 pq)}{e^2} \quad (1)$$

$$= \frac{1.96^2 \times 05 \times 0.5}{0.1^2}$$

$$= 96$$

Adjusted for the total household population of the selected study regions (N = 328,515):

$$n = \frac{n_0}{1+\left[\frac{n_0 - 1}{N}\right]}$$

$$= \frac{96}{1+\frac{96-1}{328515}}$$

$$= 95.97$$

$$= 96$$

While the statistical minimum required sample size was 96, a total of 200 households were randomly selected across the target villages to ensure robust spatial representation. Crucially, to align with the study's focus on smallholder vulnerabilities, a pre-survey screening was conducted; only households operating small agricultural landholdings (typically < 1.0 ha) were selected for final interviews. One respondent, typically the household head or a knowledgeable senior member, was interviewed from each smallholder household.

Statistical Analysis

Farmers' perceptions of cyclones were assessed as a primary study variable using a structured recall-based framework. The assessment captured three key qualitative dimensions: perceived onset (seasonal timing), perceived frequency (annual occurrence), and perceived duration (storm persistence). Given that the study targeted experienced smallholder farmers aged 30 years and older to ensure a robust historical memory of extreme weather events, respondents evaluated multi-decadal shifts in these dimensions by classifying

them into distinct categorical trajectories, such as "early," "late," "increased," "decreased," or "no change". These qualitative responses were initially quantified as binary and categorical frequencies and aggregated into localized percentages for both the Jhalakathi and Patuakhali districts to determine the dominant community consensus. To establish empirical rigor and bridge ground-level realities with scientific observations, these aggregated perception datasets were systematically cross-verified and validated against multi-decadal secondary meteorological records, including maximum wind speeds (km/hr) and storm surge heights (m) from major historical benchmarks like Cyclones Sidr, Aila, and Amphan, obtained from the Bangladesh Meteorological Department (BMD) and published papers. Moreover, to systematically measure and evaluate farm-level adaptation strategies, a multi-dimensional framework was applied. First, adaptation adoption was quantified as a binary variable to determine the percentage frequency of specific practices across the surveyed households. Second, strategies were classified into agronomic, structural, and institutional typologies to evaluate the nature of local responses. Third, the efficacy of these measures was contextualized by evaluating household economic losses (categorized by BDT range) relative to the primary crops affected across different agricultural seasons. Finally, adaptive capacity constraints were measured by assessing the percentage of farmers who relied on external institutional support, such as government subsidies and climate information services, for successful implementation.

Using survey data, we compiled findings from all households involved in the study, employing various methods, including calculating frequencies, percentages, and averages, and presenting the results through tables. In interpreting the data, farmers' responses were expressed as percentages, which also indicated statistical significance. A similar approach was used by Bhuyan et al. (2024) to assess the impact of salinity on crop production and farmers' adaptation practices in the south-central coast of Bangladesh.

Results

Demographic characteristics

We collected data from 200 respondents in Jhalakathi (n=120) and Patuakhali (n=80). Most of the respondents were in the 50-60-year age group (Table 1). The educational level points out that only a very small percentage have a secondary education. Specifically, Jhalakathi and Patuakhali had 55.83% and 60% primary education, respectively, while 30% and 28.75% had secondary education, respectively. Furthermore, the majority of participants are male, and agriculture is the primary occupation.

Table 1: Demographic characteristics of the respondents

Variables	Jhalakathi (n=120)		Patuakhali (n=80)	
Age (Years)	N	%	N	%
30-40	13	10.83	11	13.75
40-50	35	29.16	25	31.25
50-60	58	48.33	32	40
>60	15	12.5	12	15
Sex of household head				
Male	94	78.33	51	63.75
Female	26	21.66	29	36.25
Education				
Primary education	67	55.83	48	60
Secondary education (6-10)	36	30	23	28.75
Higher secondary or above (>11)	17	14.16	9	11.25
Primary Occupation				
Agriculture	76	63.34	54	67.5
Others	44	36.67	26	32.5

Farmers' perceptions of cyclone

Farmers in the study area reported variations in both the frequency and duration of cyclones (Table 2). A significant share of respondents in Jhalakathi (65%) and Patuakhali (55%) indicated that cyclones now tend to occur earlier in the season. Only a small percentage of farmers reported that cyclones occurred later. In contrast, 10.83% of respondents in Jhalakathi and 15% in Patuakhali believed that there had been no change in the timing of cyclone events.

A significant proportion of farmers in Jhalakathi (79.17%) and Patuakhali (80%) reported an increase in the frequency of cyclones. In contrast, 15% of respondents in Jhalakathi and 13.75% in Patuakhali noted a decrease in cyclone frequency. In both regions, half of the farmers (50%) stated that cyclones tend to last for a long duration. Meanwhile, 26.67% of farmers in Jhalakathi and 31.2% in Patuakhali perceived cyclones as having a short duration. Furthermore, a small percentage of farmers did not view cyclones as a significant issue for their cropland, stating that the duration of cyclone periods has remained unchanged.

Table 2: Farmer perceptions of cyclone in the south-central coast of Bangladesh

Perceptions of cyclone	Jhalakathi (120)		Patuakhali (80)	
	N	%	N	%
Onset				
Early	78	65%	44	55%
Late	29	24.16%	24	30%
No change	13	10.83%	12	15%
Frequency				
Increase	95	79.17%	64	80%
Decrease	18	15%	11	13.75%
No change	7	5.83%	5	6.25%
Duration				
Long	60	50%	40	50%
Short	32	26.67%	25	31.25%
No change	28	23.33%	15	18.75%

Validation of primary empirical data with scientific observations

A considerable variation in surge height is observed, indicating fluctuations in cyclone intensity over time in the coastal regions (Fig. 2). Higher surge heights were recorded in the 1960s and early 1970s, with a noticeable peak around 1974. In contrast, relatively lower surge heights were observed during the mid to late 1980s, suggesting a period of reduced cyclone severity. A moderate increase in surge height is evident during the early to mid-1990s. Similarly, another rise in surge levels can be observed around 2007, followed by fluctuations in the subsequent years, highlighting the persistent and unpredictable nature of cyclonic events over time.

Furthermore, scientific reports and data from the BMD, however, indicate that one or two severe cyclones or storm surges strike the coastal areas each year. Findings from the primary household interviews indicated that most farmers perceived cyclones as occurring annually and believed that wind speeds remained high during these events (Table 2). In 2021, the coastal regions experienced two cyclones that caused extensive damage to infrastructure and key crop production. Therefore, farmers' perceptions were consistent with the scientific evidence.

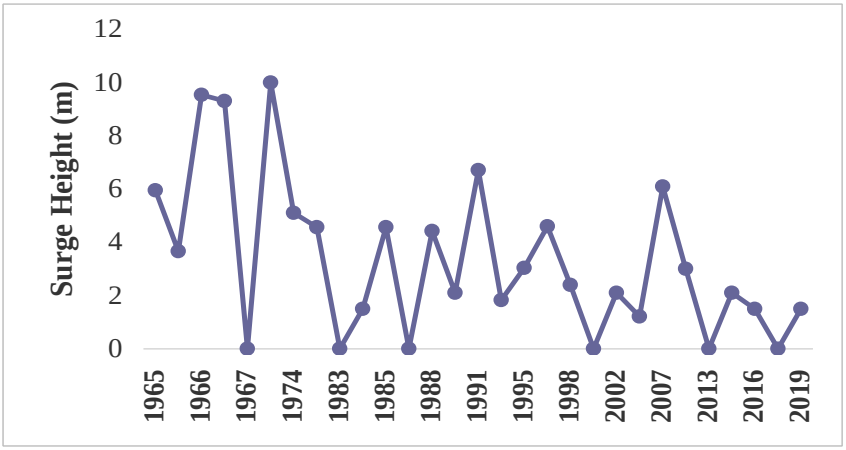

Fig. 2 Historical variation in cyclone surge height in the coastal region of Bangladesh (source: BMD)

Table 3: Major cyclones affect the south-central coastal area of Bangladesh

Cyclones/storm surges	Year of occurrence	Maximum wind speed (Km/hr)	Surge height (m)
Sidr	2007	223	3.0-5.0
Alia	2009	90	3.0
Mohasen	2013	100	2.0
Fani	2019	215	1.5
Amphan (Super cyclone)	2020	240	3.0-5.0
Yass	2021	150	2.0-2.5
Jawad	2021	88	3.0

Source: Bhuyan et al. (2024) and BMD

Impact of cyclone on cropping seasons

Farmers in the study area observed variations in how different cropping seasons are affected by cyclones (Fig. 3). A large portion of farmers in Jhalakathi (52.5%) and Patuakhali (56.25%) reported that Kharif-2 crops are particularly susceptible to cyclone impacts. Only a small percentage of farmers reported significant damage during the rabi season.

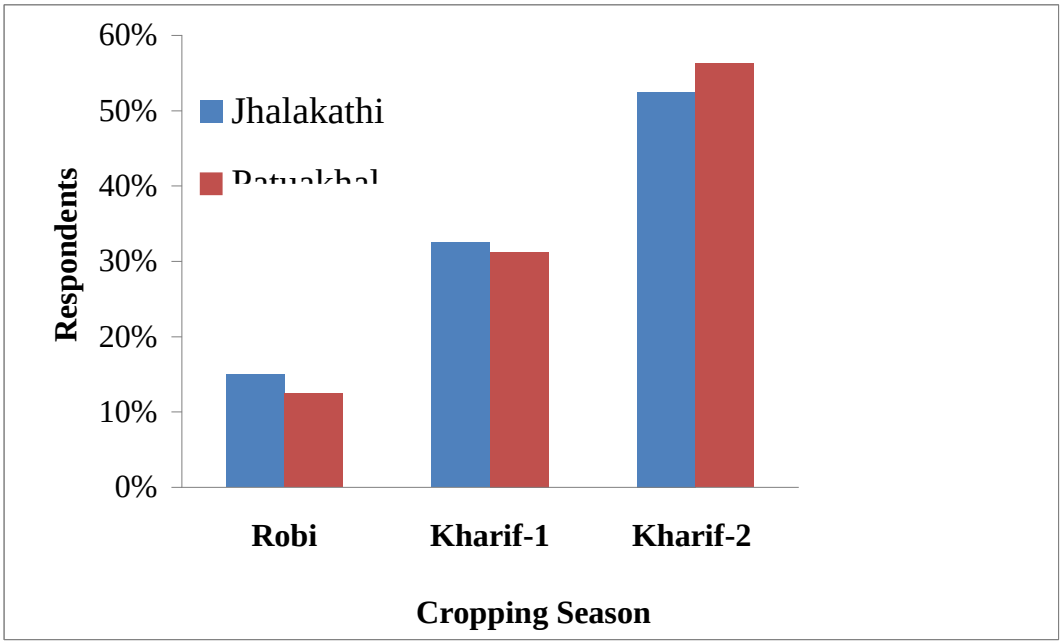

Fig. 3 Impact of cyclones on the cropping season in the south-central coastal area of Bangladesh

Farmer's perception of the impacts of cyclone on crop production

Fig. 5 presents farmers' perceptions of cyclone-induced damage to major crops in the study area. In both Patuakhali and Jalokhati districts, respondents identified T. Aman (Transplanted Aman) rice as the most severely affected crop, accounting for more than 50% of total crop damage. In Barishal district, Aus rice (25%) ranked second among the most affected crops, whereas in Patuakhali district, mungbean (31%) ranked second. By contrast, crops such as maize and vegetables were perceived to be less affected by cyclones.

'Impact of cyclone on farmers' economic loss

Figure 5 shows the economic losses caused by the cyclone. The majority of respondents in both Jhalakathi (55%) and Patuakhali (45%) reported economic losses of Tk 20000-35000 (1 USD= 123 BDT). For instance, a smaller percentage of farmers in both districts observed losses of less than Tk 20000 (12.5% in Jhalakathi and 15% in Patuakhali). In contrast, a noticeable proportion of respondents in both districts reported losses of Tk 35000-50,000 (21.67% in Jhalakathi and 26.25% in Patuakhali). Only a few farmers experienced economic losses exceeding Tk 50,000.

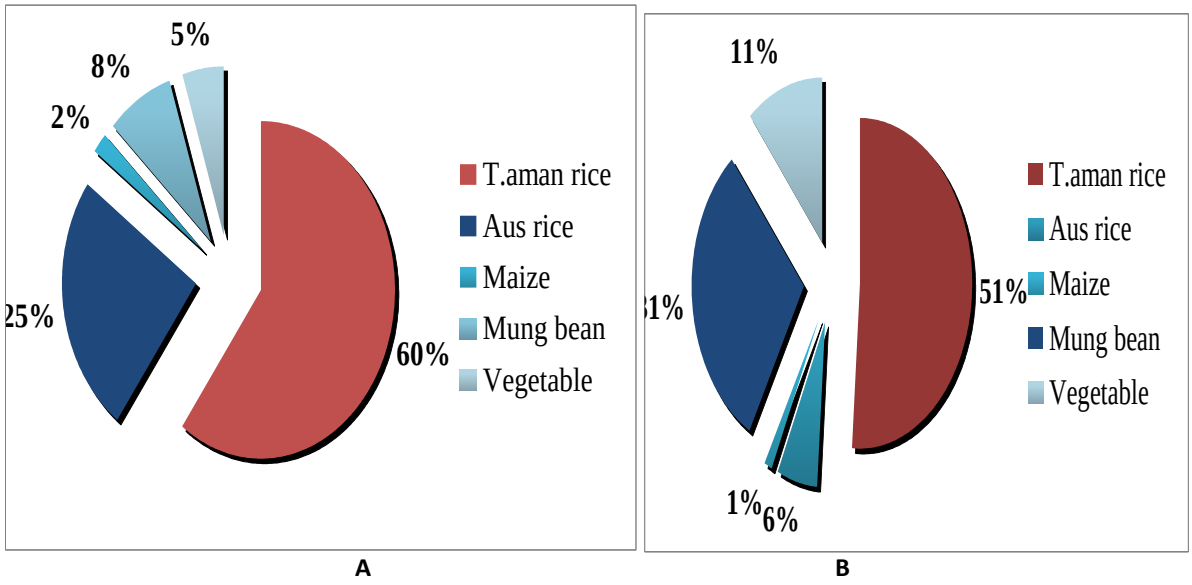

Fig. 4 Impact of cyclones on major crops in the south-central coast of Bangladesh. Panel A represents the impact of cyclones on Jalakhati districts, and Panel B represents the impact of cyclones on Patuakhali districts.

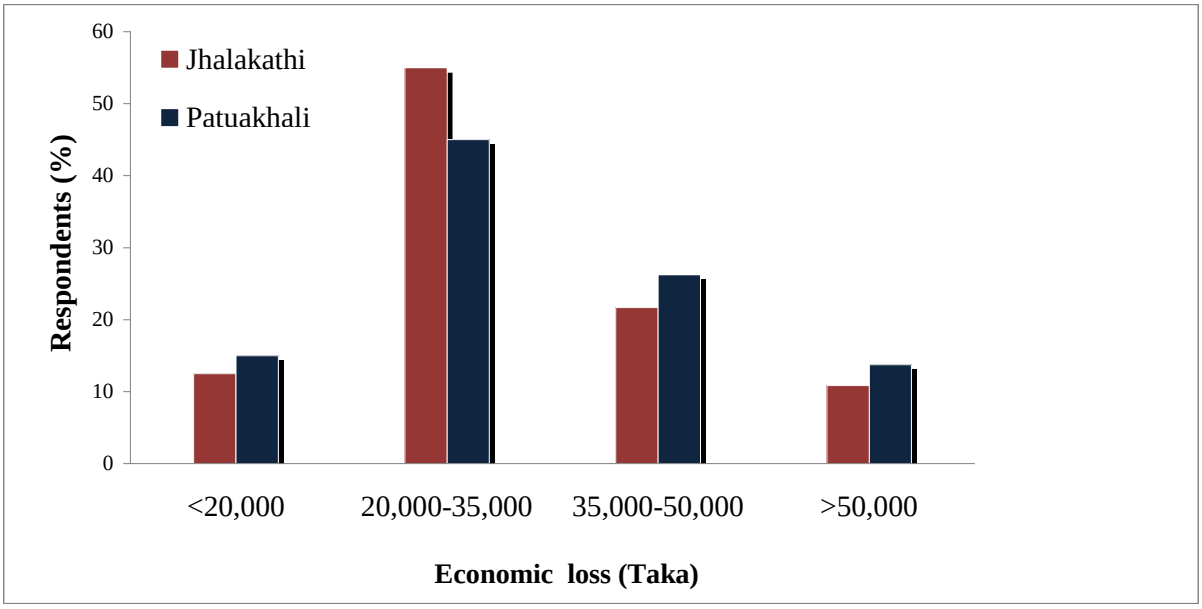

Fig. 5 Impact of cyclone on farmers' economic losses in the south-central coast of Bangladesh.

Farmers' adaptation strategies to cyclones

The majority of farmers are adopting adaptation measures based on their own experiences. A significant proportion of farmers in both Jhalakathi and Patuakhali reported changing their planting times (Table 4). However, a smaller percentage of respondents in Jhalakathi (8.75%) and Patuakhali (12.5%) districts have adopted infrastructural measures, such as building and improving drainage systems.

Table 4 Farmers' adaptation strategies to cyclones in the south-central coastal region of Bangladesh

Adaptation strategies	Jhalakathi (n= 120)		Patuakhali (n= 80)	
	N	%	N	%
Changes in planting time	65	54.16	43	53.75
Build and improve the drainage system	15	12.5	7	8.75
Social agroforestry	13	10.83	9	11.25
Early warning and preparedness activities	27	22.5	21	26.25

Farmers' support needed for implementing adaptation approaches

Figure 6 presents the types of support farmers need to effectively implement adaptation measures to cope with cyclones in the study area. In Jhalakathi, the highest proportion of farmers (61.67%) reported needing government subsidies, indicating that financial support plays a major role in facilitating adaptation decisions. This was followed by climate information services (26.67%), while a comparatively small share of farmers (11.67%) relied on extension agents for adaptation-related support.

A similar pattern was observed in Patuakhali, where government subsidies (57.50%) were also the most significant form of support, though slightly lower than in Jhalakathi (61.67%). Climate information services accounted for 27.50%, indicating comparable reliance on climate-related information in both districts. Support from extension agents remained the least needed adaptation option.

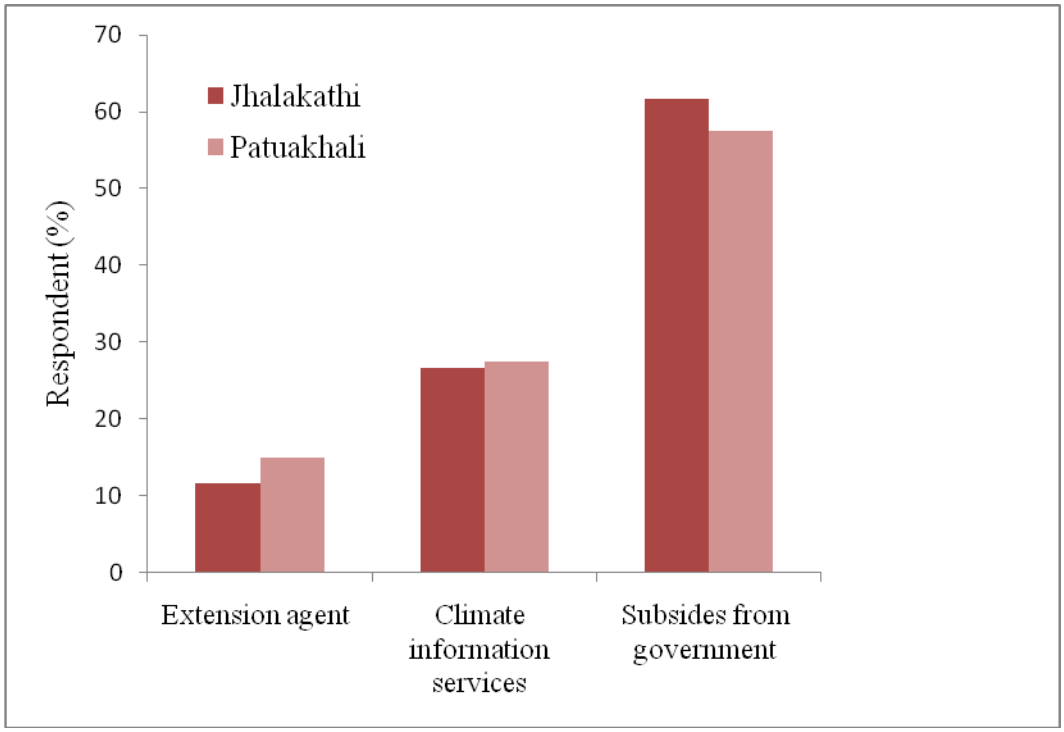

Fig. 6 Support needs for cyclone adaptation among farmers in the south-central coast of Bangladesh

Discussion

This study investigates the impacts of cyclones and the associated adaptation practices adopted by farmers in the south-central coastal regions of Bangladesh. Farmers in coastal areas are generally aware of long-term climatic changes, including cyclones, salinity intrusion, and temperature variability (Bhuyan et al., 2024). However, they often face difficulties in anticipating or responding to the sudden and extreme nature of cyclonic events before they occur. Farmers' perceptions of climate-related risks provide important evidence, as these perceptions influence the adoption of strategies that are essential for reducing potential cyclone-related losses (Anzum et al., 2023).

Cyclones usually cause substantial damage to standing crops in Bangladesh's coastal region (Rahaman and Esraz-Ul-Zannat, 2021). In this study, it was observed that farmers perceived T. aman rice is the crop most severely affected by cyclones. This is primarily due to T. aman rice being typically cultivated during the monsoon season (July-November/December) (Haque et al., 2025), which coincides with the peak cyclone season, thereby affecting the crop during its reproductive or harvesting stage (November/December). In contrast, Aman rice was reported to be less affected, as it is cultivated earlier than the recommended date and harvested before the peak of the cyclone season (Prodhan et al., 2026). Moreover, Aus rice also experiences comparatively less damage from Kalbaishakhi (Nor'Wester) storms, which are short-lived and localized, resulting in limited waterlogging and often reducing their overall impact on Aus rice production. Additionally, farmers in the study areas reported that dry-season rice (Boro rice) in coastal regions was often affected by cyclones, especially late-sown varieties. However, Islam et al. (2020) stated that Cyclones "Aila" and "Mohasen" severely affected coastal Bangladesh, significantly reducing rice production due to saline water intrusion, extended flooding, and direct crop damage. Aila, in particular, caused devastating losses to

Aman and Boro rice due to increased soil salinity, while the cyclone also damaged infrastructure and undermined local livelihoods (Bhuyan et al., 2024). Consequently, cyclones can directly cause significant economic loss. Field observations and farmers' perceptions indicate that the average economic loss in the study area ranges from 20000 (twenty thousand) to 35000 (thirty five thousand) Bangladeshi Taka (BDT) per household. In 2024, the impacts were particularly severe due to Cyclone "Remal", which struck the southern coastal belt. This single event caused estimated crop losses of approximately BDT 11.09 billion and damaged more than 62,783 hectares of farmland across coastal districts (Islam et al., 2022). Such losses increase farmers' financial vulnerability, limit their capacity to reinvest in the next cropping season, and often force them to rely on loans or external support, highlighting the urgent need for effective adaptation and risk-reduction measures.

Farmers in the study area consistently identify cyclones as a recurrent climatic hazard; however, their adaptation responses remain largely grounded in indigenous knowledge and traditional agricultural practices (Shehab et al., 2025). The most commonly reported measures include adjusting planting schedules, improving field drainage, establishing mangrove plantations and other forms of coastal protection, and engaging in early warning dissemination and preparedness activities. Farmers in coastal Bangladesh predominantly depend on low-cost, experience-based strategies (such as short-duration crop, change planting time, raised-bed farming) largely due to constrained access to modern technologies, training facilities, financial resources, and institutional support.

Despite these efforts, farmers recognize that existing adaptation practices are insufficient to substantially reduce cyclone-induced crop losses and associated livelihood disruptions. Consistent with these findings, Bhuyan et al. (2024) reported that farmers in the south-central coastal region implement climate change adaptation strategies shaped primarily by lived experience, and that such measures only partially mitigate adverse impacts. Moreover, farmers strongly perceive the need for external support to implement more effective and sustainable adaptation measures against cyclone-related impacts. Therefore, the Bangladesh government should take initiatives to strengthen farmers' capacity and provide subsidies to farmers affected by cyclones.

Most farmers in the study area are smallholders, and their current adaptation measures remain ineffective due to weak institutional support and limited interaction with extension agents (Badhan et al., 2024; Mia et al., 2025). They receive inadequate climate information and advisory services from the BMD and the Department of Agricultural Extension (DAE), and instead rely on television, radio, and other mass media, which are mostly insufficient for effective planning. Similarly, Kamruzzaman et al. (2021) noted that poor institutional connectivity and the absence of tailored climate advisory services constrain farmers' adaptive capacity in coastal regions. Farmers also emphasize the need for regular extension visits, training on climate information services, and improved advisory support. Regular visits by extension agents and timely cyclone warnings from weather stations may help reduce crop losses for farmers in coastal regions (Kumar et al., 2020). Moreover, strengthening collaboration between governmental and non-governmental organizations is essential for effective adaptation practices (Rahman et al., 2022). For long-term adaptation, government investment in new embankments, particularly in seafront areas, is critical to reducing cyclone vulnerability. Expanding access to credit would further enhance farmers' adaptive capacity. In addition, cyclones do not affect all districts in the coastal region equally. Therefore, zone-specific adaptation plans may be more effective than region-wide approaches. This study provides baseline evidence for developing effective cyclone adaptation plans and offers a foundation for further research.

Conclusion

Farmers in the south-central coastal region of Bangladesh are aware of cyclone events and their adverse impacts on major crops, particularly wet- and dry-season rice production, and they often suffer substantial losses. However, the adaptation measures they implement, including changes in planting time, social agroforestry, and embankment construction, are largely based on their own experience and indigenous knowledge. These measures are frequently inadequate because of limited financial resources, weak institutional support, and insufficient access to climate information services and extension support. The findings of this study indicate that strengthening institutional support and improving climate information services are essential to enhancing farmers' adaptive capacity in cyclone-prone coastal areas. Overall, this study offers important empirical insights to support policymakers in developing location-specific adaptation strategies and sustainable agricultural policies for climate-resilient crop production in Bangladesh. Moreover, this research focuses solely on the south-central coast of Bangladesh, although cyclones also affect the southwestern and southeastern regions of

the country. For a comprehensive adaptation plan, future research should also be conducted in other coastal areas.

Author's Contribution

S.N.: Collection and analysis of data and writing of manuscript. M.I.B.: Writing of manuscript, supervision of experiments, review of manuscript, and analysis of data. M. F: Supervision of experiments, writing of manuscript, and review of manuscript

Conflict of interest

The authors did this research and wrote the article and there is no conflict of interest with other people.

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