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Climate-induced risks, adaptation, and mitigation responses: a comparative study on climate-stressed coastal communities

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Introduction: Tildanga, Kamarkhola, and Sutarkhali under Dacope Upazila of Bangladesh are climate-stressed coastal unions, highly susceptible to recurrent hydroclimatic challenges and anthropogenic interruptions such as cyclones, storm surges, flooding, waterlogging, salinity intrusion, and erratic rainfall. These challenges significantly impact water resources, agriculture, and prevailing livelihoods. Given the increasing vulnerability of coastal communities, it is crucial to understand local perceptions of climate hazards, their socio-economic impacts, and the adaptation and mitigation strategies implemented to enhance coastal resilience.

Methods: This study adopts a mixed-method approach, incorporating 150 structured questionnaire surveys, six focus group discussions, 15 key informant interviews, and 15 in-depth interviews. The research explores community perceptions of climate risks, grassroots innovations, and adaptive responses aimed at mitigating the adverse effects of climate change.

Results: Findings indicate that communities have adopted various strategies to combat coastal challenges, including climate-resilient agriculture, rainwater harvesting, homestead vegetation, mixed cropping with fish culture, opting for saline-tolerant varieties, elevated housing, and disaster preparedness measures. However, financial limitations, inadequate technical knowledge, lack of proper training, and institutional gaps hinder the sustainability and scalability of these strategies. For instance, although solar power-based water management and climate-resilient infrastructure have proven effective, their implementation remains restricted due to resource limitations and inadequate stakeholder participation. Additionally, a gender-responsive approach has empowered women as key contributors to household resilience and inclusive adaptation strategies.

Discussion: A comparative analysis reveals that Kamarkhola is more vulnerable to cyclones and floods, whereas Tildanga and Sutarkhali are primarily affected by salinity intrusion. The study further examines the effectiveness of governance in addressing adaptation rates, livelihood and occupational patterns, increasing water stress, and declining agricultural productivity. Addressing these gaps is essential for strengthening climate resilience and ensuring human security. Finally, the study advocates for policy recommendations that integrate local knowledge, enhance institutional support, and foster community engagement to promote long-term resilience and socio-economic stability in these climate-vulnerable regions.

KEYWORDS

climate risks, community-led adaptation, mitigation, socio-economic impacts, coastal resilience, Dacope Upazila, Bangladesh

1 Introduction

Climate change is one of the most significant and urgent global challenges facing humanity today with its profound impact on ecosystems, economics, and communities all around the world (IPCC, 2014a; Singh and Singh, 2017). The concentration of greenhouse gases has caused the entire world to warm, resulting in several kinds of interrelated effects such as increasing temperatures, rising sea levels, saltwater intrusion and frequent extreme events and ecological damage (Ramanathan and Feng, 2009; Kweku et al., 2018). In addition to changing the physical environment, these changes are endangering human security, especially in areas that are already at risk (Adger et al., 2014). According to the IPCC (2014b), rising global temperature will worsen the consequences of climate change and make it harder for many people to maintain their way of life and means of subsistence.

Bangladesh is one of the countries most susceptible to these worldwide effects (Rakib et al., 2018). The country ranked seventh on the Long-Term Climate Risk Index (CRI) from 1999 to 2018, indicating its high susceptibility to climate change-related disasters (Eckstein et al., 2018). The study also states that during this period, there were 191 instances of severe weather throughout the country (Eckstein et al., 2019). Bangladesh is especially vulnerable to the effects of climate change because of its location at the meeting point of many significant rivers and its heavily populated coastal regions (Minar et al., 2013). According to studies such as those by Aryal et al. (2020), Bangladesh has encountered large losses as a result of extreme weather events, such as the catastrophic consequences of Cyclone Aila and recurrent floods which have had a negative impact on infrastructure, agriculture, and the country's economy as a whole (Aryal et al., 2020). These difficulties are made worse by the restricted ability to adapt and both urban and rural people tend to be highly vulnerable to climate shocks (Adger et al., 2003).

Bangladesh's coastal regions are particularly vulnerable to the negative effects of climate change (Uddin et al., 2019). Millions of people who rely on agriculture, fishing, and other natural resources, live along the nation's Coastline (Elisha and Felix, 2021). Based on their own experiences, Bangladeshi coastal residents conceptualize the implications of climate change, including unpredictable seasonal patterns, flooding, droughts, erosion of riverbanks, and salinity intrusion (Hossen et al., 2022). A rapidly changing environment poses a danger to local populations in coastal areas like Dacope Upazila in the southwest of the country (Rahman, 2022). Rising sea levels, cyclones, intrusions of salt water, and changing seasonal weather patterns are all contributing factors (Karim and Mimura, 2008). Traditional livelihoods in these areas have been affected by changes in land use, decreased agricultural production, and rising soil and water salinity (Roy T. et al., 2022). As a result, local innovations in resource management, migration, and agriculture have frequently been used by communities in these locations to adapt to these environmental changes (Shiferaw et al., 2009; Klocker et al., 2018). Nonetheless, attempts to adapt and mitigate continue to be intricate and context-specific, involving institutional support and local expertise (Amaru and Chhetri, 2013).

Strategies for adaptation as well as mitigation are essential for dealing with the problems caused by climate change, especially in areas that are susceptible such as Bangladesh's coastal regions (Minar et al., 2013; Afjal Hossain et al., 2012). While adaptation focuses on enabling people to deal with the changes they are presently experiencing, mitigation seeks to decrease the effects of climate change in the future by lowering greenhouse gas emissions (Ayers and Huq, 2009). Both approaches are essential for Bangladeshi coastal communities to improve resilience, safeguard livelihoods, and lessen susceptibility to future climate hazards. In addition to improvements in local behaviors, effective adaptation necessitates strong institutional backing, resource accessibility, and the incorporation of community knowledge into larger frameworks for climate action. However, the success of adaptation strategies is influenced by the institutional role of getting resources, information, or support networks (Mubaya and Mafongoya, 2017). Overcoming these obstacles institutional capacities must be strengthened to improve community resilience and incorporate local adaptation strategies into larger frameworks for climate action.

Climate change poses significant risks in the coastal unions of Dacope Upazila, where increasing hydroclimatic challenges—cyclones, storm surges, salinity intrusion, and flooding—threaten water resources, agriculture, food security, and community resilience. While existing studies provide macro-level assessments of climate impacts, they lack localized, union-specific analyses of adaptation and mitigation strategies. Additionally, limited research explores the interplay between adaptation and mitigation in these highly climate-vulnerable regions. A key strength of this study is its focus on community-led adaptation, integrating grassroots innovations such as rainwater harvesting, saline-tolerant crops, and social forestry to address local climate risks. The study addresses adaptation strategies, governance challenges, and socio-economic implications by employing a mixed-method approach, including structured surveys, focus group discussions, and key informant interviews. These insights provide valuable contributions to policy, governance, and climate action strategies tailored to vulnerable coastal populations.

However, certain limitations may influence the vigor and global acceptance, such as purposive site selection may introduce selection bias, as the chosen unions are particularly exposed to climate risks and already implementing adaptation measures. While stratified random sampling enhanced representation, self-reported data may still carry biases. Logistical constraints, including mobility issues and participant availability, particularly among marginalized groups, posed challenges during data collection. Additionally, findings are context-specific, based on local perceptions and experiences, and may not be fully generalizable to other coastal areas due to socio-economic and environmental variations. Despite these limitations, the study bridges critical research gaps by integrating both top-down and community-driven responses, offering a scalable and replicable framework for climate resilience. By identifying institutional and governance gaps, the study provides actionable policy recommendations, emphasizing the need for locally tailored, participatory approaches to enhance climate adaptation efforts.

2 Materials and methods

2.1 Study area

The research was conducted in the Tildanga, Kamarkhola, and Sutarkhali unions of Dacope Upazila, which exhibit significant vulnerability to climate change, with scores of 0.97, 1.13, and 0.57, respectively (Razzaque et al., 2019). *Sutarkhali* union is located at the base of Dacope Upazila, close to the Sundarbans. It is one of the most susceptible unions to the detrimental impacts of climate change. *Sutarkhali* union covers 47.55 square kilometers and has a total population of 30,430, of which 15,663 are male and 14,740 are female. *Tildanga* covers an area of 9, 933 hectares, comprising 26 settlements, 4,095 households, and a population of 17,006. *Kamarkhola* spans 4,137 hectares with 14 settlements, 3,559 households, and a population of 13,897 [Bangladesh Bureau of Statistics (BBS), 2011]. Alterations in land use, ecological problems, and natural calamities have profoundly impacted these regions. The area has changed land use, notably transitioning from rice agriculture to shrimp aquaculture, along with ensuing social effects. Despite the continued prominence of shrimp farming in Tildanga, Kamarkhola and Sutarkhali union returned to rice cultivation following Cyclone Aila in 2009, illustrating diverse adoption methods to ecological and economic adversities (Barai et al., 2019; Kibria et al., 2016; Figure 1).

2.2 Methodological approaches

2.2.1 Selection of sampling site

The research was conducted in the Tildanga, Sutarkhali and Kamarkhola unions of Dacope Upazila, located in the southwestern part of Bangladesh. These areas were particularly vulnerable to climate risks such as rising sea levels, cyclones, flooding, and salinity intrusion. A purposive sampling technique was used to choose the coastal unions based on their susceptibility to climate change and the variety of adaptation and mitigation practices implemented.

2.2.2 Data collection

The study employed a mixed-methods approach combining both quantitative and qualitative methods to collect and analyze data from primary and secondary sources to gain a comprehensive understanding of community-led adaptation and mitigation strategies

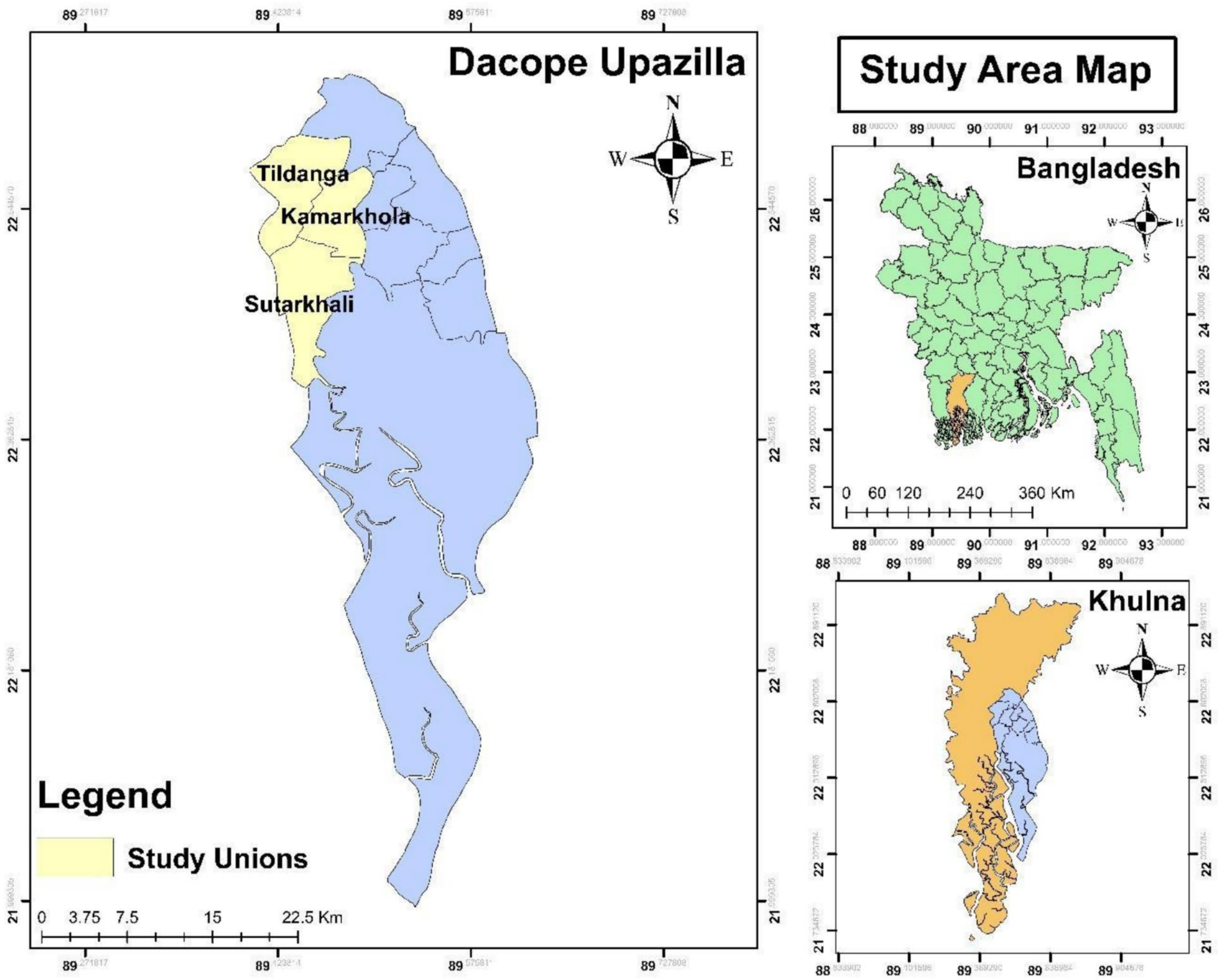

FIGURE 1
Study unions of Dacope Upazila of Bangladesh.

(Kabir et al., 2021). A stratified random sampling method was used to select respondents from various socio-economic groups within each union. Criteria such as gender, age, and livelihood type were considered to capture a diverse range of perspectives. Quantitative Data collection included structured surveys which were conducted with 50 respondents from each of the three unions, resulting in a total sample size of 150 respondents (Kothari, 2004). The survey gathered information about household demographics, livelihood activities, climate risk perceptions, and adaptive practices. Qualitative data was collected through in-depth interviews and focus group discussions (FGDs) with selected community members, local leaders, and key informants. A total of six FGDs were held across the three unions, with two sessions conducted in each union, and 15 in-depth interviews were completed with participants from all three unions. This provided nuanced insights into the socio-cultural and institutional factors influencing adaptation and mitigation efforts (Bartlett et al., 2001; Kothari, 2004; Islam et al., 2021).

2.2.3 Methodological approach for the weighted scale

The study employs a weighted scale (1 to 5) to assess the effectiveness of adaptation and mitigation strategies across multiple dimensions, including livelihood resilience, water security, disaster preparedness, and governance effectiveness. The methodology follows a quantitative assessment of qualitative data, derived from surveys, key informant interviews (KIIs), and focus group discussions (FGDs), where respondents rated different adaptation strategies and governance responses based on their perceived effectiveness.

2.2.4 Scoring scale definition (weighted scale 1 to 5)

The weighted scale is based on previous studies that use Likert-scale-based evaluations in community resilience and climate adaptation research and is interpreted as follows:

Score	Interpretation
1	Lowest Efficiency – The strategy is ineffective or has very little impact.
2	Marginally Efficient – The strategy is weakly implemented and has limited benefits.
3	Moderate Efficiency – The strategy has some effectiveness but requires significant improvements.
4	High Efficiency – The strategy is effective with minor limitations.
5	Very High Efficiency – The strategy is highly effective and widely adopted.

Source: Adapted from Joshi et al. (2015) and Pescaroli et al. (2020)

2.2.5 Weight assignment

Responses were categorized into five levels and 0 to 10 ratings, based on community perceptions and expert evaluations across the three unions (Tildanga, Kamarkhola, Sutarkhali). Comparative analysis was used to compare different union responses to adaptation strategies. Adaptation strategies such as rainwater harvesting, salinity-tolerant crop cultivation, and early warning systems were assessed using the 1–5 scale, while for climate-induced risks and mitigation responses were rated out of 10 against each sector, governance effectiveness (local government, NGOs, and institutional support) was also rated using this scale.

2.2.6 Data analysis

The quantitative data were analyzed using descriptive statistics, including tabulation, averages, frequency, and percentages, to examine socio-economic status, adaptation strategies, and the challenges and opportunities for adaptation, with the analysis conducted in Microsoft Excel. Meanwhile, the qualitative data were thematically analyzed to identify the underlying drivers and barriers of community-led initiatives.

3 Results

3.1 Demographic profile of respondents

The demographic status of respondents in the Tildanga, Kamarkhola, and Sutarkhali unions of Dacope Upazila, Bangladesh is shown in Table 1. In Tildanga, the majority of respondents are male (n = 33, 65%), whereas Kamarkhola and Sutarkhali exhibit more balanced gender distributions, with a slight female majority in Kamarkhola (n = 22, 45%) and Sutarkhali (n = 20, 40%). The largest proportion of respondents falls within the 31–45 age group (n = 20, 40%) in Tildanga, while Kamarkhola has a higher percentage of 45% in this category (n = 22). Sutarkhali, on the other hand, has the highest share of respondents aged 18–30 (n = 20, 40%). Across all three villages, a notable percentage of respondents have only received primary education ranging from 15 to 35%, with Tildanga showing the highest proportion of individuals with no formal education (n = 10, 20%). Higher education remains rare across the villages, with only a small segment of respondents attaining this level of education for improved education and livelihood diversification to strengthen resilience and socio-economic stability in these coastal unions. In terms of occupation, farming is predominant in Kamarkhola (n = 25, 50%) and Tildanga (n = 15, 30%), while Sutarkhali demonstrates greater occupational diversity, with a higher percentage engaged in shrimp farming (n = 12, 25%). Fishing and day labor remain common occupations across all three villages, though their distribution varies. These findings further emphasize the importance of education and livelihood diversification for improving resilience and socio-economic conditions in the area. In Tildanga 50% (n = 25) of the respondents has earned below 5,000 BDT, while Sutarkhali leads with the highest percentage of 60% of households in this income range (n = 30). However, Kamarkhola reports around 36% (n = 18) of respondents earning between 5,001 and 10,000 BDT, indicating a relatively higher average income. Our findings, partially correspond with the research by Roy B. et al. (2022), according to which historically 59% of the population worked in agriculture, 29% in fishing, and 12% as day laborers. This finding corroborates Roy T. et al. (2022), which indicated that 77% of homes in the study area had an annual income below 50,000 BDT (about 4,167 BDT per month), reinforcing the assertion that the majority of households earn less than 10,000 BDT monthly, with many earning under 5,000 BDT. Higher-income brackets were less common, representing a need for improved economic opportunities and income diversification in these regions.

TABLE 1 Demographic profile of respondents among three coastal unions.

Variables	Classification	Tildanga	Kamarkhola	Sutarkhali
		Number of respondents, *n* (%)	Number of respondents, *n* (%)	Number of respondents, *n* (%)
Gender	Male	33 (65)	28 (55)	30 (60)
	Female	17 (35)	22 (45)	20 (40)
Age group (in years)	18–30	17 (35)	15 (30)	20 (40)
	31–45	20 (40)	22 (45)	10 (20)
	46–60	5 (10)	10 (20)	15 (30)
	60+	8 (15)	3 (5)	5 (10)
Education level	No formal education	10 (20)	8 (15)	15 (30)
	Primary	17 (35)	15 (30)	17 (35)
	Secondary	15 (30)	16 (33)	10 (20)
	Higher secondary	5 (10)	8 (15)	5 (10)
	Bachelor's degree or Higher	3 (5)	3 (7)	3 (5)
Primary occupations	Farming	15 (30)	25 (50)	17 (35)
	Fishing	10 (20)	6 (12)	8 (15)
	Shrimp farming	7 (15)	4 (8)	12 (25)
	Day laborer	10 (20)	8 (15)	5 (10)
	Service/business	5 (10)	3 (6)	5 (10)
	Others	3 (5)	4 (9)	3 (5)
Monthly household income (in BDT)	Below 5,000	25 (50)	17 (35)	30 (60)
	5,001–10,000	14 (29)	18 (36)	9 (18)
	10,001–20,000	8 (16)	11 (21)	8 (16)
	Above 20,000	3 (5)	4 (8)	3 (6)

Source: Field Survey.

3.2 Climate risks in coastal unions: perception-based frequency analysis

Figure 2 represents several climatic events faced by Tildanga, Kamarkhola, and Sutarkhali of Dacope. The frequency of cyclones is higher than other climatic events and Kamarkhola is mostly affected by this concerned calamity. Kamarkhola experiences slightly less salinity due to freshwater-based agriculture instead of saltwater-dependent aquaculture practices, while Tildanga and Sutarkhali face severe salinity. Sutarkhali experiences slightly higher impacts due to changes in land use patterns and soil degradation while it poses a moderate impact on other regions. Erratic rainfall patterns are comparatively high in Kamarkhola while other climatic risks are more prominent in Sutarkhali. Though water logging is a predominant issue in Sutakhali, drought is relatively less common across the regions.

Our study results align with some other previous studies in coastal Bangladesh though we did not find relevant information on union level. Dasgupta et al. (2014) reported that frequent tropical cyclones and associated storm surges have been a persistent threat, with 154 cyclones recorded between 1877 and 1995. There are eight major cyclones between 2000 and 2020, including Cyclone Sidr (2007), which have affected millions of people (Hossain and Mullick, 2020). More recent cyclones like Mora (2017), Feni (2019), and Bulbul (2019) also led to fatalities and widespread damage to homes and infrastructure, while Cyclone Amphan (2020) and Yaas (2021) caused further losses in fisheries, crops, and homes (Islam, 2025). These cyclones lead to widespread flooding and prolonged saltwater intrusion, significantly impacting soil fertility and freshwater availability (Ashrafuzzaman et al., 2022). Approximately 37% of arable coastal land experiences fluctuating salinity levels, while 70% of total coastal farmland is affected by soil salinity (Dasgupta et al., 2014). Saltwater intrusion into groundwater and surface water further exacerbates drinking water shortages, potentially affecting over 20 million people (Haldar et al., 2017). Excessive groundwater extraction and rising sea levels have worsened salinization, rendering agricultural lands less productive (Salehin et al., 2018; Lam et al., 2022). Climate change is intensifying these issues, leading to prolonged droughts, erratic rainfall, and temperature fluctuations, which disrupt local agriculture, livelihoods, and food security (IPCC, 2014a; Talukder et al., 2018). By 2050, increased river and groundwater salinity could significantly worsen the freshwater crisis, affecting nearly 2.9 million people (Bannari and Al-Ali, 2020).

3.3 Comparative analysis of observed environmental changes

Table 2 represents the observed environmental changes impacting resources across the coastal unions. The study regions exhibit distinct socio-ecological and resource use changes due to recurrent climatic and anthropogenic interruptions. Water stress is a common scenario

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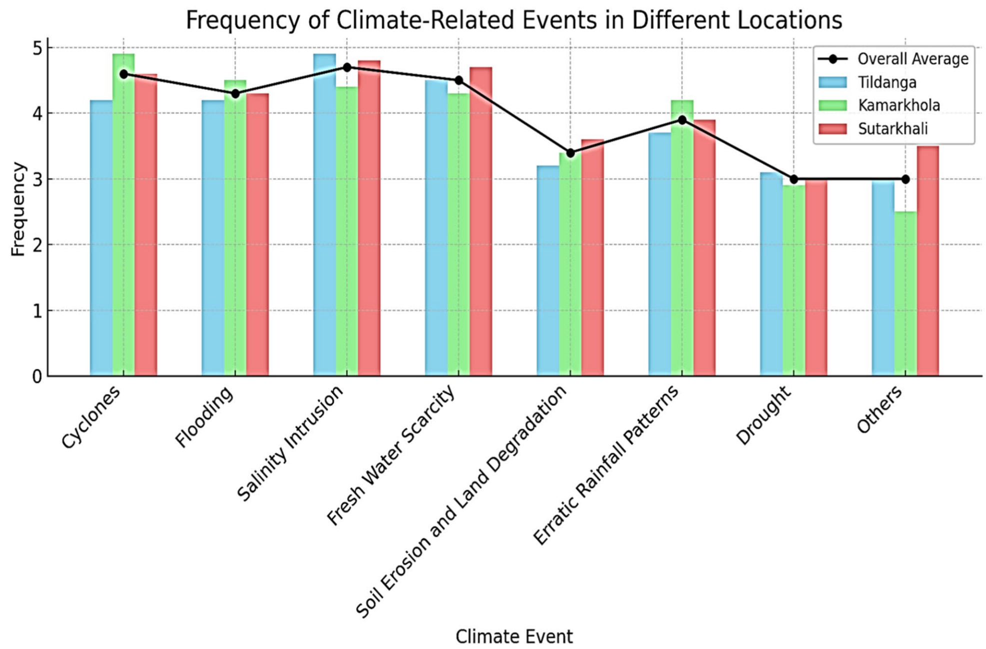

FIGURE 2
Comparative representation of climate-related events according to respondents' perception (1 = Never, 5 = Very Often).

in Tildanga, where salinity intrusion affects surface and groundwater, whereas Kamarkhola adopted rainwater harvesting to meet the growing safe water demand. Key observations include widespread salinity intrusion (72–90%) and reduced freshwater availability (58–78%), increasing reliance on rainwater. Land degradation is evident, with decreased fertility (86–96%), agricultural decline (44–92%), and a shift towards aquaculture, particularly shrimp farming (36–86%). Forest ecosystems are also deteriorating, with biodiversity depletion (58–74%), declining resources, and increased reliance on common pool resources (46–92%). Fisheries show a marked decline in species diversity (54–88%) and freshwater fish stocks (62–84%). Common pool resources are gradually declining across the three regions causing resource depletion in Kamarkhola, reduction of fish diversity in Tildanga and Sutarkhali observing reduced fish catches that demand region-specific strategies to manage these interconnected challenges.

3.4 Comparative perspectives of climate shocks and socio-economic ripple

Figure 3 demonstrates comparative climatic risks and associated socio-economic consequences that influence economic stability, food security, water access, and mobility patterns. The findings reveal that reduced access to clean water is a vital issue in the three regions and Shutarkhali is highly vulnerable to this problem. The cost of living is higher in Kamakhali which hinders the adaptation of the people living there. The migration rate is lower than other issues. Damage to livestock and crops is an alarming issue across three study unions, reflecting substantial agricultural exposures. In terms of mobility, both permanent and temporary, are less common but show a comparable lens in Tildanga and Sutarkhali, while Kamarkhola undergoes the least migration pressure. Therefore, greater importance should be given to face the interconnected socioeconomic challenges and climate-induced consequences.

3.5 Cause-effect-responses towards climate change and disaster risks

Figure 4 demonstrates the cause-effect relationships between different components of climate change, its impacts on local economies, and the potential responses to these challenges. In the figure, the solid line arrow represents the positive relationship between variables and the dash line arrow shows the negative relationship between the variables. Rising sea levels contribute to increased flooding, which in turn reduces agricultural productivity due to the inundation of farmland and crops. Flooding disrupts coastal livelihoods, reduces agricultural productivity, particularly in farming-dependent regions and causes infrastructural damage, leading to economic instability. Economic instability, in turn, often forces people to migrate in search of better opportunities, which increases exposure to disasters, as overcrowded urban areas are more vulnerable to climate-related events. This increased exposure to disasters further escalates the risk of flooding in these areas.

Resilient infrastructure plays a crucial role in stabilizing the economy by minimizing the impact of disasters. Furthermore, investing in skill development, such as vocational training, provides individuals with alternative livelihoods, helping to decrease migration by offering sustainable local employment opportunities. Climate change responses include adaptation strategies like salinity-tolerant crops, improved irrigation, resilient infrastructure, and disaster preparedness to help communities cope with environmental changes. Mitigation efforts focus on reducing future risks through renewable energy projects, ecosystem restoration (such as mangrove planting),

TABLE 2 Observed environmental changes by respondents that impact on resources.

Resource type	Indicator	Tildanga (N = 50)		Kamarkhola (N = 50)		Sutarkhali (N = 50)	
		Frequency (n)	Frequency (%)	Frequency (n)	Frequency (%)	Frequency (n)	Frequency (%)
Water	Increased salinity	41	82	36	72	45	90
	Reduced freshwater availability	39	78	29	58	38	76
	Increased reliance on rainwater	28	56	42	84	34	68
Land	Decreased fertility	47	94	43	86	48	96
	Reduced agricultural output	44	88	22	44	46	92
	Changes in land use pattern (growing shift to aquaculture)	38	76	34	68	31	62
	Prompting shrimp farming	35	70	18	36	43	86
	High salinity has degraded farmland	42	84	26	52	39	78
Forests	Biodiversity depletion	35	70	29	58	37	74
	Degradation of social forest due to rising sea level	26	52	24	48	24	48
	Declining forest resources for fuel, fruits, and honey	41	82	43	86	39	78
	Increased dependency on common pool resources	25	50	23	46	46	92
Fisheries	Reduction in fish species diversity	44	88	37	74	27	54
	Decline freshwater fish stock	31	62	42	84	33	66
	Reduced natural fish availability	39	78	34	68	48	96

Source: Field Survey; N, Number of total respondents; n, number of respondents agreed against each indicator.

and promoting non-farm income sources. These combined strategies aim to lower vulnerability, strengthen resilience, and foster sustainability for affected communities.

3.6 Bridging climate risks with community adaptation and mitigation responses

Table 3 provides a detailed summary of climate-induced vulnerabilities across several sectors, emphasizing the strategies being adopted to address risk and mitigate the obstacles faced by the communities of Tildanga, Kamarkhola, and Sutarkhali, affecting livelihoods, water access, agriculture, fisheries, housing, and migration patterns. Coastal livelihoods remain highly dependent on fishing and farming, with moderate success (efficiency: 2–3) in adaptation strategies like income diversification and microfinance-based mitigation. The drinking water crisis persists due to inadequate rainwater harvesting and PSF systems maintenance, despite moderate efficiency (2–3.5). Agriculture faces severe challenges from soil salinity and erratic rainfall, with drought-resistant crops and soil conservation showing mixed success (2.5–3.5). Fisheries and livestock suffer from declining fish stocks and saltwater intrusion,

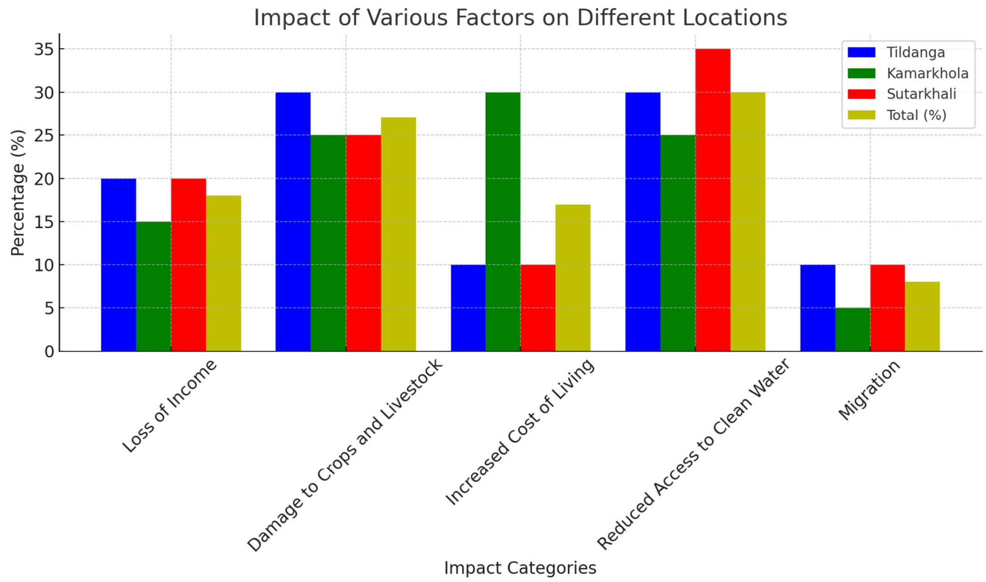

FIGURE 3
Comparative perspectives of climate risks and socio-economic impacts (according to respondent's responses).

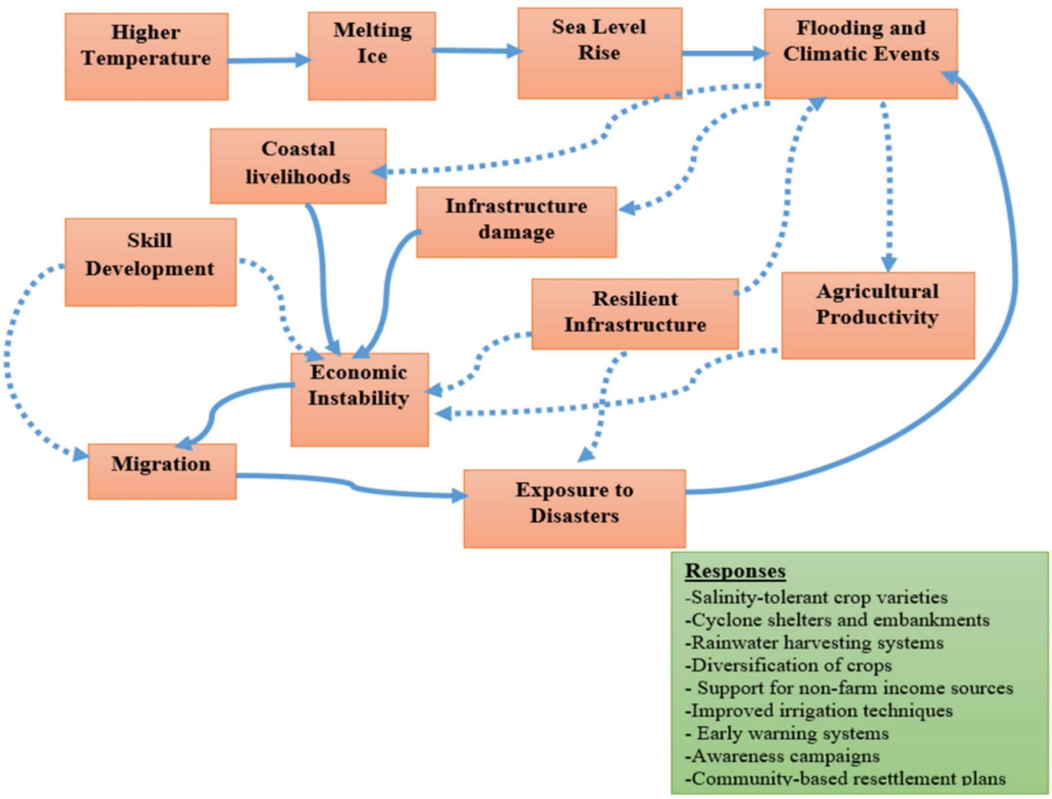

FIGURE 4
Cause-effect-responses towards climate changes and disaster risks.

with alternative farming techniques showing limited impact (2–3.5). Cyclone-resistant shelters exist but are often insufficient, with both adaptation and mitigation strategies scoring low (1.5–3.5). Vocational training offers a potential solution to job loss, but access remains limited. Climate-induced migration is increasing, particularly among younger generations, as local employment opportunities are insufficient. The overall findings emphasize the urgent need for enhanced management, expanded adaptation coverage, and sustainable livelihood programs to enhance community resilience across all three unions.

TABLE 3 Climate risks with community adaptation and mitigation responses.

Sectors	Climate-induced risks and vulnerabilities	Adaptation strategies	Efficiency (1 to 5 scale)			Community-led mitigation responses	Efficiency (1 to 5 scale)			Overall observations from respondents
			TD	KK	SK		TD	KK	SK	
Coastal Livelihood	Loss of livelihoods to environmental disasters	Diversification of income sources	2.5	3	2	Building resilient livelihoods through microfinance.	3	3	1.5	High dependence on fishing and farming; demand for more sustainable employment opportunities.
Drinking Water	Decreased freshwater availability	Establishing Pond Sand Filters (PSF) and rainwater harvesting systems	3	3.5	2.5	Ensuring equitable freshwater access through local committees.	2	2.5	2	Acute water crisis across all areas; PSFs and rainwater harvesting adopted but fail due to lack of proper maintenance, management and monitoring, need expansion and more coverage
Agriculture	Crop failure due to erratic rainfall, soil erosion, and salinity.	Drought-resistant crops, soil conservation practices, raised platforms for crops.	3.5	3	2.5	Implementing farmer-led adaptation initiatives, such as seed banks and climate-resilient farming.	3.5	3.5	2.0	Increased salinity affecting yields; need for better irrigation and financial support for adaptive practices.
Fisheries and Livestock	Decline in fish catch, livestock diseases, and saltwater intrusion.	Farming fish in controlled environments, and the introduction of salt-tolerant livestock.	2.5	3.5	2	Formation of local fishery cooperatives for better resource management.	2.0	2.0	2.5	Rising salinity impacting fish and livestock; need for better disease management and alternative fishing practices.
Housing and Infrastructure	Vulnerability to cyclones, floods, and storm surges.	Construction of cyclone-resistant shelters raised houses.	3.5	3.0	1.5	Local construction committees guiding safe housing practices.	2.5	2.0	1.5	Cyclone shelters exist but are inadequate; demand for stronger, affordable housing solutions.
Occupational Livelihood	Job loss in traditional sectors due to climate impacts	Training programs for alternative livelihoods.	3.5	3	3	Community-driven job creation initiatives through sustainable business models.	3	3.5	2	Vocational training needed but limited; alternative jobs source can help the community especially the youth.
Climate-induced Migration	Migration due to loss of land and livelihoods.	Relocation to less vulnerable areas, and creation of safe spaces for returnees.	1.5	2	2.5	Local governments collaborate with NGOs to support migration-related needs.	3	3	2.5	Increasing migration trends, particularly among younger generations; need for local job incentives to curb displacement.

TD, Tildanga; KK, Kamarkhola; SK, Sutarkhali; 1 = Lowest Efficiency; 2 = Marginal Efficient; 3 = Moderate efficiency; 4 = High efficiency; 5 = Very high efficiency.

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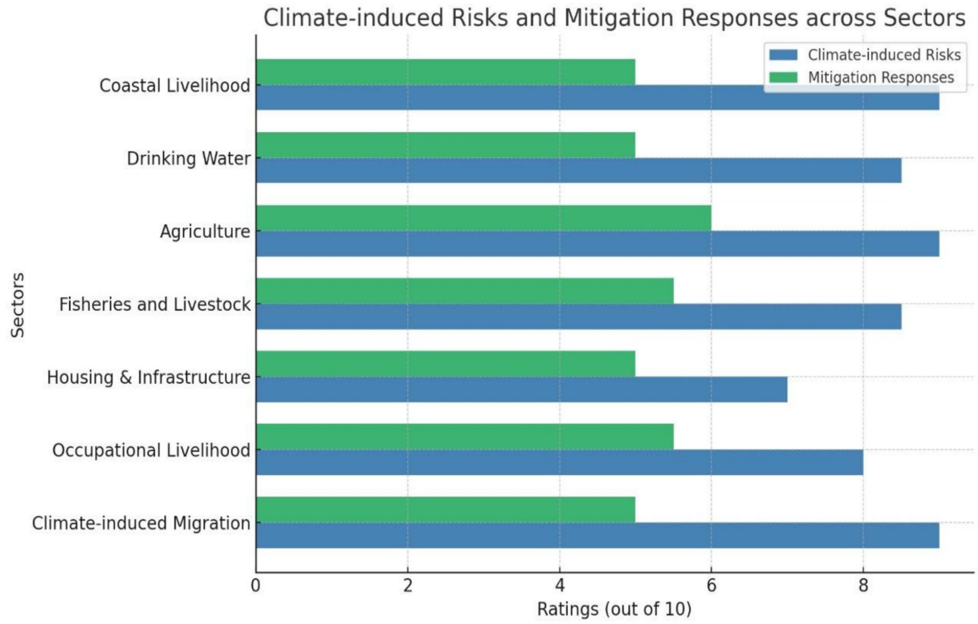

FIGURE 5
Summarized representation of climate-induced risks and mitigation responses.

TABLE 4 Scalability of community-led adaptation and mitigation strategies.

Strategy	TD	KK	SK	Overall	Key remarks
Construction of embankments	3	3	2	3	Effective, but maintenance challenging
Salt-tolerant crop cultivation	3	2	3	3	Stabilized food security but limited availability
Rainwater harvesting systems	3	4	3	3	Effective but not scalable due to infrastructure gaps
Early warning systems	4	4	4	4	Highly effective in saving lives and minimizing losses during cyclones
Social forestry	4	4	3	4	Reduced cyclone impacts; maintained ecological balance.

TD, Tildanga; KK, Kamarkhola; SK, Sutarkhali; 1 = Poor/Ineffective; 2 = Marginal effectiveness; 3 = Moderate/Effective but requires significant improvements; 4 = Good/Effective with some limitations; 5 = Excellent/Highly effective.

3.7 Climate-induced risks and mitigation responses across sectors by sector

A quantitative assessment of qualitative data is conducted to track the progress of climate resilience by scoring of different aspects (vulnerabilities, community responses). The scoring is conducted based on a conceptual analysis of the table's qualitative data, considering how climate vulnerabilities impact each sector, the effectiveness of adaptation strategies, and the strength of community-led responses. Figure 5 summarized representation of climate-induced risks and mitigation responses across different sectors such as livelihood, occupation, livestock, infrastructure, etc. From the quantitative analysis, it can be concluded that the agricultural sector of Dacope Upazilla is highly vulnerable due to climate change. Mitigation strategies are not enough to build resilience in this sector and capacity building of communities is required for achieving sustainable agriculture. Progress is prominent in housing and infrastructure design as it is sufficiently capable to combat climate change induced disasters. The status of occupational livelihood is still average where much focus is required. Capacity-building initiatives and financing are still required to achieve climate resilience.

3.8 Comparative scalability of community-led adaptation and mitigation strategies

Table 4 represents the scalability of community-led adaptation and mitigation strategies across the coastal unions of Tildanga, Kamarkhola, and Sutarkhali along with their effectiveness and challenges. In the study area, strategies such as embankment construction, which scored 3, were considered moderately effective in reducing flood impacts but faced considerable maintenance challenges. The adoption of salt-tolerant crops proved moderately effective in Tildanga and Sutarkhali Union but marginal effectiveness in Kamarkhola Union. On the other hand, rainwater harvesting was found effective in Kamarkhola compared to other two unions. Early warning systems emerged as highly effective

(Score 4) across all unions, significantly minimizing losses during cyclones.

Similarly, mangrove planting or social forestry initiatives were successful which overall scored as 4 in reducing cyclone impacts and maintaining ecological balance, though minor limitations were noted. Despite these successes, the strategies require substantial improvement and support to overcome barriers such as financial constraints and inadequate institutional backing. Addressing these issues is essential to enhance the resilience of these vulnerable coastal communities.

3.9 Effectiveness of adaptation and mitigation responses

Table 5 provides an overview of various climate change adaptation strategies, emphasizing their effectiveness, adoption rates, government and NGO support, and perceived challenges. The effectiveness (in %) was presented based on respondents' perception of the indicated response. The findings demonstrated that disaster warning systems and cyclone shelters were the most widely adopted, with adoption rates of 80 and 70%, respectively. Both are considered highly effective in reducing disaster impacts and benefit from strong government support, especially the warning systems. Training and knowledge-sharing, adopted by 70%, have proven to be highly effective in building local capacity, with moderate to high support from both governments and NGOs. Salinity-tolerant crop varieties, adopted by 60%, were moderately effective in areas with moderate salinity, though less so in more extreme conditions. These crops face low government support (2/5) and moderate NGO support (3/5). There is a noticeable gap in support between governments and NGOs. Governments tend to prioritize infrastructure projects like cyclone shelters and warning systems, while NGOs are more focused on environmental and community-based initiatives such as social forestry and rainwater harvesting. To scale effectively, interventions like rainwater harvesting and skill development require greater government support, while social forestry would benefit from enhanced community involvement and capacity-building efforts.

3.10 Human security in governance and society

Table 6 contrasts the human security of the three unions in Dacope Upazila-Tildanga, Kamarkhola, and Sutarkhali, with a particular focus on governance and societal aspects. The comparison (in %) was derived from the household survey where responses were calculated from the number of respondents' opinions with a total of 50 respondents from each union. Important factors, which include access to drinking water, agricultural production, fisheries and livestock health, housing infrastructure, occupational livelihood and climate-induced migration are studied to demonstrate the diverse impact of climate risks on these coastal communities. Access to drinking water is a fundamental element of human security. Rising sea levels and sporadic storm surges have led to an increasing worry over sedimentation in the coastal plains of Southeast Asia, which poses a serious risk to supplies of drinking water (Hoque et al., 2016). Respondents in this study reported that salinity intrusion causes severe portable water shortages for 72% of households in the three unions. Although rainwater collection systems are a key adaptation strategy, they are not able to meet the community's demands. Kamarkhola has the lowest access rate (70%) among the unions, whereas Tildanga has slightly better access (75%), indicating a general difficulty in guaranteeing water security.

Salinity has had a significant detrimental impact on agricultural output (Alam et al., 2017). This study shows soil salinity affects agricultural production with an average score of 63%. This emphasizes the necessity of focused interventions to support implementing resilient agricultural techniques and enhancing the skills of local farmers, ensuring food availability and livestock security. However, there is a scarcity of grazing land and agricultural products for livestock production as a result of rising salinity (Wisner et al., 2014). This study found the decline of these two sectors, averaging 53%, affects the food supply and income. Kamarkhola has a better position (56%) among the unions, whereas Sutarkhali has the lowest (50%). To compensate for the shortage of protein from livestock communities must use other natural resources (Alam et al., 2017). Population struggles in different regions, causing damage to housing, increasing homelessness, and pushing migration to urban areas. Presently, 53 million people are vulnerable to "very high" exposure to climate change, and over 90 million people (56%) reside in "high climate exposure areas," where there is a serious dearth of robust, reasonably priced, and easily accessible housing infrastructure. On the other hand, the housing and infrastructure of this study demonstrate relatively better resilience, with an average score of 81%. These results are in line with studies that endorse strong, climate-resilient, infrastructure as a fundamental component of human security (Wisner et al., 2014). Livelihoods in these coastal unions have been heavily disrupted with an average impact level of 68%. Many have been migrating or changing careers as a result of losses in agriculture and fisheries.

Livelihood restoration measures are necessary since job uncertainty remains to be a contributing factor to vulnerability. Within a larger framework of significant shifts in population distribution, environmental variables influence patterns of migration and mobility (Tacoli, 2009). Environmental and livelihood factors are major causes of migration, affecting 48% of people on average. Sutarkhali (45%) has the lowest migration incidence, while Kamarkhola (52%) reports highest. This trend draws attention to the growing urban demand and the necessity of sustainable rural development plans. Environmental change can boost migration incentives but also limit capacity, impacting various drivers and affecting the overall migration landscape (Warner, 2010). The investigation identifies major shortcomings in agricultural output, stability of employment, and water access that compromise regional human security. Despite the relative stability of the housing infrastructure, the entire situation emphasizes the necessity of integrated community-led governance systems.

3.11 Role of governance structures

Rural communities in Bangladesh's coastal regions face elevated vulnerability as a result of climate change, which affects their means of subsistence and compels them to take some strategies to adapt to the situation. However, these strategies are shaped not only by nature-based solutions or individual effort but also by institutional support

TABLE 5 Effectiveness of adaptation and mitigation responses.

Response	Overall adoption rate (%)	Very effective (%)	Somewhat effective (%)	Not effective (%)	Do not know (%)	Overall perception	Government support (1–5)	NGO support (1–5)
Salinity-tolerant crop varieties	60	30	50	10	10	Increased yields in moderate salinity, but challenges remain in high salinity areas.	2	3
Cyclone shelters and embankments	70	50	40	10	-	Reduced loss of life but concerns about maintenance and capacity during large-scale events.	3	2
Rainwater harvesting systems	50	20	70	5	5	Improved access to drinking water, though storage capacity is a limiting factor.	1	4
Social forestry	30	30	60	-	10	Provided natural buffers against storm surges but requires more community involvement.	2	4
Skill development for alternative livelihoods	50	50	50	-	-	Enhanced income diversification but requires further scaling for wider impact.	2	3
Disaster warning systems	80	60	40	-	-	Early warning systems tremendously help to save lives and property.	4	3
Training and knowledge sharing	70	70	30	-	-	Enhancing accessibility to information services and sharing the information with peer groups significantly helps in capacity building and practical management.	3	4

1 = Poor/Ineffective support; 2 = Marginal support; 3 = Moderate support but not enough; 4 = Good/Effective with some limitations; 5 = Excellent/Highly effective Support.

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TABLE 6 Comparative scenario of human security in governance and society.

Components	TD (%)	KK (%)	SK (%)	Average (%)	Key insights
Drinking water	75	70	72	72	Salinity intrusion causes water shortages, reliance on rainwater.
Agriculture	68	60	62	63	Reduced yields and food insecurity reported; limited adoption of salinity-tolerant crops.
Fisheries and livestock	52	56	50	53	Decline in fish stocks and livestock health, impacting food supply and income.
Housing and infrastructure	78	82	84	81	Significant cyclone-related damage; community shelters used but infrastructure requires upgrading.
Occupational livelihood	65	70	68	68	Disruption of livelihoods; migration often linked to job losses in agriculture and fisheries.
Climate-induced migration	48	52	45	48	Migration driven by environmental and livelihood stressors; urban areas under pressure.

TD, Tildanga; KK, Kamarkhola; SK, Sutarkhali.

or lack of institutional support. Institutions can play an important role in shaping adaptation strategies by giving resources and frameworks (Agrawal and Perrin, 2009; Mubaya and Mafongoya, 2017). Institutions consist of formal governance and organizational structures as well as unwritten 'rules of the game' cultural norms, and traditions (informal or institutional arrangements) that establish human interaction and behavior (Jones et al., 2010), institutions can be classified as either formal or informal and fall into one of three categories: private, public, or civic (Agrawal and Perrin, 2009). Stakeholder cooperation and integrated planning are frequently referred to as vital elements of effective governance in the case of community-led adaptation (Agrawal, 2008).

3.12 Navigating climate risks: roles and contributions of local government, NGOs, and international agencies

Governance plays a crucial role in shaping climate adaptation in coastal Bangladesh, determining the sustainability and effectiveness of various initiatives (Uddin et al., 2021). The adaptation landscape is divided between government-led infrastructure projects focused on disaster risk reduction and NGO-driven, community-based strategies. Decentralizing climate governance remains a critical challenge in climate-vulnerable regions, as limited public participation in policy design and implementation weakens the effectiveness of adaptation efforts. Similar to the governance issues observed in the Kafue Wetlands, where decision-making remains centralized within national ministries rather than being delegated to local authorities, climate governance in the coastal unions of Tildanga, Kamarkhola, and Sutarkhali of Dacope Upazila, Bangladesh, faces institutional constraints that hinder locally driven adaptation (Ndambwa and Moonga, 2024). The lack of meaningful community engagement in planning and executing climate resilience initiatives reduces their effectiveness and sustainability. However, the Bangladesh Water Development Board (BWDB) struggles with inefficiencies, leading to poor embankment maintenance and heightened flood risks, particularly in Sutarkhali. The Union Parishad facilitates disaster relief but faces financial and bureaucratic constraints that delay responses.

Water resource management remains inconsistent. While rainwater harvesting in Kamarkhola has improved freshwater access, its broader implementation is restricted by weak policy support and limited funding. Similarly, early warning systems—led by the Bangladesh Meteorological Department (BMD) and the Union Disaster Management Committees (UDMCs)—face challenges in accuracy and volunteer coverage. Agricultural adaptation, particularly salt-tolerant crops, has improved food security in some areas, but the Department of Agricultural Extension (DAE) provides inadequate technical assistance. Farmers rely on NGOs for support, as government incentives for climate-resilient farming remain insufficient. Social forestry initiatives have helped mitigate cyclone impacts in Tildanga and Kamarkhola but have failed in Sutarkhali due to weak institutional coordination and low community engagement. NGOs such as BRAC, UNDP, and Nobolok have strengthened resilience through disaster preparedness, climate-resilient agriculture, and microcredit programs. However, their efforts are often project-based and dependent on external funding, limiting long-term sustainability.

The governance framework is still donor-dependent, prioritizing short-term projects over sustainable, institutionalized adaptation. Many NGO-led initiatives fail to continue once external funding ceases, while state-led programs often neglect local needs due to top-down planning. Marginalized communities are frequently excluded, as local elites control program access, highlighting the need for transparency and equitable resource allocation. Institutional coordination remains weak, with overlapping responsibilities among key ministries causing inefficiencies. The absence of a unified national adaptation strategy results in fragmented efforts, where political influence often dictates resource allocation over actual risk assessments. Bureaucratic delays further hinder timely adaptation measures. Strengthening collaboration between government agencies, NGOs, and communities is crucial for effective and inclusive climate adaptation governance. Table 7 explores of the roles played by local governments, NGOs, and INGOs or donor agencies in supporting of community-driven adaptation and mitigation efforts.

3.13 Governance and institutional gaps

Key informants highlighted gaps in collaboration between government agencies, NGOs, and local communities. The lack of integrated planning was particularly evident in Kamarkhola and Sutarkhali. Significant gaps in institutional coordination were discovered in this study, especially between local communities, NGOs,

TABLE 7 Roles and contributions of local government, NGOs, and international agencies.

Aspect	Role of local government	Role of NGOs	Role of international agencies
Governance role	• Implements national policies at the local level; • facilitates disaster response and adaptation programs	• Works directly with communities to implement localized adaptation projects	• Provides funding, technical expertise, and policy recommendations
Climate adaptation and disaster risk reduction	• Focuses on infrastructure projects like embankments and cyclone shelters • Union Disaster Management Committees (UDMCs) coordinate disaster preparedness	• Promotes climate-resilient agriculture, social forestry, and alternative livelihoods • Strengthens early warning systems and volunteer training	• Funds large-scale climate adaptation and resilience programs • Supports national and local disaster preparedness programs (e.g., UNDP, World Bank)
Water resource management	• Limited support for freshwater conservation; manages embankments	• Implements rainwater harvesting projects (e.g., BRAC)	• Supports large-scale water management plans (e.g., Concern World, GCF)
Agricultural adaptation	• Limited technical assistance through the Department of Agricultural Extension (DAE)	• Provides salt-tolerant seeds, technical training, and financial aid for farmers	• Funds research and projects promoting climate-smart agriculture
Social forestry & biodiversity	• Implements national forestry policies, but lacks local engagement	• Promotes community-led social forestry programs (e.g., Nobolok)	• Supports biodiversity conservation initiatives through grants (e.g., GEF)
Challenges in implementation	• Bureaucratic delays, lack of coordination, and resource constraints	• Short-term project funding and dependency on external donors	• Lack of direct engagement with local communities
Institutional gaps	• Political favoritism and nepotism in resource allocation • Weak policy enforcement	• Fragmented efforts due to project-based approaches	• Fragmented coordination between international donors and local needs
Community engagement	• Limited participation in decision-making	• High community engagement but sustainability issues	• Indirect engagement through partnerships with local NGOs
Major contributions	• Disaster management infrastructure, policy implementation	• Livelihood support, capacity building, grassroots initiatives	• Large-scale funding, policy support, and climate resilience projects
Overall impact on adaptation	• Partially supportive but hindered by inefficiencies and lack of inclusivity	• Strong community involvement but dependent on external funding	• Provides critical financial and technical support but lacks local adaptation focus

Source: Focus Group Discussion (FGD) and Key Informants Interviews (KIIs).

TABLE 8 Governance and institutional gaps.

Governance aspect	Effectiveness rating (1–5)	Key challenges
Disaster preparedness	4	Early warnings are effective; recovery is slower.
Infrastructure development	2	Embankment repairs are delayed or inadequate.
Community engagement	3	Consultation is limited to NGO-led initiatives.

1 = Poor/Ineffective; 2 = Marginal effectiveness; 3 = Moderate/Effective but requires significant improvements; 4 = Good/Effective with some limitations; 5 = Excellent/Highly effective.

and Government organizations. In Kamarkhola and Sutarkhali the absence of integrated planning was particularly noticeable according to informants. Variable performance was found in several important areas of the governance effectiveness analysis (Table 8): Disaster preparedness received a score of 4 meaning that while early warning systems are useful, recovery procedures are still sluggish. Frequent delays and inadequate embankment repairs were the main causes of infrastructure development's low score of 2. Community engagement had a score of 3, indicating that government institutions have a little role in consultation which is mostly driven by NGO-led initiatives. These disparities can be reduced and coastal communities' resilience eventually increases by encouraging more cooperation among stakeholders and incorporating participatory techniques into governance.

3.14 Key barriers impeding effective climate responses

The study identified numerous barriers that hinder adaptation sustainability as climate response. Financial constraints or fund flow continuation emerged as the most prevalent challenges. Though

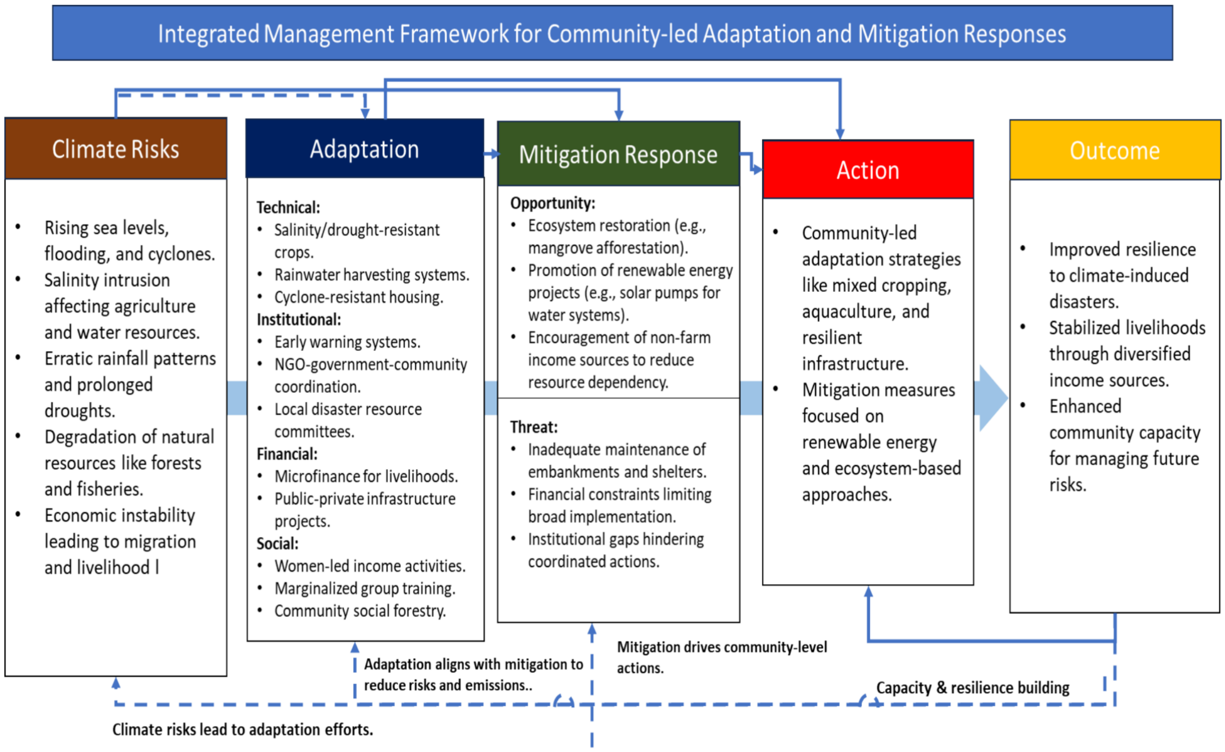

FIGURE 6
Integrated management framework for community-led adaptation and mitigation responses.

elevated housing and solar panel-based energy supply systems are effective, due to a lack of funding for implementing this type of large-scale adaptation practices are not accessible to all coastal households. The majority of the respondents reported that support from the government and NGOs is insufficient, while lack of integration or support system (e.g.: institutional gaps) is critical to overcome the obstacles faced by them. Lack of knowledge or training facilities, particularly noted in Tildanga, where adaptations and innovation remain low. Notably, in Kamarkhola and Sutarkhali, poor infrastructure, such as weak embankments and inadequate cyclone shelters appeared as significant concerns. Through homestead vegetation, and livestock rearing, women are now contributing to households' economic and educational support of their children, hence they demand more capacity-building programs to cover the whole community that meet the existing gaps. To address these barriers, respondents emphasized innovative climate-resilient technologies, awareness-raising programs, and effective disaster management strategies.

3.15 Integrated management framework for community-led adaptation and mitigation responses

This integrated management framework provides a holistic strategy for tackling climate-related difficulties encountered by coastal communities, emphasizing resilience enhancement and sustainable livelihoods. The process commences with the identification of climate hazards, such as increasing sea levels, saline intrusion, unpredictable rainfall patterns, and economic instability, which calamities both ecosystems and livelihoods. The framework highlights adaptation solutions across technical, institutional, financial, and social aspects to tackle these issues. Essential measures encompass the implementation of salinity-resistant crops, rainwater harvesting systems, cyclone-resistant infrastructure, and early warning systems, augmented by financial support mechanisms such as microfinance and socially inclusive initiatives including women-led income activities and community forestry programs. The mitigation strategy utilizes opportunities including ecosystem restoration, renewable energy implementation, and alternative income sources to diminish reliance on climate-sensitive activities while tackling issues such as infrastructure maintenance deficiencies, financial limitations, and institutional inefficiencies. The framework emphasizes community-led initiatives that prioritize solutions such as mixed crops, aquaculture, and mitigation measures centered on renewable energy. These initiatives collectively seek to attain the intended objectives, including increased resilience to climate-related disasters, stabilized livelihoods through diverse income streams, and strengthened community capacity to handle future risks. This comprehensive framework emphasizes the significance of stakeholder engagement, gender inclusivity, and sustainable practices, providing a blueprint for enhancing resilience and socio-economic stability in at-risk coastal areas (Figure 6).

4 Discussion

The coastal community often adopts several community-driven approaches derived from a grassroots scale (e.g., *Uthan Baithok*, Monthly Social Meeting etc.) such as rainwater harvesting, pond sand filter, elevated housing, climate-resilient agriculture, Basta and Tower-based homestead vegetation, even fish culture and market that cause inclusion of women into the mainstream economic income generating activities. For example. Livestock rearing helps the community to meet basic services like eggs, milk, meat, etc. and even provides additional economic support for buying necessary products and educating their children. Homestead gardening and vegetable cultivation through *Basta*, *Tower*, and *Macha* cultivation helps the local community to produce vegetables and sell them in the local market to gain profit while fish cultivation and marketing helps them to add more income and improve their livelihood conditions. Through the formation of different management committees (e.g., water source management, disaster management), they actively participated in water resources management and embraced new farming techniques like organic composting, bio-pesticides, and fisheries. As one of the participants stated, *"Now I can cultivate vegetables and rear livestock effectively. This has helped my family secure income and improve living conditions."* Many women shifted from being confined to their homes to becoming significant contributors to their households. Afia Begum said, *"She is contributing to her family by rearing ducks and native chickens. At the first stage, the number was very limited but now the number has gradually increased. The children are now getting enough meat and eggs that they had to buy in the past. She is educating her girls by selling them in the market."* Beneficiaries like Taslima Begum and Tulsi Gayen demonstrate successful adaptation through diversified income-generating activities, such as goat and swan farming, as well as composite farming (e.g., fish, vegetables, and livestock). As noted, Tulsi stated, *"I am confident to enlarge my business through cultivation, Goat rearing, and fish farming"*. Rahman and Islam (2024) conducted a study that emphasizes adaptive capacity and economic diversification based on their grassroots efforts to enhance climate resilience to cope with climate-induced consequences. Another book chapter titled *"Social Aspects of Adaptive Capacity,"* which is part of the book *Climate Change, Adaptive Capacity, and Development"* explores the factors, that influence a community's ability to adapt to climate-related risks and challenges facilitating sustainable development in the face of climate change (Adger, 2003). Our study focused on training programs that enabled women and traditionally marginalized people in the economic mainstream to emerge as climate leaders. Moyna Begum expressed newfound confidence, saying, *"Before joining as a project participant, I did not know much about this type of training and support"*. Another participant Sufia Begums's was a maidservant but later transformed into a successful farmer and entrepreneur signifies the image of women's empowerment, that's why she stated *"I am very happy to receive financial and technical support from the different NGOs and local government institutions that help me to build my virtue and made me able to support my family."* Though our study did not explore gender and livelihood development but gender-sensitive approaches in climate resilience align with works by Denton (2002), revealed how vulnerabilities and adaptive capacities vary across gender inequalities, and advocated for integrating women in adaptation strategies to ensure sustainability.

Practices such as vermicomposting and climate-resilient farming methods (adopted by Tulsi Gayen) illustrate sustainable adaptation to environmental challenges like salinity, and reduced soil fertility. These practices reflect the findings of Alam et al. (2013), emphasizing community-driven sustainable practices in coastal Bangladesh, and explore how combining validated best management practices (BMPs) can minimize the yield gap in rice production by addressing inefficiencies and improving productivity. This work contributes to efforts aimed at enhancing food security and optimizing rice yields in resource-constrained environments. As Taslima mentioned, *"We have a lack of market facilities to sell our product with high prices"*. Policy Recommendation: Strengthening market linkages can ensure fair pricing for products. A significant portion of vulnerable populations remains outside the adaptation practices and locally adopted strategies. Moyna Begum highlighted, *"There are so many women like me around us who need training and support"*. Expanding training programs and financial support can serve as a model for global climate resilience efforts to achieve widespread adoption and sustainable agricultural improvements. The findings reveal that residents of *Tildanga, Kamarkhola,* and *Sutarkhali* unions are acutely aware of the climate risks threatening their livelihoods. The high frequency of responses recognizing flooding, cyclones, and salinity intrusion as critical issues align with previous studies highlighting the vulnerability of coastal Bangladesh to climate change impacts. The identification of salinity intrusion by most of the respondents demonstrates its pervasive effect on agriculture and drinking water, accentuating the urgent need for solutions addressing water resource management as also discussed in some other studies conducted in a similar field of the community (Roy T. et al., 2022; Feist et al., 2023; Akter et al., 2025). Community-led adaptation measures, such as climate-resilient agriculture, mangrove restoration, and salt-tolerant homestead vegetable cultivation, reflect the resilience and strength of the local population (Alam, 2017). These strategies not only address immediate challenges but also enhance long-term adaptive capacity on a small scale as explored by the weighted scale (Ahmed and Khan, 2023). The adoption of elevated housing structures in Sutarkhali Union highlights the community's proactive approach to reducing flood-related vulnerabilities. However, while these efforts are promising, their scalability is constrained by limited financial and technical resources, as highlighted by three-quarters of the respondents.

The overall insights suggest the dynamic role of community-led initiatives in navigating climate risks in coastal regions like Tildanga, Kamarkhola, and Sutarkhali unions of Dacope Upazila of Bangladesh that imitate an alignment with local needs and ecological realities. However, these kinds of efforts require enhanced institutional and government policy support interlinked with NGOs and INGOs through numerous adaptive approaches and sustainable funding mechanisms to ensure long-term resilience. In terms of policy implications, the study suggests prioritizing participatory planning processes, where local knowledge and experiences are incorporated into decision-making. Additionally, the synergetic benefits of ecosystem-based adaptation, providing both protective and livelihood advantages, such as solar power, well-planned infrastructural development, and market capturing to exclude the middle man beneficiaries, into sustainable adaptive frameworks can foster holistic climate resilience in the region.

5 Policy recommendations

By introducing the following recommendations, the coastal unions of Dacope Upazila can develop more inclusive, resilient rural environments, better equipped to manage the challenges of recurrent climate change impacts. The following recommendations emphasize a holistic, community-led, and institutionally supported approach to climate resilience, ensuring long-term sustainability and socio-economic stability.

5.1 Strengthening climate-resilient agriculture

- Promote salt-tolerant crop varieties and sustainable farming practices.
- Provide training and financial incentives for farmers to adopt climate-smart techniques.
- Develop market linkages to ensure fair pricing for agricultural products.

5.2 Enhancing water security

- Expand rainwater harvesting systems and Pond Sand Filters (PSFs).
- Implement solar-powered water pumps to ensure sustainable freshwater access.
- Strengthen governance mechanisms for equitable water distribution.

5.3 Improving infrastructure and disaster preparedness

- Upgrade early warning systems and integrate community-led disaster response teams.
- Construct and maintain planned embankments and cyclone-resistant shelters.
- Establish housing guidelines for flood and storm-resistant structures.

5.4 Livelihood diversification and economic empowerment

- Introduce vocational training programs for alternative income sources.
- Provide microfinance support for small businesses and women-led enterprises.
- Strengthen fisheries management through cooperative-based resource sharing.

5.5 Institutional strengthening and governance reforms

- Enhance coordination between government agencies, NGOs, and local communities.
- Ensure community participation in adaptation planning and decision-making.
- Improve fund allocation and streamline bureaucratic procedures for climate action.

5.6 Environmental conservation and sustainable resource management

- Promote mangrove restoration and social forestry to protect coastal ecosystems.
- Encourage sustainable aquaculture and mixed-cropping systems.

5.7 Gender-inclusive approaches and social cohesion

- Expand training programs targeting women and marginalized groups.
- Strengthen community-based social support networks and cooperative initiatives.
- Integrate gender-sensitive policies into local and national climate action plans.

6 Conclusion

The study examined community perceptions of extreme climate events related risks and socio-economic impacts, the conditions of adaptation and mitigation responses in the coastal unions of Bangladesh. Community-driven grassroots innovations such as alternative water management strategies, and climate-resilient agriculture have significantly reduced susceptibilities to climate impacts like salinity intrusion, cyclones, flooding and water logging. Though these grassroots efforts have demonstrated considerable success, their expansion remains constrained by financial, technical, and institutional barriers. We found governance as a pivotal factor in addressing these challenges, while early warning systems and disaster preparedness have been effective. Empowering women and marginalized groups has emerged as a critical strategy for enhancing resilience. Training programs and income-generating activities have transformed traditional roles, enabling these groups to become active contributors to household and community resilience. However, an integrated approach involving all stakeholders is essential to ensure sustainable and equitable adaptation measures. Ecosystem-based adaptations, including social restoration and salt-tolerant crops, provide support both for environmental protection and resilience livelihood, emphasizing participatory decision-making and capacity building. Investments in resilient infrastructure, such as embankments and cyclone shelters, livelihood diversification and strengthening market linkages are vital for long-term sustainability and resource distribution. Insights from Dacope Upazila can inform similar efforts worldwide, highlighting the importance of integrating local knowledge, participatory planning, and sustainable funding mechanisms into climate adaptation strategies. This study also explores the dynamic interplay between community initiatives, institutional support, and policy frameworks that can empower vulnerable communities to build long-term resilience and ensure socio-economic stability amidst evolving climate challenges. To conclude, community-led approaches are indispensable for navigating climate risks in coastal regions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Written informed consent for participation in this study was provided by the participants.

Author contributions

SCS: Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. SM: Conceptualization, Methodology, Writing – review & editing. SDS: Conceptualization, Data curation, Formal analysis, Visualization, Writing – review & editing. AI: Data curation, Formal analysis, Investigation, Visualization, Writing – review & editing. SJ: Data curation, Formal analysis, Investigation, Visualization, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declare that no Gen AI was used in the creation of this manuscript.

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