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Article

Assessing Disaster Risk and Adaptation Strategies in Coastal Agriculture: Evidence from Chandradip Union of Bauphal Upazila, Bangladesh

Md. Faisal[1*], Imran Hawladar[2], Vladimir M. Cvetković[3,4,5]

[1] Department of Disaster Resilience and Engineering, Patuakhali Science and Technology University, Dumki, Patuakhali-8602, Bangladesh; faisal@pstu.ac.bd

[2] Faculty of Environmental Science and Disaster Management, Patuakhali Science and Technology University, Dumki, Patuakhali-8602, Bangladesh; imranhawladar96@gmail.com

[3] Department of Disaster Management and Environmental Security, Faculty of Security Studies, University of Belgrade, Serbia; vmc@fb.bg.ac.rs.

[4] Safety and Disaster Studies, Chair of Thermal Processing Technology, Department of Environmental and Energy Process Engineering, Technical University of Leoben, Franz Josef-Straße 18, Leoben, 8700, Austria; vladimir.cvetkovic@unileoben.ac.at

[5] Scientific-Professional Society for Disaster Risk Management, Dimitrija Tucovića 121, 11040 Belgrade, Serbia.

* Correspondence: faisal@pstu.ac.bd; tel.: +88-01722-417270

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ABSTRACT

The coastal zone of Bangladesh is highly vulnerable to natural disasters, which significantly affect agricultural production and livelihoods. Agriculture is the primary livelihood for most coastal communities. Patuakhali is a coastal district of Bangladesh, and Bauphal Upazila is one of its most agriculturally dependent areas. Therefore, this study was conducted in Chandradip Union of Bauphal Upazila to assess disaster risks in the agricultural sector. The main objective of the study was to identify and assess natural disaster risks in agriculture through hazard, vulnerability, and capacity assessments, and to explore suitable adaptation strategies for enhancing disaster resilience. Both primary and secondary data were used in this research. A total of 100 households were randomly selected and interviewed using semi-structured questionnaires. In addition, five Focus Group Discussions (FGDs) and five Key Informant Interviews (KIIs) were conducted. Field observations and relevant secondary data sources were also utilized. The findings reveal that riverbank erosion (1.043), storm surge (0.942), and cyclone (0.934) are the most significant disaster risks affecting the agricultural sector due to their high hazard intensity, high vulnerability, and low coping capacity. The study further identifies that alternative livelihood options (27%), loans and subsidies (25%), and short-duration rice cultivation (24%) are the most commonly recommended adaptation strategies by the farming community. These are followed by embankment construction (22%) and farm mechanization (2%). The study highlights the need for integrated risk management and strengthened adaptive capacity to enhance agricultural resilience in coastal Bangladesh. This study provided empirical evidence, based primarily on data, on how vulnerability is reduced through

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an adaptation strategy. The results of this study will help people in coastal communities reduce their vulnerability. This study can assist policymakers and donor agencies in developing policies and funding different development projects in Bangladesh's rural coastal community.

KEYWORDS

Disaster risk management; coastal agriculture; agricultural resilience; hazard assessment; vulnerability assessment; adaptation strategies; riverbank erosion; storm surge; cyclone; Bangladesh.

1. Introduction

Disasters are considered one of the most serious global threats because they can cause significant human, material, economic, and environmental losses (Ahmed, 2025; Iftikhar & Iqbal, 2024; Joshi & Poudel, 2025; Paudel, Khanal, Mathema, Maharjan, & Bhatta, 2025; Roy, Shawon, & Hasan, 2025). In many cases, the impacts of disasters exceed the capacity of affected communities to cope using their own resources (IPCC, 2001; IPCC, 2007; NCSA, 2007; Wisner & Wisner, 2004; Brochmann, 2008; Coppola, 2006). Natural disasters such as cyclones frequently result in loss of life and severe damage to infrastructure, economic assets, and livelihoods. The increasing frequency and intensity of natural disasters are significantly affecting agricultural production, particularly in coastal areas. As a result, disasters pose serious threats to environmental sustainability, human health, food security, agriculture, fisheries, biodiversity, water resources, and overall economic activities (NCSA, 2007).

Bangladesh is recognized as one of the most disaster-prone countries in the world due to its geographical location, high population density, low income level, and strong dependence on climate-sensitive sectors such as agriculture (Rahman et al., 2009; Saha et al., 2024; Faisal et al., 2024; Faisal et al., 2026). The country frequently experiences a variety of natural hazards, including cyclones, floods, salinity intrusion, waterlogging, heavy rainfall, riverbank erosion, storm surges, tidal surges, tornadoes, and droughts, especially in coastal regions (Alam, 2005; Biswas et al., 2015; Islam et al., 2016; Faisal et al., 2021; Faisal et al., 2025). These hazards cause extensive damage to lives, property, and the natural environment and severely disrupt local livelihoods. The agricultural sector in coastal areas is particularly vulnerable to these impacts (Islam et al., 2019; Saha et al., 2019; Rokonuzzaman et al., 2023; Nur et al., 2025). Agriculture is the primary livelihood for many people in coastal Bangladesh and remains one of the country's most important economic sectors (Rahman et al., 2009). It plays a vital role in increasing productivity, generating income and employment in rural areas, and improving the livelihood security of poor communities (Sen, 2003; Quddus, 2009; Biswas et al., 2015). Agriculture also contributes significantly to food security, poverty reduction, and climate change adaptation (Abedin & Shaw, 2013). In Bangladesh, agriculture—including crops, livestock, fisheries, and forestry—accounts for about 21% of the Gross Domestic Product (GDP) and employs approximately 52% of the labor force (BBS, 2011). Beyond its economic contribution, agriculture is closely related to social issues such as food and nutrition security, income generation, and poverty alleviation (Biswas et al., 2015). However, agricultural activities are highly vulnerable to various risks and uncertainties, including climatic, environmental, biological (e.g., pests and diseases), and economic factors. Many of these risks are closely linked to climate variability and climate change, which may increase their intensity, frequency, and impacts in the future (Gitz & Meybeck, 2012). Consequently, the agricultural sector is increasingly threatened by natural disasters and the impacts of climate change (NAPA, 2005).

The south-central coastal region of Bangladesh has unique environmental characteristics that make it highly vulnerable to natural hazards, including cyclones, floods, tidal surges, storm surges, riverbank erosion, and coastal erosion (Saha, 2015; Majumder et al., 2017). Among these areas, Patuakhali district, located in the south-central coastal belt, is one of the most disaster-affected regions. The district regularly experiences tidal flooding, cyclones, storm surges, river erosion, and salinity intrusion (Biswas et al., 2015; Biswas et al., 2016; Iva et al., 2017; Mukherjee et al., 2020). Bauphal Upazila within Patuakhali is particularly vulnerable to these hazards, exposing local communities and economic sectors to significant disaster risks (Biswas et al., 2015; Iva et al., 2017). Chandradip Union, located in Bauphal Upazila and surrounded by the Tetulia River, is highly exposed to various natural disasters. The local community frequently experiences hazards such as tidal flooding, salinity intrusion, pest and disease outbreaks, cyclones, storm surges, waterlogging, drought, and irregular rainfall. These hazards have severe impacts on agricultural production and farmers' livelihoods (Kabir et al., 2016; Biswas et al., 2016). Coastal agriculture in Bangladesh is particularly vulnerable to climate-related hazards, and climate change is expected to intensify these risks. For example, tropical cyclones and storm surges can damage cropland and require long recovery periods before agricultural production can resume. In many cases, farmers are forced to change their occupations or migrate due to repeated agricultural losses (Hossain, 2013). In addition, pest and disease outbreaks have become an increasing threat to crop production in recent years, causing significant damage to crops and vegetables (Fakayode et al., 2012). Coastal flooding and saltwater intrusion also negatively affect soil fertility and agricultural productivity, creating long-term challenges for coastal farming systems (IPCC, 2007). Similarly, fish farmers often lose their fish due to storm surges, tidal flooding, and saline water overflow in aquaculture ponds (Hossain et al., 2016). As a result, the agriculture-based livelihoods of coastal communities remain highly vulnerable to natural disasters.

Therefore, it is essential to identify and analyze disaster risks affecting the farming community, understand the vulnerability of agriculture from different perspectives, and explore possible strategies to strengthen livelihood security. This study also examines the existing coping and adaptation strategies used by local communities during natural disasters. Based on the identified vulnerabilities and coping mechanisms, the study proposes possible resilience-building options for the farming community. This research focuses on exploring the agricultural disaster risk profile of Chandradip Union through community participation. The main objectives of the study are to identify and assess natural disaster risks and to identify adaptation strategies to strengthen disaster resilience in the agriculture sector.

Although several studies have examined climate change impacts, adaptation, and disaster vulnerabilities in agriculture and livelihood in coastal Bangladesh (Afjal Hossain et al., 2011; Huq et al., 2015; Hossain et al., 2016; Shahjahan Mondal et al., 2019; Hoque et al., 2019), limited research has focused on integrated disaster risk assessment in the agricultural sector in newly developed coastal island communities. Previous studies mainly emphasized climate change impacts, individual hazards, or livelihood vulnerability. At the same time, limited attention has been given to the combined assessment of hazard, vulnerability, and community capacity in determining agricultural disaster risk. Moreover, locally practiced adaptation strategies and resilience-building approaches in Chandradip Union remain largely unexplored. Therefore, this study fills the research gap by conducting a comprehensive assessment of disaster risk in the agricultural sector through hazard, vulnerability, and capacity analyses, and by identifying community-based adaptation strategies to enhance resilience in coastal Bangladesh.

2. Methods

2.1. Selection of the Study Area

Bauphal Upazila consists of 15 unions, although it previously had 14 unions. This study was conducted in the newly established Chandradip Union (Figure 1), which is located in the eastern part of Bauphal Upazila. The area is mainly island land and includes nine villages, such as Raysaber Island, Khacua Island, Bred Island, Meyazan Island, Diyara Khacua, and Odel Island. Agriculture and fishing are the main sources of livelihood in this union. The local population is highly vulnerable to climate change, poor transportation and communication systems, food insecurity, and limited access to education. Approximately 9,285 people live in the union, including 4,739 men and 4,546 women (Population and Housing Census, 2023). There are six primary schools and one secondary school in the union. Notably, the primary schools also serve as cyclone shelters during emergencies. As a newly established island union on the banks of the Tetulia River, Chandradip faces several challenges but also has significant opportunities for future development.

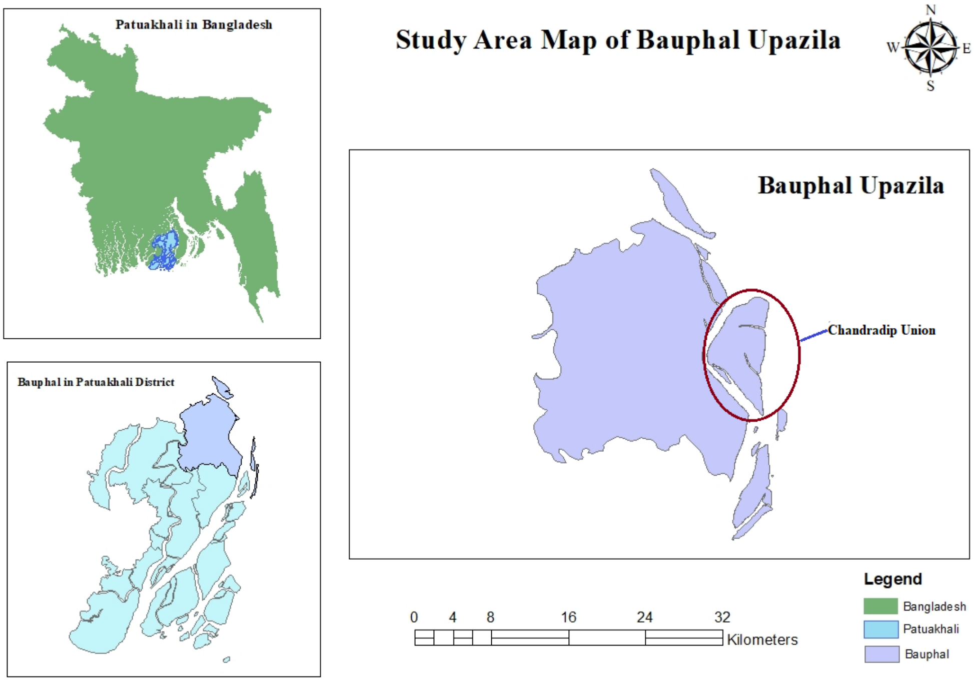

Figure 1. The study area map of Chandradip Union, Bauphal Upazila, Bangladesh.

2.2. Research design

The research design was developed to achieve the study's objectives (Figure 2). The study followed a five-stage process: Problem analysis (including problem identification, literature review, and policy analysis), Selection of the study area, Data collection (both primary and secondary), Data analysis, and Report preparation. The research design and flow of research activities are shown in Figure 2.

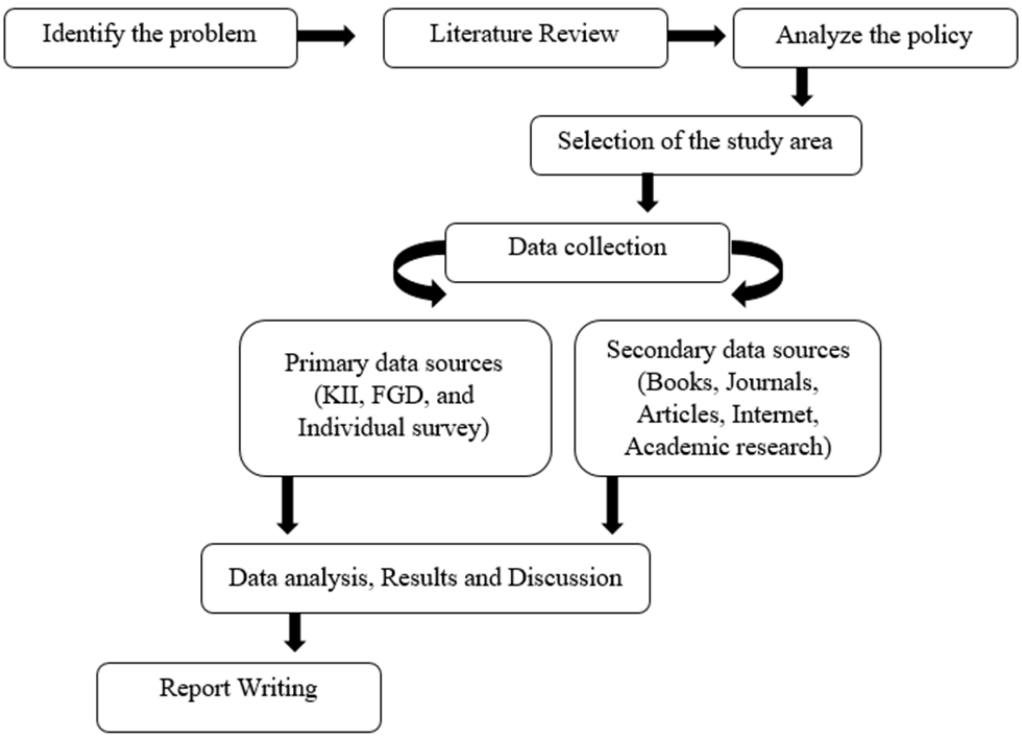

Figure 2. The research design and flow of research activities.

2.3. Sampling Design

The sample size for the household survey was determined using Cochran's (1963) formula for sample size calculation. Total population, N = 9,285; Confidence level = 95%; Margin of error, e = 10%; 95% level of significance, Z = 1.96; Estimated Proportion of success, Standard Deviation, P = 0.5; Estimated proportion of failures, q =(1-p) = 0.5

Sample Size, $n_0 = \frac{(z^2 * p * q)}{e^2}$ …………………… (Cochran, 1963).

$= \frac{1.96^2 * 0.5 * 0.5}{0.1^2}$

= 96.04

= 96

Adjusted, $n = \frac{n_0}{1+\left[\frac{n_0 - 1}{N}\right]}$ ………………… (Cochran, 1963).

$= \frac{96}{1+\left[\frac{96-1}{9285}\right]}$

= 96.97

= 97

The calculated initial sample size was 96. After population adjustment using Cochran's correction formula, the final sample size became 97. However, to improve representation and reliability, 100 household surveys were conducted.

2.4. Data Collection Methods

Both primary and secondary data were collected for this study. Primary data provided information on the current conditions and realities of the study area. In contrast, secondary data, including previous studies, reports, and project documents, helped develop a broader understanding of the research problem.

2.4.1. Primary Data Collection

Primary data were the main source of information for this research. This research used the Household Questionnaire Survey, Focus Group Discussions (FGDs), and Key Informant Interviews (KIIs) to collect primary data. Before conducting the household survey, focus group discussions, and key informant interviews, informed verbal consent was obtained from all participants. Respondents were informed about the objectives of the study, the voluntary nature of their participation, and the confidentiality of the information they provided. Participants were also assured that the collected data would be used solely for academic and research purposes.

Household Questionnaire Survey: Quantitative data were collected through face-to-face interviews using a semi-structured questionnaire (Ogunlade & Adebayo, 2009). Households were selected using simple random sampling from different villages in Chandradip Union. Before conducting the survey, a household list was obtained from the Chandradip Union Parishad office, and respondents were selected randomly from the list. The selected sample was considered representative of the farming community in Chandradip Union because respondents were randomly selected from different villages and included households engaged in diverse agricultural and livelihood activities, such as crop farming, fishing, livestock rearing, poultry production, and agricultural labor. The sample also represented different socio-economic and demographic groups within the study area. Therefore, the collected data provided a reliable representation of the agricultural community and its disaster-related experiences, vulnerabilities, capacities, and adaptation practices. The survey also collected demographic and socio-economic information from selected households. It also explored community perceptions of disaster risks, the impacts of disasters on agriculture, vulnerability levels, and strategies to improve resilience. A total of 100 household surveys were conducted to achieve the study objectives.

Focus Group Discussions (FGDs): Focus groups were conducted to gather qualitative information and community perceptions on disaster risks and adaptation practices. Participants were selected purposively from different livelihood groups, including crop farmers, fishermen, livestock rearers, poultry farmers, agricultural laborers, and women involved in homestead farming activities, to ensure diverse representation. Separate FGDs were conducted for male and female participants to encourage active participation and open discussion. Each FGD consisted of 6-10 participants and was facilitated using a checklist of discussion topics covering natural hazards, agricultural impacts, vulnerability, coping strategies, and resilience-building practices. Each session lasted approximately 60-90 minutes, and important responses and observations were recorded through written notes. Participants discussed local conditions, exposure to hazards, the impacts of disasters on crop production, challenges related to climate-induced hazards, and potential strategies to strengthen community resilience. A total of 5 FGDs were conducted to achieve the study's objectives.

Key Informant Interviews (KIIs): Key informants are individuals with specialized knowledge and experience regarding a particular issue and can provide valuable insights (Kothari, 2004; Kumar, 2018). Key informant interviews were conducted with individuals with professional knowledge and practical experience in agriculture, disaster management, and local community development. Participants were selected purposively based on their expertise and involvement in local activities. Key informants included Sub-Assistant Agricultural Officers (SAAOs), a local government representative, an NGO representative, a community leader, and a school teacher. Semi-structured interview guidelines with open-ended questions were used during the interviews. The KIIs were conducted through face-to-face meetings. Each interview focused on disaster risks, agricultural vulnerability, adaptation practices, institutional support, and community resilience. All responses were carefully recorded and documented. A total of 5 key informant interviews were conducted.

2.4.2. Secondary Data Collection

Secondary data were collected from books, journal articles, reports, online documents, office records, NGO publications, and other relevant sources. Various websites were also consulted to obtain recent information on the study topic. These secondary sources were used to complement and validate the primary data.

2.5. Data Collection Instruments

Structured and semi-structured questionnaires were developed to achieve the study objectives (Kumar, 2018). The questionnaires included both open-ended and closed-ended questions. Open-ended questions allowed respondents to express their opinions and experiences in their own words, which provided deeper insights into local perceptions and practices. The household questionnaire was divided into several sections to collect comprehensive information related to the study objectives. The first section focused on respondents' demographic and socio-economic characteristics, including age, gender, education, occupation, household size, income, and housing conditions. The second section included questions on disaster experience, hazard perception, vulnerability, and community capacity for different natural hazards in the study area. The third section assessed the impacts of disasters on agricultural activities, including crop production, fisheries, livestock, and livelihood conditions. The final section explored existing coping mechanisms, adaptation strategies, and barriers to adaptation practices. Both closed-ended and open-ended questions were used to obtain quantitative data and detailed qualitative insights from respondents.

2.6. Data Processing and Analysis Methods

Data analysis is an important component of the research process (Hasan et al., 2015). After data collection, the information was manually edited, coded, and tabulated. The coded data were then entered into Microsoft Excel 2013 for analysis. For disaster risk analysis, risk was considered a function of hazard, vulnerability, and capacity, a widely accepted approach in disaster studies (Faisal et al., 2021). To assess disaster risk (R), hazard (H), vulnerability (V), and capacity (C) scores were calculated and combined using the following equation (Wisner, 2004; Wamsler et al., 2012; Blaikie et al., 2014):

Risk = (Hazard × Vulnerability) /Capacity [R = (H × V)/ C] ……………………eq. (1)

Here, R = Risk; H = hazard; V = Vulnerability, and C = capacity.

The disaster risk analysis framework used in this study is based on the widely accepted concept that the interaction among hazard, vulnerability, and community capacity determines disaster risk. In this framework, hazard represents the frequency and intensity of natural disasters, while vulnerability reflects the agricultural community's susceptibility to damage and loss. At the same time, capacity refers to the community's ability to cope with and recover from the impacts of disasters. Therefore, the formula R = (H×V)/C was considered appropriate for this study because it provides an integrated approach for evaluating agricultural disaster risk in the coastal context. The model also allows comparison across hazards by combining hazard intensity, vulnerability level, and existing coping capacity into a single risk index.

To calculate the hazard, vulnerability, and capacity indices, respondents were asked to rank each hazard based on predefined priority categories. Numerical weights were assigned to each response category to quantify the level of hazard, vulnerability, and capacity. For hazard assessment, respondents ranked hazards by perceived frequency and intensity into five categories: priority, second priority, third priority, fourth priority, and no priority. These categories were assigned weights of 1.00, 0.75, 0.50, 0.25, and 0.00, respectively. For vulnerability assessment, respondents evaluated vulnerability severity across five categories: extremely vulnerable, very vulnerable, moderately vulnerable, slightly vulnerable, and not vulnerable. The corresponding weights were 1.00, 0.75, 0.50, 0.25, and 0.00, respectively. For capacity assessment, respondents assessed community coping capacity using five categories: very good, good, fair, poor, and very poor. The assigned weights were 1.00, 0.75, 0.50, 0.25, and 0.00, respectively.

The index for each hazard was calculated by multiplying the number of responses in each category by its assigned weight and summing the weighted scores. The total weighted score was then divided by the total number of respondents to obtain the final index value. The calculated indices ranged from 0 to 1, with higher values indicating greater hazard intensity, greater vulnerability, or stronger coping capacity. Finally, the disaster risk index was calculated using the equation R = (H × V)/C, where hazard and vulnerability increase disaster risk, while higher community capacity reduces overall risk. The findings are presented through tables and figures, and the report was prepared systematically using Microsoft Word. The final document reflects both quantitative and qualitative findings in accordance with the study objectives.

3. Results and Discussion

3.1. Demographic and Socio-Economic Condition of the Study Area

Understanding the demographic and socio-economic characteristics of the respondents is essential for identifying local risk factors, their impacts on agriculture, and the resilience capacity of farming households. This section presents the socio-demographic profile of the respondents in the study area.

According to Table 1, 93% of respondents were male, and 7% were female. Women in the study area are mainly involved in household gardening, livestock rearing, poultry management, and supporting male family members in agricultural activities during times of economic hardship. During the Rabi season, women often assist in irrigating vegetable gardens using traditional methods such as buckets and jars. Information collected from both male and female respondents was useful in understanding local perceptions of disaster risk, agricultural vulnerability, and resilience practices. Although men play the dominant role in crop cultivation, women also contribute significantly to agricultural production, especially in female-headed households. However, women are generally less involved in formal agricultural decision-making and have fewer opportunities in commercial farming activities. Previous studies have shown that women's participation in agriculture can reduce household vulnerability and strengthen resilience as they often play an important role in post-disaster recovery and livelihood diversification (Hossain & Roy, 2012).

The age distribution of respondents indicates that the majority belonged to the economically active age groups. Respondents aged 41–50 years accounted for the highest proportion (33%), followed by those aged 31–40 years (24%). Respondents aged 18–30 years and 51–60 years each accounted for 18%, while only 7% were over 60 years of age. Age is an important factor influencing disaster perception, agricultural decision-making, and adaptation practices. Farmers aged 40 to 60 often possess greater practical knowledge and experience regarding climate variability, agricultural risks, and coping strategies (Biswas et al., 2015).

The educational status of respondents shows that more than half (51%) had no formal education. Among the remaining respondents, 12% completed primary education, 16% completed secondary education, 19% completed higher secondary education, and only 2% attained tertiary-level education. Low educational attainment may limit access to information, modern farming practices, early warning messages, and disaster preparedness measures. Household size varied among respondents, with most households comprising 3 to 6 members. Specifically, 82% of households had between 3 and 6 members, while 18% had more than 6 members. None of the respondents reported having more than 9 family members. Compared to the national average, the household size in the study area is not particularly large (BBS, 2011). However, larger families are generally more vulnerable to natural disasters because they require more food, shelter, and financial resources during and after hazard events.

Agriculture is the main occupation in the study area. About 95% of respondents reported that their primary source of income was related to agriculture, including farming, fishing, livestock production, poultry rearing, homestead gardening, and agricultural labor. Only a small number of respondents were involved in non-agricultural occupations such as handicrafts, rickshaw pulling, hawking, and shopkeeping. People in the area cultivate various crops and engage in diverse livelihood activities to support household income. Women also play an important role in income-generating agricultural activities. Previous studies have found that people in coastal areas often adapt to climate-related risks through livelihood diversification, including day labor, small business, and seasonal migration (Khaled, 2009; Billah, 2013).

The number of earning members in a family is an important factor influencing household resilience. The study found that 62% of households had only one earning member, while 21% had two earning members and 17% had three earning members. Households with more earning members generally have greater financial capacity to cope with the impacts of disasters and recover more quickly. Economic strength is an important factor in adopting new agricultural practices, improving housing conditions, and investing in risk-reduction measures (Hossain & Roy, 2012).

Monthly family income varied among respondents depending on livelihood opportunities and the number of earning members in the household. Around 35% of respondents reported a monthly family income between BDT 5,000 and 14,000, while 40% reported an income between BDT 15,000 and 24,000. Only a small proportion of respondents had a monthly income above BDT 35,000. The average annual income of the respondents was approximately BDT 100,000. Compared with the national average, households in the study area have relatively low incomes and limited economic security. Low income reduces households' ability to invest in improved farming technologies, stronger housing, and disaster-preparedness measures.

Housing conditions in the study area are generally poor. According to Table 1, 45% of respondents lived in kacha houses (houses made of mud, bamboo, and tin), while 39% lived in semi-pucca houses (the walls may be made of brick, while the roof may be made of tin). Only 5% lived in pucca houses (house made of brick, cement, or concrete), whereas 4% lived in huts (house made of bamboo, straw, wood, golpata, or thatch) and 7% in jhupri-type houses (house made of bamboo, polythene, old cloth, straw, or other locally available materials). These poor housing conditions increase households' vulnerability to natural disasters, including cyclones, floods, storm surges, and heavy rainfall. During major disasters such as Cyclone Sidr and Cyclone Aila, many houses in the area were severely damaged or partially destroyed due to weak housing structures. Therefore, poor housing conditions remain an important factor contributing to disaster vulnerability in the study area.

Table 1. Socio-demographic Information of the Respondents (Frequency, n = 100).

Variable	Values	Percentage (%)
Gender	Male	93
	Female	7
Age profile	18-30 years	18
	31-40 years	24
	41-50 years	33
	51-60 years	18
	> 60 years	7
Educational Status	No formal education	51
	Primary Education	12
	Secondary Education	16
	Higher Secondary Education	19
	Tertiary Education	2
Household size	3 persons	9
	4 persons	29
	5 persons	27
	6 persons	17
	7 persons	10
	8 persons	7
	9 persons	1
Primary Occupational Status	Farmer	30
	Fisherman	21
	Livestock Production	18
	Poultry Production	16
	Homestead Gardening	1
	Farming Labor	9
	Rickshaw Pulling	1
	Handicraft	2
	Hawker	1
	Shop Keeping	1
Number of earning persons in the family	1 person	62
	2 persons	21
	3 persons	17
Monthly family income (BDT)	5000-14000	35
	15000-24000	40
	25000-34000	18
	35000-44000	5
	45000-54000	2
Housing pattern of the study area	Kacha	45
	Semi Pacca	39
	Pacca	5
	Hut	4
	Jhupri	7

3.2. Disaster Risk Assessment in the Agriculture Sector in the Study Area

Disaster risk in the agricultural sector refers to the impacts of natural hazards, stresses, and shocks on farming activities and agricultural livelihoods. These impacts are particularly severe for poor rural households that depend directly on agriculture and food systems for their survival. As a result, disaster risks have major implications for livelihood security, food availability, income, and overall well-being. However, not all stresses and shocks have entirely negative impacts. Agriculture is inherently associated with seasonal risks and uncertainties, and farming communities often develop their own adaptation and risk-management practices over time. Local people use different coping strategies to reduce losses and maintain agricultural production during difficult periods. Reducing losses from weather-related disasters, achieving broader development goals, and responding effectively to climate change require an integrated approach. Therefore, disaster risk reduction, climate change adaptation, and sustainable agricultural development should be addressed together to strengthen resilience in farming communities.

3.2.1. Hazard Assessment of the Agricultural Sector

The study area is exposed to a considerable number of natural hazards. However, due to limitations in data availability, only six major hazards were selected for analysis. These hazards include storm surge, salinity intrusion, riverbank erosion, cyclones, pest and disease outbreaks, and thunderstorms. All of these hazards are highly relevant to the study area and pose serious threats to local communities and agricultural activities. Each hazard differs in terms of its frequency and intensity. Therefore, it is not possible to assign a single ranking system for all hazards without considering these differences. In this study, each hazard was assessed based on a combination of its frequency and severity. Hazards that occur more frequently and have greater impacts were assigned higher priority values.

The hazard priority index was developed based on the opinions of both local communities and experts. This index was used to assign weights to each hazard type (Table 2). To identify the most severe hazards, all selected hazards were classified into five categories. A value of 1 indicates the highest priority hazard, while a value of 0 indicates that the hazard exists but is not considered a major threat by the community. According to Table 2, riverbank erosion was identified as the most severe hazard in the study area, with a priority index of 0.850. This high ranking is mainly due to its high frequency and intensity. Cyclone ranked second with a priority index of 0.783, followed by pest and disease outbreaks (0.750), storm surge (0.748), salinity intrusion (0.733), and thunderstorm (0.715). The ranking was determined based on the responses of 100 respondents. Among all hazards, thunderstorms received the lowest priority index, although they remain an important hazard in the area. The severity of each hazard largely depends on its effect on agricultural production. Since different hazards have different impacts on crops, respondents were asked to discuss the specific effects of each hazard on the agricultural sector. The priority index for each hazard was calculated by multiplying the frequency of each response category by its assigned weight and then dividing the result by the total number of responses.

Faisal et al. (2024) revealed that riverbank erosion is the most critical hazard, with a score of 7.42. Following closely behind are Storm Surge and Cyclone, which finished in second and third place, with scores of 6.35 and 6.14, respectively. The study was conducted in Dashmina Upazila in Patuakhali District, Bangladesh. A similar result was also found in the study of Faisal et al. (2021).

Table 2. Community Hazard Index in Chandradip Union.

Hazards	Hazard Priority							
	1st (1)	2nd (0.75)	3rd (0.5)	4th (0.25)	No (0)	Total Frequency	Priority index	Rank
Storm surge	41	33	13	10	3	100	0.748	4
Riverbank erosion	61	24	9	6	0	100	0.850	**1**
Salinity intrusion	23	57	12	6	2	100	0.733	5
Cyclone	53	19	17	10	1	100	0.783	**2**
Pest and diseases	35	43	13	5	4	100	0.750	**3**
Thunderstorm	33	39	17	3	8	100	0.715	6

Note: (Priority index is calculated for each facility by multiplying each priority by its relative weight given in parentheses and dividing by the sum of the frequencies.

3.2.2. Vulnerability Assessment of the Agricultural Sector

High population density, limited agricultural knowledge, and inadequate access to resources and services increase the vulnerability of communities in the study area. This situation becomes more severe when combined with limited coping capacity and repeated exposure to natural hazards. To assess vulnerability, this study considered four major dimensions: physical, social, economic, and environmental.

The existing natural hazards affecting local communities were used to determine the vulnerability level for each hazard (Table 3). A total of 100 respondents participated in the vulnerability assessment. Respondents were asked to indicate the degree of vulnerability caused by different hazards using five categories: extremely vulnerable, very vulnerable, moderately vulnerable, slightly vulnerable, and not vulnerable at all. Table 3 shows that cyclone was identified as the most significant source of vulnerability in the study area, with a vulnerability index of 0.818. This indicates that cyclones cause the greatest damage and disruption to agriculture and livelihoods. The high vulnerability to cyclones is largely due to the study area's geographical location near the Tetulia River, where communities frequently experience severe cyclonic storms, strong winds, storm surges, and flooding. In addition, the area has limited protective infrastructure and weak disaster-preparedness measures, further increasing vulnerability. Storm surge ranked second with a vulnerability index of 0.775, followed by riverbank erosion (0.758), pest and disease outbreaks (0.743), and thunderstorms (0.700). These hazards also significantly affect agricultural production, household assets, and local livelihoods. Salinity intrusion had the lowest vulnerability index among the selected hazards (0.630). Although salinity intrusion affects crop productivity and soil fertility, respondents perceived its impact to be comparatively lower than that of other hazards because it occurs more gradually, and communities have developed some coping mechanisms over time. The vulnerability index ranged from 0 to 1, where 0 indicates no vulnerability and 1 indicates extremely high vulnerability. The results suggest that most hazards in the study area pose moderate to high vulnerability, particularly in relation to agriculture and livelihood security.

Faisal et al. (2024) reported that cyclones, storm surge, and riverbank erosion emerged as the most severe threats, with vulnerability scores of 8.25, 8.34, and 7.23, respectively. A similar result was also found in the study of Faisal et al. (2021).

Table 3. Communities Vulnerability Index in the Chandradip union.

Hazards	Vulnerability Priority							
	Extremely (1)	Very (0.75)	Moderately (0.5)	Slightly (0.25)	Not at all (0)	Total Frequency	Priority index	Rank
Storm surge	43	36	12	6	3	100	0.775	**2**
Riverbank erosion	45	31	12	6	6	100	0.758	**3**
Salinity intrusion	28	33	13	15	11	100	0.630	6
Cyclone	52	28	16	3	1	100	0.818	**1**
Pest and diseases	37	42	7	9	5	100	0.743	4
Thunderstorm	41	17	25	15	2	100	0.700	5

3.2.3. Capacity Assessment of the Agricultural Sector

Coping mechanisms in the agricultural sector for hazards such as storm surge, salinity intrusion, riverbank erosion, cyclone, pest and disease outbreaks, and thunderstorms refer to the strategies used by individuals, households, communities, institutions, and governments to reduce the negative impacts of disasters. These coping strategies vary among communities depending on the availability of local resources, market access, environmental conditions, and livelihood opportunities (Watts, 2013; Fews, 1999).

Community capacity is considered an important component of resilience building. Therefore, this study examined local communities' existing capacities to cope with various natural hazards. In the study area, communities have developed various capacities through their past experiences with disasters. These capacities were grouped into four categories: physical, social, economic, and environmental capacity. To assess community capacity, four major indicators-physical, social, economic, and environmental capacity-were considered. Each indicator was further divided into several sub-variables to assess communities' ability to cope with different hazards. Respondents were asked to assess their capacity for each hazard on a five-point scale: very good, good, fair, poor, and very poor.

According to Table 4, pest and disease outbreaks received the highest capacity index (0.730), indicating that communities have relatively strong knowledge and experience in managing crop pests and diseases. This may be because farmers regularly face such problems and have developed local techniques, practices, and adaptation measures over time. Cyclone ranked second with a capacity index of 0.685, followed by thunderstorm (0.663), salinity intrusion (0.620), riverbank erosion (0.618), and storm surge (0.615). The relatively higher capacity for cyclone management reflects the experience of local people in dealing with repeated cyclone events. Communities have gradually improved their resilience through better infrastructure, local technologies, early warning awareness, health practices, livelihood diversification, and disaster-related skills. Faisal et al. (2024) revealed that the pest attacks, with a score of 6.48, have the highest capacity score. Then, storm surge, cyclones, and river bank erosion, rated at 3.44, 3.47, and 4.71, respectively, indicate lower management capacities, making them more severe threats than other hazards. A similar result was also found in the study of Faisal et al. (2021)

However, the results indicate that community capacity is relatively weak in relation to storm surge and riverbank erosion. Every year, these hazards damage large areas of agricultural land, yet there are limited formal or informal measures to reduce their impacts. Many respondents reported that they do not take any preventive measures when storm surges or riverbank erosion affect cultivated land. In addition, there is a lack of specific training, technical support, and institutional guidance to help communities cope effectively with these hazards. The findings suggest that although communities have developed some coping capacities through experience, there remains a need for greater support in areas such as disaster-preparedness training, climate-resilient agriculture, erosion control, and protective infrastructure to strengthen long-term resilience in the study area.

Table 4. Communities Capacity Index in the Chandradip union

Hazards	Capacity Priority							
	Very good (1)	Good (0.75)	Fair (0.5)	Poor (0.25)	Very poor (0)	Total Frequency	Priority index	Rank
Storm surge	26	32	19	8	15	100	0.615	6
Riverbank erosion	24	36	19	5	16	100	0.618	5
Salinity intrusion	27	26	24	14	9	100	0.620	4
Cyclone	29	34	25	6	6	100	0.685	**2**
Pest and diseases	34	42	11	8	5	100	0.730	**1**
Thunderstorm	24	38	24	7	7	100	0.663	3

3.2.4. Disaster Risk Assessment in the Agricultural Sector

Chandradip Union is highly vulnerable to various natural disasters due to its coastal location and proximity to the Tetulia River. To identify the most significant disaster risks affecting agriculture in the study area, an integrated disaster risk assessment approach was applied. Disaster risk was calculated using the widely accepted formula: Risk = (Hazard X Vulnerability) /Capacity.

Table 5 presents the calculated hazard, vulnerability, capacity, and overall disaster risk values for the selected hazards. According to Table 5, riverbank erosion had the highest disaster risk index (1.043), making it the most serious threat to the agricultural sector in the study area. This is mainly due to its high hazard level, high vulnerability, and relatively low community capacity to cope with its impacts. Riverbank erosion causes the loss of agricultural land, homesteads, and infrastructure, creating long-term economic and social problems for farming households.

Storm surge had the second-highest risk index (0.942), followed closely by cyclone (0.934). These hazards frequently damage crops, fish ponds, agricultural land, roads, embankments, and housing structures. Respondents reported that riverbank erosion, storm surge, and cyclones cause major agricultural losses almost every year. As a result, these hazards significantly reduce agricultural production and livelihood security in the study area. Pest and disease outbreaks ranked fourth with a risk index of 0.763, followed by thunderstorm (0.755) and salinity intrusion (0.744). Although these hazards also affect agriculture, their overall risk values were lower due to either lower hazard intensity or comparatively higher community coping capacity.

Riverbank erosion, storm surge, and cyclone emerged as the highest-risk hazards because of their frequent occurrence, severe impacts on agricultural production, and the limited coping capacity of local communities. The geographical location of Chandradip Union, surrounded by the Tetulia River and situated in Bangladesh's coastal zone, makes the area highly exposed to riverbank erosion and cyclone-induced storm surges. Riverbank erosion continuously destroys agricultural land, homesteads, roads, and other infrastructure, leading to long-term livelihood insecurity. Similarly, storm surges and cyclones frequently inundate cropland with storm water, damage standing crops, fisheries, and livestock, and disrupt agricultural activities. In addition, poor infrastructure, weak embankment systems, limited financial resources, and inadequate institutional support further increase community vulnerability and reduce adaptive capacity. As a result, these hazards produced higher overall risk values compared to other hazards in the study area.

The findings of this study are consistent with previous research conducted in Bangladesh's coastal regions. For example, Faisal et al. (2021) identified riverbank erosion as the highest-risk hazard in coastal areas, followed by cyclone-associated storm surges. Likewise, Faisal et al. (2024) reported that storm surge, cyclone, and riverbank erosion were the most critical risks, with scores of 15.24, 15.22, and 11.38, respectively. Consistent results have been observed in other studies as well (Hossain, 2015; Islam et al., 2019). Similar results were reported by Faisal et al. (2021), Hasan et al. (2018), Roy et al. (2021), and Murshed et al. (2021), who identified riverbank erosion as one of the most significant disaster risks affecting coastal livelihoods and agricultural production. Likewise, studies by

Ahsan et al. (2020), Kabir et al. (2016), Sadik et al. (2018), Faisal et al. (2021), and Faisal et al. (2024) reported that cyclones and storm surges are among the most critical hazards in coastal Bangladesh due to their severe impacts on crops, fisheries, infrastructure, and household livelihoods. Moreover, recent research indicates that the frequency of cyclone events in coastal Bangladesh has increased significantly in recent years (Murshed et al., 2022; Sarkar et al., 2024). These findings support the results of the present study and highlight the growing vulnerability of coastal agricultural systems to multiple climate-induced hazards. These similarities indicate that disaster risk in Chandradip Union reflects broader patterns of vulnerability and resilience in the coastal zone of Bangladesh.

The findings indicate that disaster risk in the study area is not determined solely by the frequency and intensity of natural hazards, but also by socio-economic vulnerability and limited adaptive capacity. The high dependence of local communities on agriculture and natural resources increases their exposure to climate-related hazards. Poor housing conditions, low income levels, limited access to agricultural training, and weak institutional support further intensify vulnerability. In addition, the geographical location of Chandradip Union in the coastal riverine environment makes the community highly susceptible to riverbank erosion, cyclones, and storm surges. Although local communities have developed several adaptation practices based on indigenous knowledge and previous disaster experiences, many of these measures remain insufficient due to financial limitations, weak infrastructure, and a lack of technical support. The findings, therefore, highlight the importance of integrated disaster risk reduction approaches that combine community-based adaptation, institutional support, resilient infrastructure, and sustainable livelihood development to enhance agricultural resilience.

Table 5. Disaster Risk Index in the Chandradip Union

Hazards	Values of Hazard (H)	Values of Vulnerability (V)	Values of Capacity (C)	Values of Risk R=(H*V)/C	Rank
Storm surge	0.748	0.775	0.615	0.941971545	2.00
Riverbank erosion	0.850	0.758	0.618	1.042712551	1.00
Salinity intrusion	0.733	0.630	0.620	0.744314516	6.00
Cyclone	0.783	0.818	0.685	0.933859489	3.00
Pest and diseases	0.750	0.743	0.730	0.762842466	4.00
Thunderstorm	0.715	0.700	0.663	0.755471698	5.00

The findings also indicate that community capacity remains limited in several areas, particularly for coping with riverbank erosion, storm surge, and cyclones. Existing resilience measures are insufficient to reduce the impacts of these hazards effectively. Most disaster risk reduction activities are not fully community-based and often have limited connection with local needs and priorities. In addition, there is a lack of strong institutional support, training, protective infrastructure, and long-term planning for managing major coastal hazards. The results suggest that if local communities are provided with stronger coping capacity, improved disaster preparedness, and better adaptation measures, the overall disaster risk in the agricultural sector could be significantly reduced.

3.3. Adaptation Strategies in the Agricultural Sector

Agriculture in coastal Bangladesh is highly exposed to climate change-induced natural disasters, making it one of the most vulnerable livelihood sectors. Since agriculture is the primary source of income for coastal communities, developing effective adaptation strategies is essential to reduce disaster risks and ensure livelihood security. In this context, the present study aims to identify locally appropriate and sustainable adaptation measures based on community experiences and practices. Overall, the findings indicate that farmers in the study area are actively adopting a range of adaptation strategies based on local knowledge and available resources. Among these, alternative livelihood options (27%), loan and subsidies (25%), and short-duration rice cultivation (24%) were the most commonly recommended strategies, followed by embankment construction (22%) and farm mechanization (2%). Strengthening these adaptation measures through institutional support, training, and financial assistance can significantly enhance resilience in the agricultural sector. The findings (Figure 3) highlight several key adaptation options adopted or recommended by the farming community.

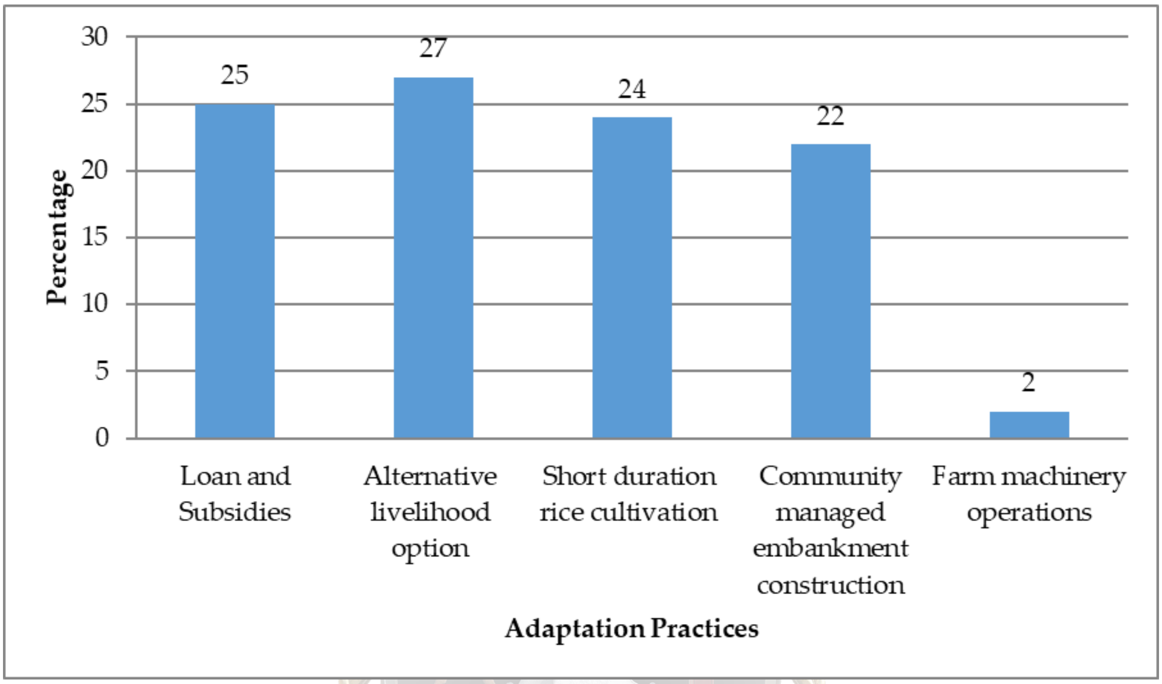

Figure 3. Potential adaptation strategies for disaster risk reduction in agricultural

3.3.1. Loan and Subsidies

Access to financial support is an important adaptation strategy for farmers in the study area. About 25% of respondents identified loans and subsidies as a key measure for coping with agricultural losses. Most farmers, being economically vulnerable, rely on loans from NGOs to recover from disaster-related damages. Approximately 98% of respondents reported taking loans from NGOs, while only a small proportion accessed formal banking services. The average interest rate ranges from 10% to 15%, and repayment is typically made weekly. Although loans help farmers resume agricultural activities by purchasing inputs such as seeds and fertilizers, many households fall into a cycle of repeated borrowing due to recurring losses. Therefore, subsidies-such as support for agricultural inputs or compensation for losses are crucial for strengthening resilience. However, subsidies should be carefully designed to promote sustainable agricultural practices and avoid long-term dependency.

3.3.2. Alternative Livelihood Options

Alternative livelihood options are another important adaptation strategy, particularly during the agricultural off-season. About 27% of respondents recommended livelihood diversification as a key coping mechanism. Due to limited agricultural opportunities, many households engage in daily wage labor (72%), small businesses such as tea stalls or grocery shops (7.3%), auto-rickshaw driving (6.4%), and seasonal fishing (14.3%). These diversified income sources help households maintain financial stability and reduce their dependence on climate-sensitive agriculture. Livelihood diversification is therefore an effective strategy for enhancing household resilience in disaster-prone areas.

3.3.3. Short-Duration Rice Cultivation

Short-duration rice cultivation is widely practiced as an adaptation to flooding and climate variability. About 24% of respondents identified this strategy as effective. In the study area, monsoon flooding often occurs during the rice maturity stage, leading to significant crop losses. To address this, farmers cultivate short-duration rice varieties (e.g., IRRI dhan varieties) during the Kharif-1 season, allowing them to harvest crops before the onset of floods. In addition to short-duration crops, farmers adjust cropping patterns based on soil conditions, salinity levels, and climatic variability. While research is ongoing to develop climate-resilient crop varieties (e.g., salt-tolerant and heat-tolerant crops), farmers currently rely on improved crop management practices and local knowledge to sustain agricultural production.

3.3.4. Community-Managed Embankment Construction

Due to its location near the Tetulia River, much of the agricultural land in the study area is highly vulnerable to tidal flooding and storm surges. As a result, cropping is often limited to a single season (Kharif-2), leaving land fallow during Kharif-1 and Rabi seasons. To address this issue, local communities have initiated small-scale embankment construction using their own labor and resources. About 22% of respondents recommended large-scale embankment construction around the union as a key adaptation strategy. These embankments help prevent saline water intrusion and tidal flooding, enabling farmers to cultivate multiple crops annually and improve food security and income.

3.3.5. Farm Machinery Operations

The use of agricultural machinery is an emerging adaptation strategy, although it is currently adopted by a small proportion of farmers (2%). Due to erratic rainfall and increasing soil salinity, timely land preparation and irrigation have become critical challenges. Farmers use motor pumps to irrigate crops during dry periods, particularly in the Kharif-1 and Rabi seasons. Mechanized farming tools such as tractors, power tillers, harvesters, threshers, and irrigation pumps can significantly improve agricultural efficiency and reduce labor dependency. Mechanization also allows for timely planting and harvesting, which is essential under changing climatic conditions. However, limited access to capital restricts the widespread adoption of these technologies.

The adaptation strategies identified in this study demonstrate the importance of both community-based practices and institutional support in reducing agricultural disaster risk in the study area. The identified adaptation strategies are closely linked to the major disaster risks identified in the study area. Alternative livelihood options reduce dependence on climate-sensitive agriculture and provide income security during crop failures caused by riverbank erosion, cyclones, and other environmental stressors. Similarly, Short-duration rice cultivation helps farmers reduce crop losses caused by cyclones, floods, and excessive rainfall by allowing earlier harvesting before peak hazard periods. Community-managed embankment construction plays an important role in protecting agricultural land from storm surge, tidal flooding, and salinity intrusion. At the same time, farm mechanization improves the efficiency and timeliness of agricultural operations under changing climatic conditions and helps farmers manage seasonal uncertainties more effectively. Financial support through loans and subsidies helps farming households recover from disaster-related losses and continue agricultural activities after extreme events.

From the perspective of local farmers, many of these adaptation measures are practical and locally acceptable because they draw on indigenous knowledge, past disaster experiences, and locally available resources. However, poor farmers often face financial constraints, limited access to technology, inadequate training opportunities, and weak market access, which reduce the effectiveness of adaptation practices. Institutional support from government agencies, NGOs, agricultural extension services, and local authorities is therefore essential to improve the feasibility and sustainability of these adaptation measures. Strengthening coordination among institutions, ensuring regular maintenance of embankments and water-control structures, and providing technical and financial assistance can significantly enhance the resilience of coastal agricultural communities.

3.3.6. Barriers to Adaptation Measures

Long-term sustainability is essential for the success of any adaptation strategy, particularly in the face of climate change and its adverse impacts. However, several constraints limit the effectiveness and durability of these adaptation measures in the study area. The findings indicate that a significant proportion of adaptation efforts face multiple barriers (Figure 4). Among these, lack of capital was identified as the most critical constraint, reported by 49% of respondents. Limited financial resources restrict farmers' ability to invest in improved technologies, inputs, and infrastructure necessary for effective adaptation. Due to financial constraints, many farmers are unable to invest in improved seeds, irrigation facilities, farm machinery, embankment protection, and other climate-resilient agricultural practices. As a result, farming households often remain highly vulnerable to disaster-related losses and struggle to recover after extreme events. Lack of information and knowledge was the second major barrier, reported by 26% of respondents. Lack of climate-related information, agricultural training, and extension services reduces farmers' knowledge of disaster preparedness, climate-resilient crop management, and modern adaptation technologies. Weak dissemination of weather forecasts and early warning information further limits farmers' ability to make timely and informed decisions. Similarly, lack of coordination among stakeholders was reported by 9% of respondents, indicating weak collaboration between communities, government agencies, and non-governmental organizations. Corruption was identified by 12% of respondents as a barrier, which may affect the fair distribution of resources and support services. In addition, a lack of institutional capacity (4%) further limits the implementation and sustainability of adaptation measures. Weak institutional support reduces access to training, financial assistance, and technical guidance. Corruption and weak institutional capacity also negatively affect resilience-building efforts in the study area. Local communities reported that inadequate transparency and poor coordination in development and disaster management activities often delay the implementation and maintenance of embankments, sluice gates, and other protective infrastructure. In addition, limited institutional manpower, insufficient technical expertise, and weak monitoring systems reduce the effectiveness of government and NGO support services.

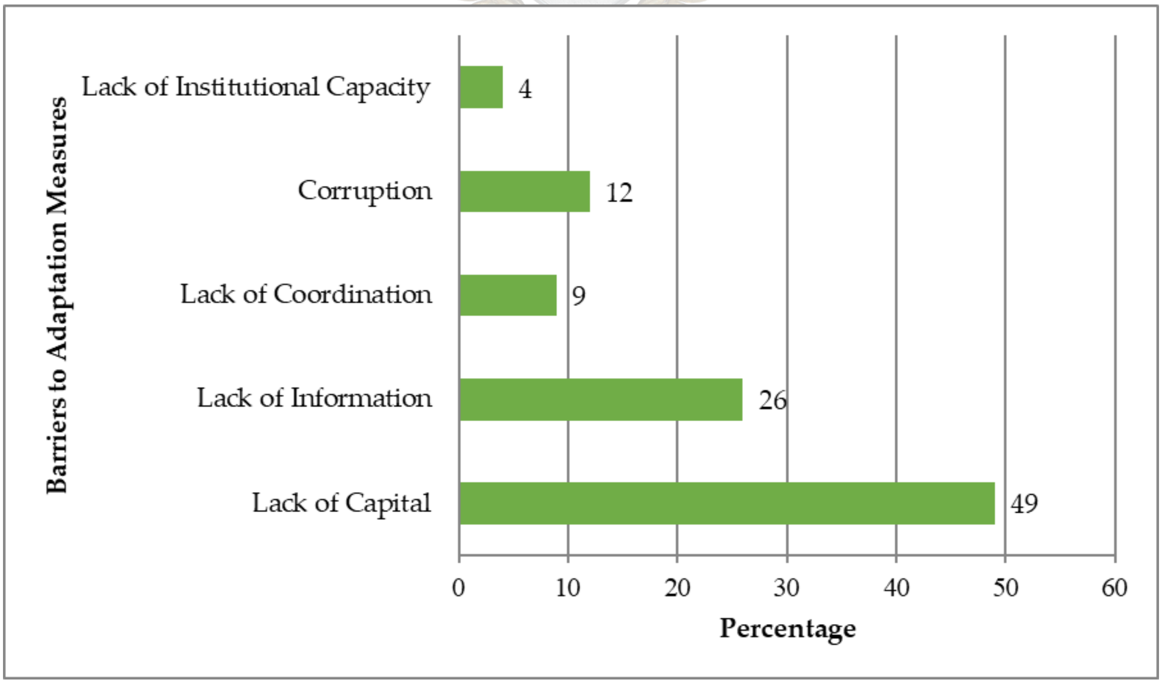

Figure 4. Barriers to the Adaptation Measures.

The identified barriers to adaptation are closely associated with the broader socio-economic and institutional vulnerabilities of the study area. Limited financial resources restrict farmers' ability to invest in resilient agricultural technologies, improved seeds, irrigation systems, and protective infrastructure. Similarly, inadequate access to information, training, and agricultural extension services limits farmers' understanding of climate-resilient practices and disaster preparedness measures. Weak institutional coordination and governance problems further reduce the effectiveness of adaptation initiatives and delay the implementation and maintenance of embankments, water-control structures, and other protective measures. As a result, these barriers not only constrain the successful adoption of adaptation strategies but also increase the long-term disaster risk and vulnerability of coastal agricultural communities. Previous studies also highlight that limited knowledge and inadequate support from responsible organizations or practitioners can hinder the successful implementation and long-term sustainability of adaptation strategies (Alauddin & Rahman, 2013).

Overall, these barriers significantly reduce the effectiveness of adaptation measures and increase the vulnerability of farming communities. Addressing these challenges through improved financial support, better information dissemination, stronger institutional frameworks, and enhanced coordination is essential for achieving sustainable agricultural resilience in the study area.

3.4. Limitations of the Study

This study has several limitations that should be acknowledged. First, the analysis was primarily based on perception-based data collected from local communities, which may be influenced by respondents' personal experiences, memory recall, and subjective judgment. Second, the hazard, vulnerability, and capacity indices were developed using community-based weighted scoring methods, which may involve some level of subjectivity in ranking and prioritization. Although these indices provide useful insights into local disaster risk conditions, they may not fully capture the complexity of all environmental and socio-economic factors influencing agricultural risk. However, to improve the reliability of the findings, multiple data collection methods, including household surveys, focus group discussions, key informant interviews, and field observations, were used for data triangulation and validation.

4. Conclusions

This study assessed disaster risk and adaptation strategies in the agricultural sector of Chandradip Union, a highly vulnerable coastal area of Bangladesh. The findings revealed that riverbank erosion, storm surge, and cyclones are the most critical hazards affecting agricultural production and rural livelihoods due to their high hazard intensity, community vulnerability, and limited coping capacity. The study also identified several locally practiced adaptation strategies, including alternative livelihood options, short-duration rice cultivation, embankment construction, and financial support mechanisms, that enhance community resilience. The main scientific contribution of this study is the integrated assessment of hazard, vulnerability, and capacity to evaluate agricultural disaster risk at the local level using community-based evidence. The study provides important insights into the relationship between environmental hazards, socio-economic vulnerability, and adaptation practices in coastal agriculture. The findings may support policymakers, development organizations, and local institutions in designing effective disaster risk reduction and climate adaptation strategies for vulnerable coastal communities in Bangladesh. Strengthening institutional support, improving access to financial and technical resources, and promoting community-based adaptation approaches are essential for building sustainable agricultural resilience in coastal regions.

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