The Role of Innovation and Adaptation Technologies in Climate Change-Induced Disaster Risk Reduction: Enhancing Resilience in Satkhira Communities of Bangladesh

BY

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A Thesis Submitted to the Faculty of Graduate Studies of
the University of Manitoba
in partial fulfillment of the requirement of

MASTER OF NATURAL RESOURCES MANAGEMENT

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ABSTRACT

Climate-induced disasters, exacerbated by the changing climate, pose significant threats to the coastal communities of Bangladesh. This thesis investigates the multifaceted strategies of innovation, adaptation technology, and institutional processes to respond to and mitigate the impacts of climatic disasters and strengthen local communities' resilience. The required field data were collected from December 2022 to February 2023 in two coastal *Unions* of Bangladesh using various Participatory Rural Appraisal (PRA) tools such as key informant interviews, household surveys, and focus group discussions.

The research findings revealed that innovation and adaptation technologies emerge as critical components to minimize vulnerability and enhance preparedness in the face of catastrophic events. Innovations such as the Cyclone Preparedness Programme (CPP) help vulnerable communities by disseminating warning information and evacuating them to safer locations with the help of the CPP volunteers. The households avail loans and/or credit from various microfinance institutions (MFIs) to "bounce back" from climatic disasters. Such financial assistance has proven instrumental in facilitating timely repairs and reconstruction of houses in the aftermath of extreme climatic events, while also assisting in restoring livelihood activities and income generation. Adoption of adaptation technology is another strategy that is being widely practiced in the study area to cope with the shocks and stresses arising from climate change.

The formal, quasi-formal, and informal institutions were found to be deeply engaged locally in promoting climatic risk reduction efforts. These institutions facilitate the development of livelihood strategies, provide access to credit services, and help in mitigating climatic risks through knowledge sharing within the local community. The policy recommendations from the research underscore the necessity of a comprehensive framework for enhancing the resilience and adaptive capacity of coastal communities. Furthermore, it also emphasizes the integration of innovation and adaptation technologies at the local level for sustainable development.

ACKNOWLEDGEMENT

First and foremost, my heartfelt gratitude goes to my parents Md. Helal Uddin Khan and Shamsunnahar, and my brother Shakil Ahmed Khan. Their unwavering support, sacrifices, and belief in my potential have been the bedrock of my academic journey. I am profoundly grateful for their love and encouragement, which have fueled my determination to pursue excellence. Finally, now they can stop asking “When will you graduate?”.

I am deeply grateful to my academic supervisor Dr. C. Emdad Haque, Natural Resources Institute, University of Manitoba for his exceptional guidance and support throughout my master’s program. Dr. Haque’s expertise and insightful advice have shaped the direction of my research work and enhanced its quality. His dedication to nurturing my intellectual growth has been a constant source of inspiration, and I am truly fortunate to have had the opportunity to learn from him.

I extend my sincere appreciation to my advisory committee members Dr. Nirupama Agarwal and Dr. David Walker for their invaluable guidelines and thoughtful feedback in refining my ideas and arguments.

Furthermore, I would like to convey my gratitude to the faculty members and staff of the Natural Resources Institute, University of Manitoba. Special thanks to Dr. John Sinclair, Dr. Glen Hostetler, Dalia Naguib, and Tamara Keedwell for their support at the NRI. I would like to thank the International Development Research Centre (IDRC) and Faculty of Graduate Studies, University of Manitoba for funding my Master’s program and Research.

I also want to acknowledge the unwavering support and camaraderie of my friends and colleagues who have been with me throughout this academic journey. I extend my heartfelt thanks to M. Abul Kalam Azad and Alvira Farheen Ria for their consistent support and valuable insights into my research. Special thanks to Mohammad Wasif, Musarrat Zaman Auroni, Salit Chakma, Rifat Hossain, Nasir Uddin Khan, Sanjida Zaman Tashfi, Rehnuma Mahjabin, Tracy Hamilton, and Dr. Mahed Choudhury for their continuous support in pursuing my higher studies in Canada.

I would also like to extend my appreciation to the community people of the study areas, and my research assistants, Md Asaduzzaman and Arif Hossain from the Bangladesh Center for Advance Studies (BCAS), for assisting in my fieldwork in Bangladesh.

This thesis represents the collective support and contributions of those mentioned above, as well as those names that may not appear here but have played meaningful roles in my academic and personal growth.

DEDICATION

This thesis is dedicated to the

Vulnerable community people in coastal Bangladesh and my parents

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CHAPTER 1

Introduction

1.1 Background and Context

The frequency and intensity of climate-induced disasters have increased considerably worldwide. Over the past few decades, these disasters have resulted in high morbidity and mortality, caused severe damage to infrastructure, and disrupted natural ecosystems (United Nations Office for Disaster Risk Reduction [UNDRR], 2019; International Panel on Climate Change [IPCC], 2022). Scientists, scholars, practitioners, and policy experts have been looking for ways to tackle the possible factors of climate-induced disaster destruction and integrate innovation and adaptation technologies to improve the adaptive capacity of communities at risk (UNDRR, 2019; Rahman & Huq, 2021).

Bangladesh ranks among the most vulnerable countries globally to climate-induced disasters (Kamal, 2013). In the last 50 years, the country experienced several extreme climatic events such as cyclones, tidal storm surges, severe floods, river erosion, excessive rainfall, and extensive salinity intrusions, mainly in the coastal regions (Ahmed et al., 2007; Salequzzaman et al., 2009). According to the Global Climate Risk Index 2010, from 1990 to 2008, "an average of 8,241 people died each year in 244 cases of extreme weather conditions in Bangladesh", along with annual damages of over $2 billion and a 1.81% decrease in the GDP (Bangladesh Centre for Advanced Studies [BCAS], 2010; Rahman, 2010, p. 2).

In the coastal areas of the country, local inhabitants are becoming more vulnerable and exposed to increasing climatic disasters (Kamal, 2013; Choudhury et al., 2021). Coastal people's lives and livelihoods are being adversely affected disproportionately by extreme events. International Organization for Migration (2009) reported that since 1971 approximately 6.5 million people in the coastal belt have migrated to urban areas due to recurrent disasters such as cyclones, storm surges, salinity intrusions, increasing river erosion, and other extreme events. Climate scientists and experts predict that, by the year 2050, an increase in the sea level by 1 meter will inundate approximately 17% of the country's territory and over 35 million people living in the coastal areas will be displaced (Rabbani, 2009; Khan et al., 2011; Roy et al., 2022).

The progress in science and technology has enormous importance and potential to mitigate climate risk at national and regional levels. Presently, innovation and technologies are widely used, particularly to deal with disaster vulnerability and climate hazard conditions. The development and adoption of climate change innovation and adaptation technology is a continuous process requiring the generation, collection, and dissemination of information and awareness-raising on disaster and emergency, planning, designing, implementation, monitoring, and evaluation at all levels (Agrawal, 2010; IPCC, 2012).

The significance and application of innovation and adaptation technologies are reflected in many ways, such as the development of an enhanced early warning system, the construction of sea walls, improvements to coastal embankments, modification of farming practices, rainwater harvesting, and development of local institutions, all of which have been helping to mitigate climate risks and associated impacts (Grønning, 2008; Schulenburg et al., 2017; also see Izumi et al., 2019). It allows vulnerable communities to perform critical roles and integrate local and indigenous knowledge through the learning process of developing and implementing local plans and strategies. These are essential to address the current and future challenges in strengthening resilience against adverse climatic events (Berkes, 2009). For instance, as an innovation, the community-based disaster risk management (CBDRM) approach has been popular worldwide in disaster risk mitigation. Another notable example is the wider use of climate-resilient crops that increase crop production and support the livelihoods of coastal communities in Bangladesh.

Innovation and adaptation technologies can strengthen local communities' capacity by enhancing their flexibility and preparedness activities in the face of uncertainty associated with climate change. Therefore, enhancing communities' adaptive capacity has been touted as a vital technique for dealing with growing disaster risk (Folke et al., 2002; Tompkins & Adger, 2004). This can be achieved by improving the early warning system (EWS) that uses multiple forecasting data from satellite, ground, ocean surveillance, and advanced computer simulations to assess potential vulnerabilities and prepare communities to respond with proactive mitigation plans and risk reduction measures (Akhand, 2003; Saha & Pittock, 2021).

In reducing and responding to climatic disasters, institutions assist in the formulation of various rules, regulations, policies, and knowledge dissemination measures through activities such as climate risk simulation, which allows more comprehensive and accurate strategies that minimize the adverse effects of climatic events at diverse scales (Agrawal, 2010). They can facilitate the integration of multifaceted understandings and cultural values for collective actions by engaging multiple stakeholders, as well as assist in implementing various innovations and adopting adaptation technologies in climate risk reduction at the grassroots level. These include training and knowledge development, generating relevant policies, and support services (Folke et al., 2002; Agrawal, 2010; Islam & Nursey-Bray, 2017).

In sum, the coastal communities of Bangladesh are extremely vulnerable to climate extremes, and the consequences of climate catastrophes are expected to amplify future climate risks. In the context of climate change, noticeable institutional and policy efforts have been taken in the strengthening process, little systematic knowledge is available on innovation and adaptation technologies as well as their linkage to institutional processes in coastal Bangladesh. These areas deserve both conceptual and empirical investigations for furthering existing knowledge and for formulating sustainable interventions.

1.2 Purpose and Objectives

In consideration of the above backdrop, the overall purpose of this study is to examine the role of innovation and adaptation technologies in reducing climate-induced disaster risk and impacts in coastal communities, as well as the contribution of such actions to enhancing adaptive capacity and community resilience in Bangladesh. The specific objectives are to:

1. Identify the existing innovation and adaptation technologies in response to climate change impacts in coastal communities of Bangladesh;
2. Analyze the drivers that promote the adoption of innovation and adaptation technologies at the local community level for minimizing climate disaster risk and impact; and
3. Examine the role of multi-level institutions in reducing climate-induced disaster risks and enhancing resilience through facilitating innovation and adaptation technology at the local community level.

1.3 Methodological Approaches

To achieve the above-stated three objectives of the present study, I have used a mixed-methods study design that combines both qualitative and quantitative research approaches. In this regard, Johnson et al. (2007) defined mixed methods research as "*the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches for the broad purposes of breadth and depth of understanding and corroboration*" (p. 123). Thus, mixed methods study is associated with increased understanding and validity of the observed reality (Schoonenboom, & Johnson, 2017).

The application of the mixed-method approach allowed the investigation of the existing innovation and adaptation technology used in coastal Bangladesh to minimize climate risk impacts. It also enabled me to analyze the major drivers as well as to examine the role of various institutions in enhancing adaptive capacity and strengthening community resilience. As the research involves social and human aspects, behavioral patterns, technological aspects, and key issues in the social environment, it is coherently suitable to use both qualitative and quantitative research design (Creswell, 2009). To accomplish the objectives, a combination of close-ended questions designed to gather quantitative data and open-ended inquiries intended for qualitative data collection were incorporated within the questionnaire survey, interviews, and discussions in a participatory setting. Both the qualitative and quantitative data were merged in a complementary way that offered a comprehensive analysis of the results.

1.3.1 Study Area and Population

The study focuses on the coastal regions of Bangladesh as this region is most vulnerable to climate change impacts (Shaw et al., 2022, p. 1457-1579). The coastal region of Bangladesh consists of 47, 211 sq. km with a population of 43.9 million, which is about 31% of the total population. The population size is expected to increase to 60.8 million by 2050 (Rahaman & Esraz-Ul-Zannat, 2021). The region comprises 19 coastal districts with central, southeastern, and southwestern parts of the country (Shaibur et al., 2017).

The research was carried out in the southwestern part of Bangladesh, specifically in Satkhira District of the Khulna Division. The District is located "*between 21º36' and 22º54' North Latitudes and between 88º54' and 89º20' East Longitudes, with a total area of 3, 817.29 sq. km*" (Shaibur et al., 2017, p. 101). Based on the baseline study (IDRC project), two *Unions*, namely Dakshin Sreepur *Union* of Kaligaj Upazila (sub-district) and Padmapukur *Union* of Shyamnagar Upazila, respectively, were purposively selected for the present research as a part of the IDRC project. They are considered among the most vulnerable coastal areas in Satkhira District to climate-induced disasters (Kabir et al., 2016).

In recent years, the southwestern region of Bangladesh has experienced numerous extreme events including cyclones, coastal flooding, tropical storms, and tidal surges that have caused the loss of thousands of human lives and livelihoods (Rahaman & Esraz-Ul-Zannat, 2021). One of these extreme events includes 2007 Cyclone SIDR, which affected 2.3 million households with physical destruction, causing a loss of approximately $1.1 billion; another extreme event was 2009 Cyclone Aila, which affected 3.9 million people, with a total financial loss of $240 million (Islam et al., 2015; Khan et al., 2015; also see Tajrin & Hossain, 2017). The overall impacts were catastrophic loss and damage to thousands of acres of cropland, livestock, fish farms, and physical infrastructure. These figures of loss and damage due to climate change-related disasters depict the degree of vulnerability of the study region.

1.3.2 Data Collection Methods

For conducting this research, primary data were collected using various Participatory Rural Appraisal (PRA) data collection tools and methods (Table 1.1). The field investigation was carried out from December 2022 to February 2023. The PRA tools used in the study were: key informant interviews (KII), household surveys, and focus group discussions (FGD).

For Objectives One and Two, a total of 300 randomly selected households were surveyed. Household heads were interviewed using a semi-structured questionnaire (see Chapter 2 and Appendix 3). The selection of households was based on their socio-economic circumstances, including individuals and communities from poor, middle, and rich classes. I conducted 25 KIIs with the key stakeholders using a set of guiding questions (see Chapter 2 and Appendix 4). The key informants were the representatives of local government organizations, non-governmental organizations (NGOs), community-based organizations (CBOs), microfinancing institutions (MFIs), volunteers, and community leaders. A total of 4 FGDs were organized in both the study *Unions* (see Chapter 2 and Appendix 5). For FGDs, selected groups of community people were invited, typically consisting of 6-8 participants including male and female, to engage in discussions and express their perspectives, collective actions, and decision-making process. To construct a comprehensive viewpoint, KIIs, household surveys, and FGDs proved instrumental in providing an in-depth understanding of the detrimental impacts of climate-induced disasters on communities;

identifying the existing innovation and adaptation technologies to reduce climate risk impacts and strengthen community resilience at the local level; and analyze the drivers of innovation and adaptation technology.

Table 1.1: Data collection methods

Objectives	Data collection tools
Objective 1: To identify the existing innovation and adaptation technologies in response to climate change impacts in coastal communities of Bangladesh. Objective 2: To analyze the drivers that promote the adoption of innovation and adaptation technologies at the local community level for minimizing climate disaster risk and impact.	Household surveys (300) * Key informant interviews (25) Focus group discussions (4)
Objective 3: Examine the role of multi-level institutions in reducing climate-induced disaster risks and enhancing resilience through facilitating innovation and adaptation technology at the local community level.	Household surveys (300) * Key informant interviews (26) Focus group discussions (2)

*Figures within parentheses show the frequencies.

For the Third Objective, a total of 300 households were surveyed and 2 FGDs were organized to obtain insights on formal, quasi-formal, and informal institutional dynamics, and barriers to adopting various innovation and adaptation technologies to reduce climate risks and enhance resilience (see Chapter 3 and Appendix 3—4). Each FGD session consisted of 6-8 participants. To understand institutional processes and their role in adopting innovation and adaptation technology, I carried out 26 KIIs involving representatives from multi-level institutions including formal, quasi-formal, and informal institutions (See Chapter 3 and Appendix 5). The key informants provided data on critical aspects of how institutional processes implement the adoption of innovation and adaptation technologies at the community level and often transform them into resilience-building against climate-induced disasters.

In addition to primary data sources, secondary data were also collected and used in this study. Secondary data have been collected through assessment reports of government, NGOs, and international non-governmental organizations (INGOs); policy documentation; relevant gazettes; scholarly articles; magazines; newspapers; and books. The primary data collection complied with the human ethics protocol and guidelines of the University of Manitoba. The required written consent was obtained from each participant involved in the study.

1.3.3 Data Analysis

The data analysis followed the ongoing and interactive processes—I carried it out simultaneously while collecting and transcribing data from household surveys, KIIs, FGDs, and secondary sources. All data were collected in Bengali and then transcribed into English for analysis.

For analyzing the field data on the aspects of innovation and adaptation technology, I pursued an Explanatory Sequential analysis, following a systematic and rigorous approach that aligned with the study's key objectives and contextual considerations (Creswell, 2009).

For analyzing the field data on the role of institutions, I applied a Triangulation data analysis design, which facilitated the identification of distinct issues and the streamlining of themes, enabling the simultaneous analysis of both qualitative and quantitative data (Creswell, 2009). This integration contributed to the comprehensive interpretation of the findings.

1.4 Organization of the Thesis

The organization of the thesis consists of four chapters. Chapter 1 serves as the introduction, while Chapter 4 offers an elaborate discussion and draws conclusions about the overall research.

Based on the three objectives of this study, Chapters 2 and 3 were prepared as manuscripts intended for publication in academic journals. Chapter 2 (manuscript 1) focuses on identifying existing innovation and adaptation technologies, as well as analyzing the drivers that promote these technologies in response to climate change impacts and strengthen community resilience within coastal communities in Bangladesh. In Chapter 3 (manuscript 2), the focus shifts to the role of multi-level institutions in climate risk reduction through facilitating innovation and adaptation technologies at the local level. This chapter was submitted as a manuscript, entitled *"Role of Multi-*

level Institutions in Facilitating Innovation and Adaptation Technologies for Climatic Risk and Impact Mitigation: Evidence from Coastal Communities of Bangladesh", to the International Journal of Disaster Risk Reduction, and it is presently under review.

It is worth noting that there are some overlaps in the methodological sections of both chapters, as the data collection tools, and analysis processes were the same.

1.5 Contribution of Authors

In this thesis, I am the sole author of Chapters 1, 2 and 4 with the direct supervision of Dr. C. Emdad Haque.

Chapters 2 and 3 were prepared as manuscripts for publication in academic journals. Chapter 3 was submitted (under review) to the *International Journal of Disaster Risk Reduction* and co-authored by me as the lead author, Dr. C. Emdad Haque and Dr. Mahed Choudhury. Below are the descriptions of the chapter's contributions:

Chapter 2: The Use of Innovation and Adaptation Technology in Reducing Climate-Induced Disaster Risk: A Case of Strengthening Community Resilience in Satkhira, Bangladesh.

I conducted the fieldwork for data collection, collaborating with Dr. C. Emdad Haque on developing the conceptual framework, and completed the manuscript under his direct supervision.

Chapter 3: Role of Multi-level Institutions in Facilitating Innovation and Adaptation Technologies for Climate Risk and Impact Mitigation: Evidence from Coastal Communities of Bangladesh. This chapter was submitted to the *International Journal of Disaster Risk Reduction* and is presently under review.

I conducted the fieldwork for data collection and collaborated with Dr. C. Emdad Haque on developing the conceptual framework. The manuscript was written by me as the lead author, with guidance and support from Dr. C. Emdad Haque and Dr. Mahed Choudhury. Dr. C. Emdad Haque supervised the overall project.

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CHAPTER 2

The Use of Innovation and Adaptation Technology in Reducing Climate-Induced Disaster Risk: A Case of Strengthening Community Resilience in Satkhira, Bangladesh

Abstract

Climate change is one of the most pressing global challenges of recent times, with its impacts disproportionately affecting vulnerable coastal regions in Bangladesh. As climate change continues to intensify, coastal communities face increasing risks associated with various climatic disasters. In this backdrop, the present study aims to identify the existing innovation and adaptation technology in mitigating disaster impacts while enhancing the resilience of communities at risk. The research adopts a comprehensive mixed-method approach, integrating both qualitative and quantitative data. Primary data were collected through household surveys, interviews, and focus group discussions. The results identified the current innovation and adaptation technologies in the study area that included a diverse set of applications of new technologies and formulating new institutional structures to reduce disaster risk vulnerability. The results also revealed the challenges and barriers to implementing innovative and adaptive solutions, including resource constraints, institutional capacity, and socio-economic disparities. The policy recommendations of the research highlight the comprehensive framework needed to enhance the adaptive capacity of coastal communities and mainstream innovation and adaptation technologies at the local level. It is also suggested that the incorporation of community-driven approaches to address the complex challenges posed by climate-induced disasters will help to achieve sustainable development goals.

KEYWORDS: Climate change; innovation and adaptation technology; disasters; community resilience; Bangladesh

2.1 Introduction

Bangladesh, a low-lying South Asian nation, stands at the forefront of climate change challenges. Its unique geographical location, with a vast coastline along the Bay of Bengal and a predominantly low-lying landscape, renders it acutely susceptible to the adverse impacts of climatic disasters that include cyclones, floods, river erosion, storm surges, and salinity intrusion (Rabbani et al., 2021; Sammonds et al., 2021). The detrimental effects of climate change have already been witnessed at the local levels, resulting in approximately $16 billion in costs in the past 30 years (The Asia Foundation, 2012).

Science and technology are effective tools to accelerate the progress in climate risk reduction. It helps to synergize and develop new theories and approaches, solve existing issues, and create better standards and more evidence-based solutions. Over the past few decades, the exposure to climate risk has increased in an unprecedented manner due to population growth, unplanned urbanization, increase in poverty, exposure to harmful chemicals in the atmosphere, and human settlements in hazard-prone areas. On the global scale, from 1980 to 2005, the total loss due to climatic events was about $1.02 trillion, where climate change is considered as the primary driver (United Nations Framework Convention on Climate Change [UNFCCC], 2014). While climate risk varies from region to region, the adaptive capacities are much lower in developing and least-developed countries (Burton et al., 2006). In climate change, "adaptive capacity" denotes the capability of individuals, communities, and institutions to adapt, prepare for climate vulnerability, mitigate possible risks, exploit potential opportunities, or deal with the aftermath (Intergovernmental Panel on Climate Change [IPCC], 2022). Thus, developing the adaptive capacity of an individual or community aims to connect various forms of social, economic, and human capital, enabling more effective adaptation measures at both the local and national levels (Armitage & Plummer, 2010; Dev & Manalo, 2023).

To address these issues, the Sendai Framework for Disaster Risk Reduction (SFDRR) advocates for investment in the advancement of innovation and technology through sustained, solution-oriented research in disaster risk management (Shaw et al, 2016; Izumi et al., 2019a). In the climatic disaster context, innovation and adaptation technology provide both structural and non-structural measures to strengthen community resilience (Chowdhooree, 2019; Izumi et al., 2019b; Haque et al., 2022). Formulating and implementing them is a continuous process to deal with future risks and threats. Innovation and adaptation technology in climate-induced disasters aims to reduce vulnerability and strengthen resilience, urging an integrated approach in the development of planning and decision-making processes at the national, regional, and global scales.

The overall purpose of the present study is to identify innovation and adaptation technology to reduce climatic disaster impacts and strengthen community resilience in the southwestern coastal regions of Bangladesh. The two specific objectives, as discussed in this chapter, are to: i) identify the existing innovation and adaptation technology at the local level; and ii) analyze the drivers that promote the adoption of innovation and adaptation technologies.

2.2 Conceptual Consideration: Innovation and Adaptation Technology in Climate Change

2.2.1 Categorization of Innovation

Innovation is the driving force behind the progress and transformation of our society, fostering change and growth in different domains (Phills Jr. et al., 2008). Joseph Schumpeter—an eminent early 20th century economist—offered a distinctive perspective on innovation, particularly the notion of 'social innovation'. He defined 'social innovation' as the process of introducing new ideas, products, services, or organizational structures that disrupt established norms, challenge traditional practices, and ultimately lead to societal advancement. (McCraw, 2007; Hochgerner, 2013; McNeill, 2013). McCraw (2007) extended its scope by asserting that innovation is not limited to technological advancements, but also includes novel approaches to addressing societal challenges, fostering economic development, and improving the overall well-being of communities in shaping a better, more inclusive, and dynamic world.

In the context of climate change, drawing upon the assertions by Lei et al. (2013), we consider innovation as the process of combining scientific, social, and technological knowledge with new and existing ideas, as well as the integration of innovative and appropriate theories. In this regard, Afuah (1998) defined innovation as referring to the *"new knowledge incorporated in products, processes, and services"* (p 61). According to the OECD, *"Innovation drives growth and helps to address social challenges"* (Organisation for Economic Co-operation and Development [OECD], 2010; Gault, 2018, p. 1/617). It cannot be characterized as a binary phenomenon; rather it can be radical and evolve with the process of time and nature. In climate change issues, Gault (2018) cites that innovation significantly mitigates climate risk, enhances sustainable development, and facilitates social fabric. In addition, Dabral et al. (2021) finds that innovation in climate change assists in community engagement and creates a platform for problem-solving in vulnerable areas. Thus, it offers a valuable mechanism to deal with potential hazards and vulnerabilities.

The integration of innovation in social and behavioral sciences into climate risk reduction strategies has fostered a deeper understanding of human behavior in crises, leading to the development of more effective communication and evacuation strategies (Izumi et al., 2019a). Innovation is at the forefront of building a more resilient and responsive global community in the face of climate risk by continuously fostering creativity and technological advancement. Innovation, therefore, must be viewed as both an *outcome* and a *process* (Kahn, 2018).

Analyzing the diverse characteristics of innovation in the context of climate risk mitigation and adaptation, innovation can be categorized into three main types: i) product, ii) approach, and iii) institution (Huq et al, 2013; Hills et al., 2018; Izumi et al., 2019a). In this respect, innovation aims to mitigate its impact and to enhance adaptive capacity to the changing climate. All categories of innovations are focused on addressing the root causes or consequences of climate vulnerability by creating new solutions, improving existing ones, and fostering resilience at all levels. Innovation in this context is a key driver for effective climate risk reduction. Therefore, this Chapter seeks to explore and analyze these three distinct types of innovation in the realm of climate risk reduction.

Innovation as a *product*

Innovation as a *product* in the context of climate risk reduction encompasses the development and implementation of new technologies, tools, and physical solutions that enhance resilience to climate risks. This includes, for example, the creation of advanced early warning systems, incorporating hardware of GIS and remote sensing or new communication technologies. The goal is to create products that mitigate the impact of disasters and enhance the ability of communities to prepare for, respond to, and recover from climatic disasters.

For instance, SNS plays a crucial role in disseminating disaster information through various communication channels such as TV, radio, mobile phone, Facebook, Twitter, Flickr, and others. The SNSs facilitate quick response, continuously update situations, reduce panic, and prevent misinformation during any emergency (Borthwick, 2020). For instance, the wide use of SNS in the 2013 Calgary flood was evident by the Calgary Police Services (CPS). They used Facebook, Twitter, and Flickr to disseminate flood information, evacuation routes, and emergency shelter locations to protect local communities (Borthwick, 2020). Evidence from previous disasters depicts that local communities often rely heavily on various SNS platforms to obtain updates during emergencies.

Innovation as an *approach*

Innovation as an *approach* refers to exchanging information and integrating local and indigenous knowledge to develop and implement local plans and strategies, which is essential for addressing underlying challenges in building and strengthening resilience against climatic disasters (Izumi et al., 2019a). This may include adopting more community-centred approaches, incorporating traditional knowledge, and embracing holistic and interdisciplinary methods. The aim is to find more effective and sustainable ways to reduce vulnerabilities and enhance resilience at individual, community, and societal levels.

During the last few decades, there has been remarkable advancement in managing extreme climatic events due to an exponential increase in knowledge sharing and information on climate risk and learning from previous disasters. Innovative approaches generally focus on promoting a "culture of prevention" that can create a safety net for vulnerable communities (Habiba & Shaw, 2012). For example, the Caribbean sub-region has successfully implemented the Community-Based Disaster Risk Management (CBDRM) approach. The region is highly exposed to various climatic disasters, such as hurricanes, floods, and landslides. The local stakeholders identify and minimize vulnerabilities through hazard identification and foster local ownership, promoting local and indigenous knowledge that enhances local capacities in building community resilience. They emphasize disseminating effective early warning systems, awareness-raising, livelihood support, and enhancing the capacity to develop disaster mitigation in local communities (Habiba & Shaw, 2012). The sub-region also initiated the Caribbean Natural Resources Institute (CANARI) project focusing on "climate-proofing" (i.e., agriculture, fisheries, forestry, and tourism), aiming at mainstreaming climate resilience and sustainable livelihoods for vulnerable communities (Meira & Bello, 2020).

Innovation as an *Institution*

To reduce climate risk in the contemporary complex world, innovation incorporates various components to enhance risk reduction governance in its institutional and collaborative approach at the local and national levels. This dimension focuses on the development of organizational structures, policies, and governance mechanisms that facilitate effective climate risk reduction (Grønning, 2008). Innovations in institutions may involve the creation of collaborative networks, the establishment of regulatory frameworks, and the integration of DRR considerations into various levels of governance. It also includes the development of financial instruments to better cope with and recover from climatic hazards. In this regard, Scott (1995) defined institutions as *"cognitive, normative, and regulative structures and activities that provide stability and meaning to social behaviour. Institutions are transported by various carriers —cultures, structures, and routines—and they operate at multiple levels of jurisdiction"* (p. 33). Scott's position encompasses perceptual, moral, and legislative structures and practices simultaneously.

However, March and Olsen's concept of institutions is broader, and to them, "[a]*n institution is an enduring collection of rules and organized practices, embedded in structures of meaning and resources that are relatively invariant in the face of turnover of individuals and changing external circumstances*" (March & Olsen, 2008, p. 3). In climatic disasters, innovation as an institution provides more comprehensive and relevant policies and plans to reduce the impacts of extreme climatic events.

2.2.2 Climate Change Adaptation and Technology

Adaptation to climate change is a critical response strategy aimed at minimizing the adverse impacts of global climate change on ecosystems, economies, and societies (Currie-Alder et al., 2021; McKinley et al., 2021). IPCC defined climate change adaptation as "*the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*" (International Strategy for Disaster Reduction [ISDR], 2008, p. 7). It is viewed as a multifaceted approach that encompasses a wide range of actions, from implementing resilient infrastructure and sustainable crop production to enhancing water resource management and promoting biodiversity conservation (Chrobak, 2020; Abbass et al., 2022). Climate change adaptation acknowledges the inevitability of climate-related challenges and focuses on preparing communities and ecosystems to withstand and recover from the impacts, ensuring a more sustainable and resilient future for all. Concerning climate variability, adaptation to climate risk aims to ensure the survival and development of the ecosystem (Brundiers & Eakin, 2018; Shaw, 2020).

In human efforts to adapt to climate change impacts as well as in building the adaptive capacity of the social-ecological systems, technology plays a critical role. In this regard, UNFCCC (2014) defines adaptation technology as *"the application of technology in order to reduce the vulnerability, or enhance the resilience, of a natural or human system to the impacts of climate change"* (p. 2). According to the Organisation for Economic Co-operation and Development (2021), technology is among the trio of factors that facilitate action on enhancing climate resilience. Adoption of adaptation technologies is a complicated process that involves integrating multiple stakeholders and actors at different levels. It also requires consideration of social, economic, and political aspects that help to link numerous factors, such as capacity development, transfer of technologies, and knowledge sharing to mitigate disaster risk reduction (Hu et al., 2018; Shaw, 2020).

Technological approaches to adaptation include both Equipment-Oriented Technologies (EOT) and Behavioral Aspects of Technologies (BAT). EOT refers to capital goods, the use of physical structures, and engineering solutions to protect against climatic hazards (Huq et al., 2013; Schulenburg et al., 2017). These technologies are often tangible and visible, designed to withstand or redirect the impact of climatic disasters. Conversely, BAT encompasses non-structural, nature-based, capacity and knowledge development, policy, and strategy enhancement that work in harmony with natural systems. These strategies often focus on building adaptive capacity, promoting sustainable practices, and enhancing community resilience (Levina & Tirpak, 2006; Huq et al., 2013; Schulenburg et al., 2017). The promotion of adaptation technology to climate change is a continual process that requires technological development and knowledge development to ensure its effectiveness at all levels (Nelson, 2011; Intergovernmental Panel on Climate Change [IPCC], 2012).

In adaptation technologies, EOT and BAT work simultaneously to reduce adverse climatic impacts through various approaches and technologies with multifaceted understandings (Schulenburg et al., 2017). It is essential to acknowledge that adaptation technologies need not necessarily be new or newly developed; rather, existing technologies can be refreshed and developed for use in the adaptation process. For example, technologies including rainwater harvesting and crop diversification based on seasons to deal with extreme weather conditions are centuries-long-standing traditions used globally. In the local communities of coastal Bangladesh, as Huq et al. (2013) also observed, adaptation technologies are being adopted as a crucial strategy to minimize vulnerability and strengthen community resilience to climate change-related stresses and shocks (see Table 2.1).

Table 2.1: Identified Equipment-Oriented Technologies (EOT) and Behavioral Aspects of Technologies (BAT) in the study *Unions*. (Adopted and modified from Huq et al., 2013)

Sector	Equipment-Oriented Technologies (EOT)	Behavioral Aspects of Technologies (BAT)
Agriculture	Genetically modified crop varieties (saline-tolerant such as *BRRI*-52, 47, 67, and 72, *BINA*-10; flood-tolerant such as *BRRI*-55, 68, 73, and 87; and other climate stress-tolerant such as *BRII*-27, and 10).	Hydroponic and aquaponic agricultural practices; dyke cropping; vermi and organic composting; knowledge and practice of vertical towering; mulching methods; agricultural practices using gunny bags, concrete pots, or cork boxes; integrated farm management (IFM); and crop diversification based on seasons.
Water Resources (Drinking and Irrigation)	Reverse osmosis (RO), Pond sand filters (PSF), Deep and Shallow tube wells	Knowledge and practice of rainwater harvesting (RWH), Drip irrigation, and Freshwater mini pond
Infrastructures	Multipurpose cyclone shelters, Sea walls, Block embankments, Sluice gates, Polders, Culverts, Geobags, Geosynthetics	Dissemination of early warning information

Source: Field data, 2023.

In climate-related challenges, innovations, and adaptation technologies have emerged as powerful tools in enhancing resilience. The importance of these tools and measures cannot be overstated, as they empower communities to prepare for, respond to, and mitigate the risks posed by climate change. They offer comprehensive and multifaceted approaches and technologies for building resilience.

Community resilience is deeply embedded in society, helping in risk reduction and recovery from extreme climatic events. It is defined as coping and adapting to stresses caused by climatic hazards and utilizing community resources to reduce the negative impacts as well as enhancing resilience at all levels (Adger et al., 2005; also see Magis, 2010). Uddin et al. (2020) define community resilience as

> *the ability of a socio-spatial entity to cope with and adapt to stresses caused by local and wider societal-level social, political, and environmental change, and to engage community*

*resources to overcome adversity and take advantage of opportunities in response to such changes (*p. 2).

Resilience thus relies on the communities' capacity to react to and adapt to the ongoing transformation (Magis, 2010). As a potential measure to mitigate climate threats, strengthening community resilience through implementing various innovations and technologies is becoming more widely acknowledged (IPCC, 2022).

2.3 Methods

2.3.1 Study Area

The study was conducted in two selected *Unions*—Padmapukur and Dakshin Sreepur, of the Shyamnagar and Kaliganj Upazilas, respectively from December 2022 to February 2023 (see Figure 2.1). These *Unions* were selected considering the degree of climate disaster vulnerability and recent experiences, socioeconomic base, geographical location relative to the rivers and the Bay of Bengal shoreline, and composition and size of the population. This region is one of the most vulnerable areas in coastal Bangladesh where different climate-induced disasters such as cyclones, storm surges, erosion, sea level rise, and sanity intrusion are common (Subhani & Ahmad, 2019). For example, during the 2009 Cyclone Aila, approximately 48,457 households were severely damaged and around 36,000 people were displaced (Subhani & Ahmad, 2019). Furthermore, Cyclone Aila caused extensive destruction to croplands, damaging 168 hectares of crops with an estimated value of BDT 2.4 million and resulting in livestock losses of BDT 2.1 million (Kumar et al., 2010; Subhani & Ahmad, 2019; Parvin et al., 2022).

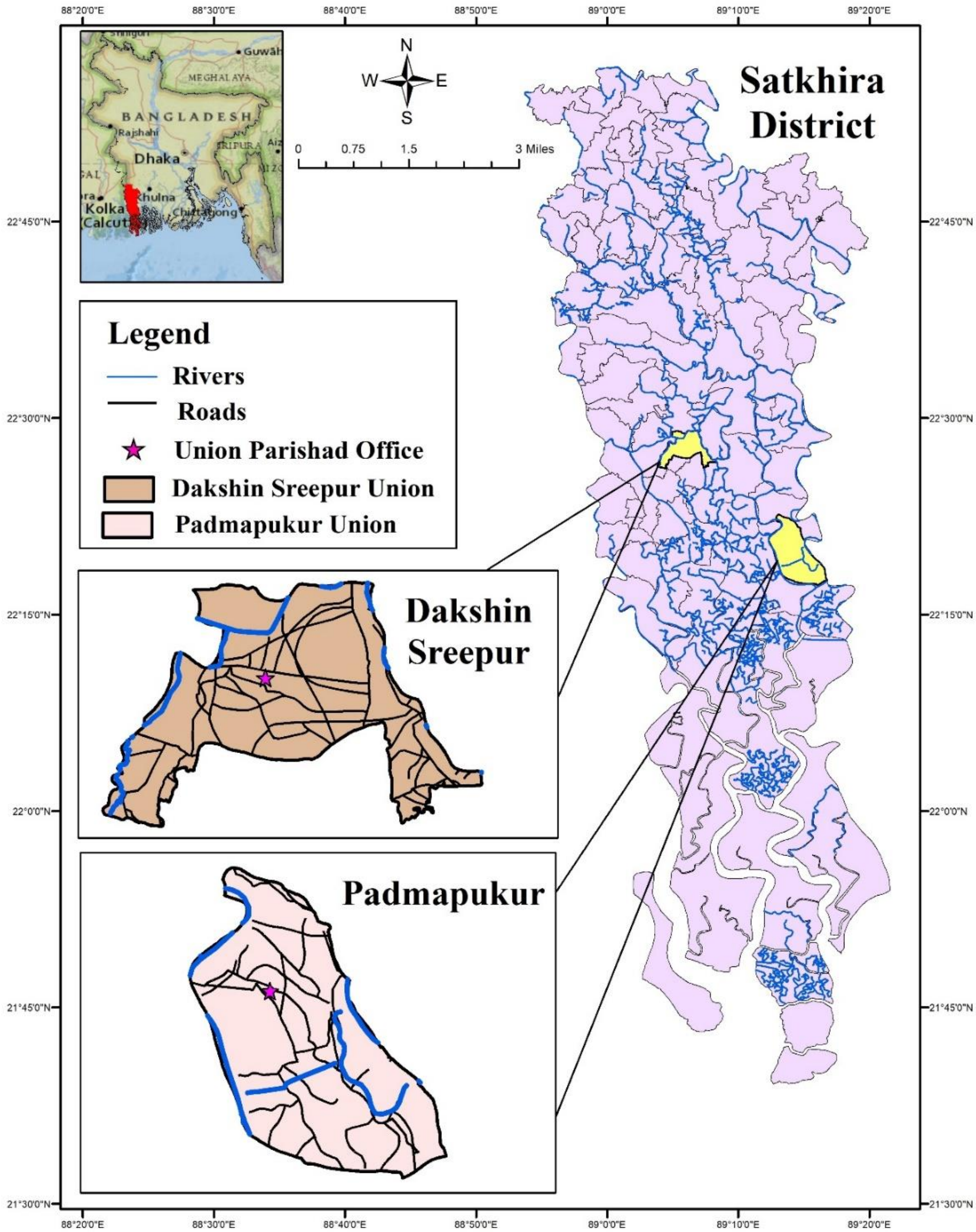

Figure 2.1: Study area map

2.3.2 Data Collection Procedures

In achieving the research objectives, I adopted a mixed-method approach. Data for this study were collected from both primary and secondary sources. The primary data were collected between December 2022 and February 2023 (see Table 2.2).

Table 2.2: Sample size of the study

Tool/Instrument	Sample Size	Participants
Household Survey	300	Household head
Key Informant Interview (KII)	25	Community people (6) Union Project Implementation Officer (PIO), Disaster Management (1) Cyclone Preparedness Program officials (CPP) and volunteers (2) Union Disaster Management Committee (UDMC) (2) local NGOs (3) Microfinancing Institutions (MFI) (8) Local Government Engineering Department (LGED) (1) Bangladesh Water Development Board (BWDB) (2)
Focus Group Discussion (FGD)	4	Disaster-affected community (2) Credit borrowers from MFIs (1) Mixed occupational group including farmers, community people, reverse osmosis committee (RO) and fishermen (1)

The household survey using *a simple random* sampling technique with a set of semi-structured questionnaires was followed. A total of 300 households were surveyed, of which 150 households were from Padmapukur *Union* and 150 households were from Dakhin Sreepur *Union*. For household surveys, face-to-face interviews were conducted with household heads representing their respective units. For focus group discussions (FGD) and key informant interviews (KII), a '*snowball'* sampling procedure was used. A total of 25 KII were conducted and each KII lasted for 30–40 minutes with a set of guided questions for the participants. To capture valuable insights into innovation and adaptation technology processes and outcomes, I conducted a total of 4 FGDs in both study areas. The focus group consisted of 6–8 participants including males and females. The duration of each FGD was 60–90 minutes. The primary data collection procedures adhered to the human ethics protocol and guidelines of the University of Manitoba and written consent was obtained from all participants.

The secondary data were collected from various sources such as archival research, studies, reports, and document reviews. These sources specifically focused on the topic of innovation, adaptation technology, and community resilience to climate-induced disasters in coastal Bangladesh.

2.3.3 Data Processing and Analysis

To analyze and synthesize the data, based on the key objectives and context of the study, I used the Explanatory Sequential analysis as a systematic and rigorous approach (Creswell, 2009). Explanatory Sequential analysis utilizes a diverse set of analytical methods to derive results from both qualitative and quantitative data, aiding in both contextualizing the findings and recognizing recurring themes within the context of the study (Ivankova et al., 2006). It serves as a descriptive representation of both qualitative and quantitative data (Creswell, 2009).

2.3.4 Adaptation Weight Ranking

The adaptation criteria were assessed using a rating scale consisting of three levels: “Low”, “Medium”, and “High”. This scale was used to rank the current adaptation technology in place by using the Common Vulnerability Scoring System (CVSS), version 3 (Barua & Rahman, 2018). The numerical formula for scoring ranges from 0–5. The severity ratings for the textual descriptions were categorized as follows: None (0), Low (0.1–2), Medium (2.1–4), and High (4.1–5). Community people in the study areas were consulted to gather their preferences and assigned scores regarding the adoption of various innovation and adaptation technologies implemented by government and non-governmental institutions, non-governmental organizations (NGOs), international non-governmental organizations (INGOs), community-based organizations (CBOs), and local groups. A total of 300 respondents participated in this process, sharing their perceptions.

2.4 The Coastal Bangladesh Context

The southwestern coastal region of Bangladesh is highly vulnerable to a range of climatic disasters due to its geomorphological conditions and the impacts of climate change (Whitehead et al., 2015; Rezaie et al., 2019). The region is situated in a low-lying delta close to the Bay of Bengal with a population of about 2 million (Rezaie et al., 2019). This area is prone to frequent cyclones, storm surges, flooding, and sea-level rise, making it one of the most disaster-prone regions in the world. The intricate river network of the delta, vital for sustaining the livelihoods of millions, also amplifies vulnerability to severe storm surges (Shampa et al., 2023). Additionally, the region's high population density, combined with socio-economic disparities, inadequate infrastructure, and limited access to resources further intensifies its vulnerability. According to scientific projections, the expected sea level rise by the end of the 21st century will vary between 0.5 and 0.9 meters across 37 coastal areas in the Bay of Bengal (Rahman et al., 2019; Ashrafuzzaman et al., 2022). In comparison, the projected global sea level rise will span from 0.09 to 0.9 meters (Sovacool et al., 2017). The World Bank's 2018 assessment suggests that between 1.5 and 1.6 million individuals will experience the impact of a one-meter sea level rise by the end of 2050, leading to permanent displacement of approximately 13 million people in the coastal zone (Ashrafuzzaman et al., 2022).

During the 1970–2020 period, a total of 11 major cyclonic disasters impacted the southwestern coastal region (see Table 2.3). Notably, Cyclone Sidr 2007 and Cyclone Aila 2009 left the most devastating mark on the Satkhira region. The heightened intensity of these cyclonic events could elevate the potential risks faced by the local communities in terms of both their lives and their livelihoods (Rabbani et al., 2021).

Table 2.3: List of major cyclones and storm surges with their impacts in coastal Bangladesh.

Year	Cyclonic Disaster	Death trolls	Impact on croplands	Livestock deaths
1970	Cyclone *Bhola*	300,000	US$63 million	280,000
1973	Cyclone and Tropical storm	600	US$14 million	25,350
1985	*Urir Char* Cyclone	11,069	132,860 acres	104,700
1986	Cyclone	14	240,186 acres	No data found
1988	Cyclone *04B* and Tropical storm	5,708	US$85 million	65,000
1991	*Bangladesh* Cyclone	138,958	74,000 acres	900,000
1998	Cyclone and Tropical storm	155	8,180 acres	No data found
2007	Cyclone *Sidr* and Tropical storm	3243	742,826 acres fully and 1,730,507 acres partially	532,000
2009	Cyclone *Aila* and Tropical storm	190	77,486 acres fully and 245,968 acres partially	58,450
2019	Cyclone *Bulbul*	20	494,200 acres	1,135,393
2020	Cyclone *Amphan*	31	368,187 acres	41,782

Source: Compiled from (UNDHA, 1985; Dove & Khan, 1995; Karim & Mimura, 2008; Islam & Peterson, 2009; Kabir et al., 2016; Afroz et al., 2018; Rabbani et al., 2021).

In the past few decades, there have been significant transformations in the discourse of disaster management approach, and the changes have had a profound impact, particularly in the coastal communities of Bangladesh. These shifts have proven effective in reducing the number of human casualties and livelihood impacts in the face of disasters. Prior to 2000, the disaster management approach primarily focused on post-event response such as relief and rehabilitation activities (Mallick et al., 2005; Haque & Uddin, 2013). However, starting in the early 2000s, the discourse shifted towards pre-disaster activities, leading to the implementation of mitigation measures aimed at strengthening community resilience and fostering partnerships at local and national levels (Haque & Uddin, 2013; Quader et al., 2023). The rationale behind such transition stemmed from the notion that if individuals and communities are adequately prepared for ongoing disasters, they can mitigate their consequences, ultimately resulting in decreased demand for relief and recovery efforts.

A significant decline in the death rate was registered between the 1991 Bangladesh Cyclone and the 2007 Cyclone Sidr in Bangladesh, revealing a remarkable achievement in the field of disaster management and resilience (Haque et al., 2012). Paul's (2009) study highlights the substantial progress made in reducing casualties during climatic disasters in the last two decades in this region. These achievements are primarily attributed to improved early warning systems, the construction of more resilient multipurpose cyclone shelters, enhanced risk communication and awareness programs, well-organized evacuation plans, coastal embankment projects, restoration of coastal forest vegetation, and more efficient coordination of disaster response and mitigation efforts at the local levels (Paul, 2009; Haque & Uddin, 2013).

The transformative impact of disaster management discourse not only highlights the resilience and adaptability of communities but also serves as a model for disaster-prone regions worldwide. While challenges persist, such as long-term sustainability and ongoing adaptation to climate change, the reduction in the death rate is a testament to the efficacy of proactive measures and underscores the importance of continued innovation and investment in disaster risk reduction (Mallick et al., 2005).

In Bangladesh, innovation and adaptation technologies to adapt to, cope with, and mitigate climate risk have become increasingly evident in recent years due to the country's susceptibility to adverse impacts of climate change, and its associated effects on the lives and livelihood of coastal communities (Chowdhooree, 2019; Choudhury et al., 2021; IPCC, 2022). The coastal communities collaborate, pooling their knowledge and resources to adapt to the changing conditions and coping mechanisms by integrating traditional and scientific knowledge with social capital (Haque et al., 2022).

There have been significant efforts to develop and implement innovative solutions to address the challenges of climate change, including dissemination of early warning information through the Cyclone Preparedness Programme (CPP) (which minimizes disaster-related casualties by enabling timely evacuations and preparedness); providing microcredit through MFIs; and promoting technologies such as climate-resilient agriculture (e.g., drought and flood-resistant crop varieties), sustainable farming practices, rainwater harvesting systems (RWHS), reverse osmosis (RO), multipurpose cyclone shelters (MPCS), and embankment projects (Huq et al., 2013; Nasreen et al., 2014; Hussain & Saha, 2019; Ahsan et al., 2020; Ghosh & Ahmed, 2022; Nasreen et al., 2023).

All these approaches and solutions not only mitigate climate risks but also empower communities to adapt and thrive to climate challenges, strengthening community resilience among the coastal population. However, the existing literature on innovations and adaptation technologies in Bangladesh is predominantly discipline-oriented, focusing largely on agriculture and water-related technologies. Moreover, the interplay between innovation and adaptation technologies and the enhancement of community adaptive capacity remains understudied.

2.5 Findings and Analysis

2.5.1 Innovation

A wide range of innovations have been implemented and adopted in coastal Bangladesh since independence in 1971. Based on the existing literature and scientific analysis, we divided our findings on innovation into 3 groups: product, approach, and institutions. The distribution of the community people's knowledge and uses of specific innovations that significantly mitigate climate risk, enhance sustainable development, and facilitate social fabric in the study *Unions* are shown in Table 2.4.

Table 2.4: Distribution of knowledge and uses of various innovations to mitigate climate-induced disaster impacts by the community people of the study area (n=300).

Innovation	**Respondents who adopted innovations**	
	Dakhin Sreepur Union (%)	**Padmapukur Union** (%)
Product		
Early Warning System (EWS) related equipment	89	98
Approach		
Community-Based Disaster Risk Management (CBDRM)	71	96
Use of local knowledge for Hazard Mapping	43	78
Institutions		
Cyclone Preparedness Program (CPP)	81	100
Microfinancing Institutions (MFIs)	71	92

Source: Field data, 2023.

2.5.1.1 Innovation as a *Product*

In the context of coastal Bangladesh, Early Warning Systems (EWS) can be considered as an innovation in the category of "*product*" that has been saving millions of lives, the natural environment, and infrastructure by reducing the impacts of climate-induced disasters. EWS is considered a critical source of information for the local coastal communities that allows vulnerable people to establish preparedness plans and strategies to reduce fatalities and livelihood risks.

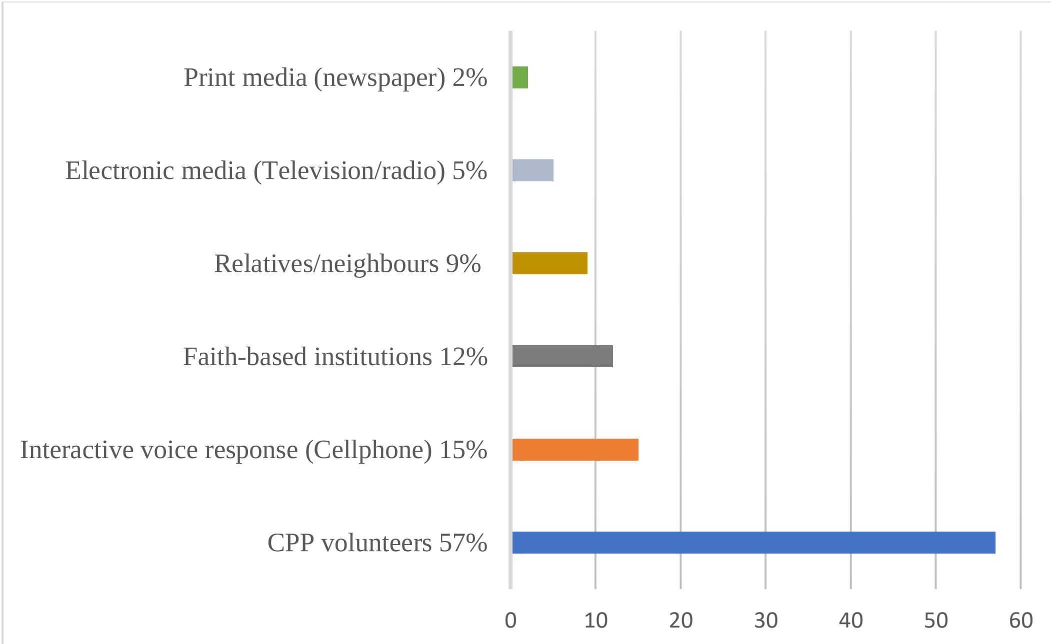

Figure 2.2: Sources of early warning signal.
Source: Field data, 2023.

As can be seen in Figure 2.2, most people in the coastal regions receive early warning information from the Cyclone Preparedness Programme (CPP) volunteers (57%) before the onset of any climatic disaster. In coastal Bangladesh, it has been proven that CPP has been pivotal in disaster risk reduction. With the new initiatives of CPP, the overall process of forecasting and dissemination of warning information among the local communities takes about 8 minutes. Locally, institutions disseminate warning information through sirens, megaphones, and upholding red flags to mobilize the communities. The findings identified that CPP has more than 4,980 volunteers at the Upazila level, and most of these volunteers get activated immediately before any disaster strikes.

A local fisherman explained that:

During Cyclone Bulbul in 2020, I was in the Sundarbans Forest collecting honey. However, as the wind pressure escalated rapidly, we became acutely aware that a severe disaster was imminent. Immediately at that critical juncture, we turned on the radio and received cyclone signal information to get back to the shore as early as possible.

The survey data also illustrates the presence of multiple mechanisms for early warning services (EWS). Interactive Voice Response (IVR) accounts for 15% of the system and is accessible through any phone operator by dialing '10941' (also see Ahsan et al., 2020). Faith-based institutions contributed 12%, while 9% of early warning information is received from relatives and neighbors. Consequently, these sources ensure the proper circulation of risk communication from authorities to at-risk communities. Our findings also reaffirm that 82% of the vulnerable population relocates to safer places, primarily cyclone shelters, in response to these EWS.

The incorporation of Geographic Information Systems (GIS) and remote sensing (RS) are computer-based model systems used to map and analyze potential hazards. They incorporate real-time location-based information and provide data to analyze vulnerabilities, population characteristics, and the ecosystem for predicting future consequences and planning strategies (Izumi et al., 2019b).

Relying upon the empirical evidence from the disaster-affected areas, GIS and RS are used widely to create cyclone and flood hazard maps and vulnerability assessments to minimize any major disaster impacts (Habiba & Shaw, 2012). In this regard, the Space Research and Remote Sensing Organization (SPARSO) and Centre for Environmental and Geographical Information Services (CEGIS) have been playing a pioneering role in GIS and RS over the past few decades. The Local Government Engineering Department (LGED) provides critical technical support with the spatial database for protecting rural infrastructures and optimizing institutional capacities for planning and oversight of pre and post-disaster mitigation strategies to protect humans and resources at risk. These institutions primarily use LANSAT, SPOT, SAR, and airborne radar data to generate GIS maps and databases.

At the local level in the study area, entities like *Union* Parishad, the Local Government Engineering Department (LGED), and the Bangladesh Water Development Board (BWDB) receive comprehensive GIS and RS databases from the central office in Dhaka. These databases serve as invaluable resources for local authorities in their ongoing efforts to address the persistent and imminent threats of cyclones, sea-level rise, and flooding. GIS, as a powerful tool, facilitates the precise mapping of vulnerable areas, allowing for the identification of high-risk zones and densely populated centers at risk. The integration of remote sensing data, including satellite imagery, equips local authorities to continuously monitor alterations in land use, shoreline erosion, and environmental conditions. This, in turn, aids in the development of early warning systems, disaster management plans, and damage assessment plans for the vulnerable population. These technologies thus empower local stakeholders in Bangladesh to mitigate the impact of climatic disasters and protect their communities. In explaining the process, A local LGED Engineer stated that:

> *We receive GIS and RS data from the head office in Dhaka as there is no provision to access the main data server directly at the local level. All these data prove instrumental in optimizing resource allocation, thereby streamlining the efficient deployment of search and rescue operations, relief efforts, and the construction of infrastructure designed to withstand extreme climatic events in this area.*

2.5.1.2 Innovation as an *Approach*

The community-based disaster risk management (CBDRM) approach is an excellent example of innovation as an *approach*. It involves the analysis of risks and the implementation of disaster risk management strategies, which are both initiated and coordinated by local communities (Azad et al., 2019). The CBDRM approach is widely adopted in coastal Bangladesh to mitigate climate risk. It primarily focuses on a people-centered and bottom-up approach allowing local communities' to participate and the involvement of multi-sectoral stakeholders, from the planning to the monitoring phase. This is because the community stakeholders understand the underlying challenges and resource constraints at the local level due to climate change. Local people are considered an integral part of the decision-making and implementation process for mitigating risk. Communities' preparedness and capacity development are always essential, and each community has its unique resources for dealing with disaster events. These include local and indigenous knowledge, understanding of warning signals, knowledge of vulnerable locations and shelter places, the experience of previous events, survival strategies, and social connections (also see Kafle & Murshed, 2006).

Empirical analysis from this study reveals that, over the past two decades, the southwestern region of Bangladesh has, at least partially, been successful in implementing the CBDRM approach. The local CBDRM works closely in collaboration with the *Union Parishad* Disaster Management Committee (UMDC) and Ward Disaster Management Committee (WMDC) to ensure the active participation of all stakeholders involved. In both the *Unions* of the study area, we found that the CBDRM committee has 8-10 members from the local community including vulnerable groups and stakeholders from both government and NGOs. They organize training workshops biannually on various topics such as vulnerability identification and assessment, dissemination of early warning signals, preparedness mechanisms, and first aid—with the support of local NGOs like Friendship, Rupantar, Gonomokhi, Karitash, World Vision, and GOs including *Union* Parishad Office, CPP, PIO (Project Implementation Office) Disaster Management. The primary goal of these training programs is to mainstream climate resilience and sustainable livelihoods for the vulnerable community.

The CBDRM approach provides vital help in developing hazard maps that effectively reduce future risks. As the study area is highly vulnerable to climate extreme events, this approach functions as a foundation for developing relevant risk reduction policies and mitigation strategies (Izumi et al., 2019b). For the hazard-risk map, the group involves 10-12 members from the community and representatives from WMDC, UMDC, UP, PIO, and CPP volunteers. The hazard-risk map is developed after every major disaster or in every 5 years. In 2017, a group of experts including the *Union* chairman, members from disaster management committees, members from the *Union Parishad*, PIO, and CPP volunteers developed a hazard map for Padmapukur *Union*, Shyamnagar (see Figure 2.3). It was identified that the area is extremely vulnerable to climate-induced disasters and that the fish farming could be destroyed fully (based on the previous disaster record; cyclone Aila 2009), and various infrastructures (i.e., roads, culverts, embankments, polders, and sluice gates) making up to 70-85% surrounding the area. The exercise also reported that approximately 66.5% of the infrastructure is at "high" risk of future climatic events including cyclones, storm surges, and flooding. Community members access hazard information through hazard mapping, allowing better preparedness and evacuation during any disaster.

Through hazard mapping, the local stakeholders and actors had a detailed understanding of the level of exposure, which allowed them to incorporate numerous management strategies, such as: embankment strengthening projects; sluice gates; protecting critical assets; planting saline-resistant and green belt trees [such as sundari (*Heritiera fomes*), keroa (*Sonneratia apetala*), coconut (*Cocos nucifera*), sisu (*Acacia nilotica*), Keroa Babla (*Pithocello biumdulce),* Hijal (*Barringtoniaacutangula),* Supari (*Areca catechu),* Tetul (*Tamarindus indica), and* Silkoroi (*AlbiziaproceraBenth)*]; identifying safe and unsafe areas; effective land use planning; developing shelter places; and undertaking remedial measures such as public awareness and introducing flood warning signs (Barua & Rahman, 2018).

Figure 2.3: Hazard map (2018-2025) for Padmapukur *Union*, Shyamnagar.
Source: *Union* Parishad, Padmapukur 2022.

A community member explained that:

From 2016 to 2020, the Bangladesh Forest Department and local NGOs brought approximately 3,500 acres of land under coastal mangrove plantations. They primarily planted species such as sundari (Heritiera fomes), keroa (Sonneratia apetala), coconut (Cocos nucifera), sisu (Acacia nilotica), and Keroa Babla (Pithocello biumdulce), as these species have an average success rate of 71–78%.

Further, the local government initiated multiple projects for farmers that included distributing free seeds, pesticides, and fertilizers; providing accessible credit facilities from government banks; and offering technical expertise to develop and cultivate crops mostly in water, like floating farming.

2.5.1.3 Innovation as an *Institution*

To reduce climate risk, innovation incorporates various components to improve risk reduction governance in its institutional and collaborative approach at the local and national levels. In climatic disasters, innovation as an *institution* provides more comprehensive and relevant plans and approaches to mitigate the impacts.

In the context of coastal Bangladesh, the Cyclone Preparedness Programme (CPP) has been playing a key role in disaster risk reduction and building resilience. With the help of the Government of Bangladesh (GoB) and the Bangladesh Red Crescent Society (BRCS), it started its operation in 1973, establishing a partnership program management system through the formation of a policy committee and an implementation board (Habib et al., 2012). CPP operates its activities at the grassroots levels, including wards, unions, and Upazilas, with the help of more than 76,000 community volunteers (Singh, 2010; Haque et al., 2022). In Bangladesh's coastal regions, community volunteerism under the CPP umbrella has emerged and evolved as a major innovation in DRR (Lejano et al., 2022). The program aims to disseminate cyclone warning signals to vulnerable communities and assist in the evacuation process. They collaborate with multi-sectoral stakeholders, collecting meteorological information from the Bangladesh Meteorological Department (BMD) and then disseminating those warnings to the local levels.

A local CPP volunteer reported that:

> *For the past 15 years, I have dedicated my efforts to working with CPP (Community Preparedness Program). Our mission involves aiding vulnerable communities during all stages of disasters, including the pre-disaster, during, and post-disaster phases. Upon receiving disaster alerts from the Upazilla CPP office, we promptly initiate our activities. This entails disseminating warning signal information to the local population in their native dialect, employing megaphones and hand sirens, evacuating vulnerable people, and relocating them to cyclone shelters.*

Results from the field data revealed that CPP is the main source of early warning systems for the community people. According to the survey, 93% of the community members reported that they can easily comprehend the CPP broadcast signals. The cyclone signals are categorized from 1 to 10 based on their area and wind speed (Mohanty et al., 2022). To simplify the understanding, these 10 signals have been condensed into a 3-flag system (see Figure 2.4).

In signals 1–4, the indication is that a storm has formed with the possibility of transforming into a cyclone. During this period, one flag is hoisted to raise awareness. Signals 5–7 signify the development of a cyclone that may reach this location. In such situations, two flags are hoisted, and warning signals are disseminated using megaphones and loudspeakers. Signals 8–10 are considered the most severe and indicate a devasting cyclone has already formed and is anticipated to make landfall in this area. In such circumstances, an emergency is declared with three flags hoisted and warning messages are disseminated using megaphones and loudspeakers, sirens, and hand mikes by the local CPP volunteers. Furthermore, in this critical situation, communities are often relocated to cyclone shelters for their protection.

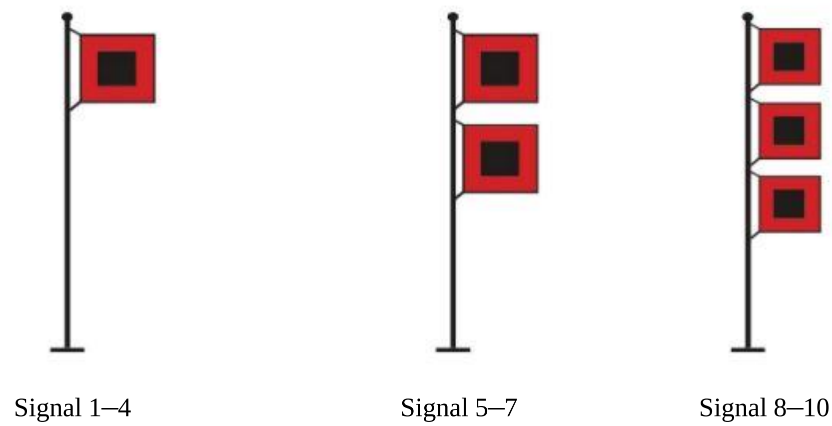

Figure 2.4: CPP warning signal flags (Mohanty et al., 2022)

However, it has been observed that 7% of the population is either unfamiliar with or lacks orientation with this signaling system. Both study *Unions* have CPP committees with 20 volunteers in each Ward having an equal ratio of male and female volunteers. They collaboratively work with the Ward Disaster Management Committee (WDMC), and *Union* Parishad Disaster Management Committee (UDMC) along with the *Union Parishad* Office (UPO). As stated earlier, the primary responsibilities of the CPP volunteers include disseminating warning information and addressing people with megaphones, loudspeakers, sirens, and hand mikes. Additionally, they are also actively involved in transferring vulnerable populations to cyclone shelters, search, and rescue operations, first aid, assisting in relief and rehabilitation, and strengthening community capacity-building activities. They remain continuously involved in public awareness through cyclone drills, video shows, posters, leaflets, radio broadcasts, and telecasting to the community.

Since the 1980s, the microfinancing sector has been functioning as an innovation as *institution* in both study *Unions*. Microfinance works as a financial service provider to poor communities. Bangladesh's microfinancing institutions (MFIs) work under the central bank of

Bangladesh, namely, Bangladesh Bank as the regulatory authority to serve the poorer and vulnerable communities. Microfinance strategies used to reduce household risks are also pertinent to minimizing disaster vulnerability. It provides financial credit facilities with minimal conditions, which significantly helps the poor to cope with and adapt to any adverse impacts of extreme events and contributes to building social capital. In this regard, ACEDRR (Advanced Centre for Enabling Disaster Risk Reduction) and DHAN Foundation (2011) research suggest that microfinancing works as a potential mechanism in minimizing disaster risk and vulnerabilities through different financial services as well as in enhancing social partnerships in coping and adapting to disaster risks.

The findings in Table 2.5 depict that microfinancing institutions (MFIs) like Grameen Bank, Brac, PKSF, Nawabenki, Shushilan, Satkhira Unnayan Sangstha (SUS), BK Social Safety Net, Sonakhali Bohumukhi Somobay Somity, ASA, and Ektee Bari Ektee Khamar (EBEK) project provide credits to the poor, vulnerable, and disaster-affected communities. The size of credit ranges from BDT 2,000 to 10,000,000 ($18–$9,300) in various terms and conditions. The interest rate varies from 4% to 24%. Depending on the adversity of the disasters, the credit amount may even decrease. About 92% of households reported that they take loans/credit from multiple MFIs. Specifically, females (95%) are always given priority while taking credit from any MFI. The respondents mentioned that the credit had facilitated them to repair and rebuild their houses immediately after any extreme climate events and restore their livelihood and income sources.

During the 2009 Cyclone Aila, Nawabenki Gonomukhi Foundation (Affiliated with Palli Karma Sahayak Foundation) responded immediately by disbursing credit of BDT 7,000 (US $65) to BDT 25,000 ($230) to the affected households without any interest payment (maximum for 18–24 months). Following the 2019 Cyclone Amphan, they also allocated BDT 2.32 crore ($185K) as a "Disaster Management loan" with a 4% interest rate to the cyclone-affected groups. Through this credit facility, approximately 14,500 households were benefited. Besides the credit operations, they donated cash incentives (non-refundable) of BDT 700,000 ($6500) to the affected households with other supports such as creating awareness programs, carrying out emergency operations in repairing and rebuilding houses, agricultural activities, emergency relief items (lentils, rice, soyabean oil, flattened rice, jaggery, torchlights, matches, and drinking water), and livelihood restoration activities including livestock, poultry, and fish farming.

Table 2.5: Loan/credit size of various MFIs placed in the study *Unions* with their interest rate.

Microfinancing institutions (MFIs)	**Loan/Credit Size** (US$1=BDT 108)	**Interest Rate** (%)
BK Social Safety Net	Minimum BDT 10,000 and Maximum BDT 100,000	12–14
Sonakhali Bohumukhi Somobay Somity	Minimum BDT 10,000 and Maximum BDT 100,000	12–14
Nawabenki Gonomukhi Foundation (Affiliated with Palli Karma Sahayak Foundation)	Minimum BDT 2,500 and Maximum BDT 1,000,000	The interest rate varies from 0–24; for the vulnerable community 0 (Max 6 months); for disaster management 4(Max 2–3 years)
Uttaran	Minimum BDT 20,000 and Maximum BDT 25,000	13
Satkhira Unnayan Sangstha (SUS)	Minimum BDT 10,000 and Maximum BDT 1,000,000 (Based on emergency and proper mortgage documents)	12.5
Shushilan	Minimum BDT 10,000 and Maximum BDT 450,000	14.5
Grameen Bank	Minimum BDT 2,000 and Maximum BDT 50,000	20
ASA	Primary loan facility minimum BDT 5,000–99,000; Special loan facility minimum BDT 100,000–1,000,000	22–24
Ektee Bari Ektee Khamar (EBEK) project	Minimum BDT 10,000 and Maximum BDT 30,000	4

Source: Field data, 2023.

Further, the results from the analysis identified that institutions like Uttaran, Satkhira Unnayan Sangstha (SUS), and Shushilan help with microcredit that mostly facilitates the poorer and vulnerable groups in restoring their livelihood activities. Their credit varies from BDT 10,000 to BDT 450,000 ($90–$4170) with an interest rate of 12.5% to 14.5%. Uttaran assisted the cyclone Amphan-affected groups with an emergency loan of BDT 1.25 crore ($115K) with the support of donor agencies like Educo BD, Save the Children, and the EU for repairing and rebuilding damaged houses.

Besides these, a government project Ektee Bari Ektee Khamar (EBEK) has been actively carrying out its operation since 2009. The credit amount for the first term is BDT 10,000 ($90) and the highest is around BDT 30,000 ($280) with an interest rate of 4%. The disaster-affected farmers primarily benefited from this type of credit facility to restore their agricultural activities within a shorter period, allowing them to repay the loan after selling out the crops. The loan repayment period in the microfinancing system is often flexible (i.e., weekly, or monthly), to address imminent risk and economic recovery.

Other MFIs such as ASA, Grameen Bank, Sonakhali Bohumukhi Somobay Somity, and BK Social Safety Net only provide credit services ranging from BDT 2,000 to BDT 100,000 ($19–$925) to disaster-affected households with a rate of interest varying from 12%–24%, depending on necessity and the maximum 60 months of repayment opportunity.

A local credit lender cited that:

> *In Cyclone Bulbul 2020, severe wind pressure damaged the roof of my house. Shortly after this incident, I was fortunate to receive a disaster loan of BDT 50,000 (US $460) from the Nawabenki Foundation, which carried no interest for three years. It significantly helped me to bounce back and undertake the necessary repairs to reconstruct my house.*

Approximately 78% of the survey respondents stated that they have borrowed money from more than one MFI, which often increases the incidence of default rate. The importance of microfinance institutions (MFIs) in acknowledging vulnerability is clear from the fact that a substantial percentage of families have borrowed money to meet various needs, such as repairing damaged assets and restoring their livelihoods and agricultural activities. However, the significance of MFIs is indeed limited in that only a small percentage of households have access to loans immediately after any climatic disaster.

2.5.2 Adaptation Technologies

In the coastal regions of Bangladesh, freshwater availability is limited, and climate change is expected to exacerbate the situation. To address this emerging issue, different means of adaptation technologies are widely used in the study area (see Table 2.6). To adapt to the changing climate in the agricultural sector, the Government of Bangladesh, and other agencies, including NGOs and INGOs, have introduced various climate-resilient crop varieties, benefiting the local farmers. Rice varieties such as *BRRI*-27 and *BRRI*-10 are commonly known for being favorable to climate-related stress.

The data in Table 2.6 illustrates a comprehensive analysis of adaptation technologies and their respective effectiveness, based on the knowledge and perception of the local communities in the study area. These adaptation technologies are categorized into three major groups, each reflecting their capability to address the challenges posed by climate change. In the study area, adaptation technologies combine risk-reduction and mitigation measures to minimize climate-induced disaster impacts, thereby strengthening the resilience of the community (see Table 2.6).

High-efficacy technologies include rainwater harvesting, multipurpose cyclone shelters, sea walls, and interactive voice response-based early warning systems. These solutions demonstrate robust capabilities in ensuring water security, disaster resilience, coastal protection, and effective risk communication in anticipating impending calamities. In the medium efficacy tier, the present study identified a diverse set of adaptation strategies. Climate stress-tolerant crops, hydroponic and aquaponic farming practices, and integrated farm management contribute to food security and resilience in both *Unions*. Hydroponic and aquaponic agricultural practices, dyke cropping, vermi and organic composting, vertical towering, mulching methods, and integrated farm management (IFM) offer resource-efficient techniques for sustainable agricultural practices. Furthermore, reverse osmosis (RO) technology is vital for desalination and water purification in these areas due to higher salinity. Structural adaptation measures include block embankments, sluice gates, polders, culverts, geobags, and geosynthetics. These measures enhance water management and protect against flooding and storm surges.

Conversely, low-efficacy technologies such as pond sand filters and tube wells, have very limited acceptance within local conditions. This classification system aids in understanding the effectiveness and suitability of adaptation technologies across a range of contexts, guiding stakeholders in making informed decisions to address the pressing challenges associated with climate change, as well as strengthening resilience.

Table 2.6: Knowledge and perception of adaptation technologies and weight ranking of their effectiveness among the respondents (n=300) in the study *Unions* (Adopted after Barua & Rahman, 2018).

Adaptation Technologies	**Level of Quality**					**Weightage Analysis**		
	Excellent	Very Good	Good	Fair	Poor	Total Frequency	Weight	Ranking*
Genetically modified crops (saline-tolerant, flood-tolerant, and climate stress-tolerant)	75	129	25	67	4	1104	3.68	Medium
Hydroponic and aquaponic agricultural practices; dyke cropping; vermi and organic composting; knowledge and practice of vertical towering; mulching methods; agricultural practices using gunny bags, concrete pots, or cork boxes; integrated farm management (IFM)	61	93	77	30	39	1007	3.35	Medium
Reverse Osmosis (RO)	104	111	67	18	0	1090	3.63	Medium
Pond Sand Filters (PSF)	0	0	19	92	189	430	1.43	Low
Deep Tube wells, and Shallow Tube wells	8	15	28	31	218	464	1.54	Low
Rainwater Harvesting (RWH)	165	64	35	19	17	1241	4.13	High
Multipurpose Cyclone Shelters (MPCS)	207	43	29	16	5	1331	4.43	High
Sea walls	155	71	48	8	18	1237	4.12	High
Block embankment	119	77	41	38	25	1127	3.75	Medium
Sluice gates	109	88	49	34	20	1132	3.77	Medium
Polders and Culverts	13	122	68	42	55	896	2.98	Medium
Geobags and Geosynthetics	0	30	97	69	103	652	2.17	Medium
Early warning (Interactive Voice Response)	233	39	26	4	0	1407	4.69	High

Source: Field data, 2023. * Low (0.1 – 2), Medium (2.1 – 4) and High (4.1 – 5)

2.5.2.1 Agricultural Sector

In agriculture, climate-induced disasters are causing severe destruction and damage to crops and croplands. It is estimated that, in coastal Bangladesh, about 30–45% of crops are damaged yearly due to extreme events, and such loss and damage adversely affects the overall economy, food security, and livelihoods (UNFCC, 2006; Shaw et al., 2022, p. 1457-1579). Some existing adaptation technologies are spontaneous in nature, while others are dynamic and flexible (Rabbani, 2010). To adapt to the changing climate, the Bangladesh Rice Research Institute (BRII), Bangladesh Institute of Nuclear Agriculture (BINA), Department of Agricultural Extension (DAE), and other agencies, (including NGOs and INGOs), have introduced and demonstrated various crop varieties and cropping patterns that are climate stress tolerant and cultivated in the coastal zones.

The field data reveals that climate-resilient rice technology like *T Aman* and *BARRI dhan* 33,56,57 and 62, have been introduced to withstand and adapt to changing climate conditions. These varieties exhibit specific traits that are more resilient to environmental stresses such as drought, submergence, saltiness, and heat. These varieties of rice are commonly cultivated in the study area because of their high-yielding capacity and can be tilled mostly in the dry season requiring less water. The cultivation of saline-tolerant rice varieties is also a deliberate adaptation to the persistent salinity stress on agricultural production along the coastline. They provide the highest yield, around 30–40%, with a net marginal profit of 81% higher than other varieties (Bangladesh Centre for Advanced Studies [BCAS], 2010; Rabbani, 2010). It was further found that flood-tolerant rice varieties such as *BRRI-55*, *BRRI*-68, and *BRRI*-73 are widely cultivated in both *Unions* to minimize the adverse impacts of climate change on rice production.

Results of the study also identified that 15 households are actively involved with dyke cropping. Typically, this refers to the agricultural practice of cultivating vegetables seasonally and year-round along the edge/dyke of the fish farming fields (*gher*). The coastal areas, particularly Satkhira region, experience frequent salinity intrusion and therefore exhibit diversification strategies such as shrimp farming and construction of "*gher*" throughout the year. Through dyke cropping, many households practice fish and vegetable cultivation on the same land throughout the year. They cultivate vegetables such as tomato, okra, water gourd, chichinga, korola, pumpkin, green chilli, cucumber, and many other seasonal varieties. Evidence suggests that dyke cultivation is up to 5 times more profitable than the traditional farming method, as it involves no or little cost in land preparation, irrigation, and the use of chemicals (Asian Development Bank [ADB], 2014). We found that the female members of the households are actively involved in the dyke cropping to manage and cultivate fish and vegetables. The household consumes these vegetables and fish to meet their nutritional requirements and generate income by selling the surplus in the local market.

A local farmer on dyke cropping stated that:

> *I have been doing the dyke cropping for the last 2 years. This type of adaptive technology has provided me with the opportunity to meet my family's consumption requirements and generate income. In the previous year, I was engaged in the cultivation of shrimp and various vegetables, including tomatoes, cucumbers, green chilli, and ginger. After fulfilling my family's nutritional needs, I managed to generate a profit of approximately BDT 18,000 by selling these vegetables and shrimp within the local market.*

It has also been observed that farmers and household groups have recognized several other adaptation technologies identified by the Technology Need Assessment (TNA) project of GoB that are applicable in the study area (Nasreen et al., 2023). These technologies and strategies encompass the cultivation of crop varieties that can tolerate salinity, floods, and waterlogging. By cultivating these varieties, farmers can benefit through early crop harvesting before the cyclone and flood seasons. Other adaptation techniques farmers use to support their lives and livelihoods as mitigation to rapid climate-induced disasters include crop diversification through using hydroponic and aquaponic systems, integrated farm management, vertical farming structures, mulching methods, and agricultural practices involving gunny bags, concrete pots, or cork boxes.

Case Study – 1

Hydroponic farming

Due to high exposure to salinity intrusion, a group of 27 female members (referred to as the Popi Group) is presently involved with Hydroponic farming supported by the Center for Natural Resource Studies (CNRS), a local NGO committed to mitigating climate risk in coastal Bangladesh (see Figure 2.5). Hydroponics, known by various appellations such as aquaculture, nutriculture, soilless culture, or tank farming, constitutes a method for cultivating plants in nutrient-enriched water. This cultivation technique can be implemented with or without the use of mechanical support for the plants. This type of farming is quite popular worldwide, with up to 3 times more profitable. It can provide crop yields 30% faster than traditional farming methods as it involves little or no cost in land preparation, irrigation, and chemicals.

Figure 2.5: Hydroponic farming in Shyamnagar

The farm started in January 2022 with the aim of commercial profit and meeting household food nutrition demand. At present, various vegetables are cultivated, such as tomatoes, brinjal, okra, and green pepper. The Popi Group anticipates a year-end harvest of 800 kilograms of vegetables, yielding a profit ranging from BDT 20,000 to BDT 28,000. It is noteworthy that this profit is equitably distributed among all the members of the group.

The Center for Natural Resource Studies (CNRS) plays an instrumental role in facilitating comprehensive training facilities for all the group members on the crop cultivation process in such farming processes. Furthermore, the irrigation process is efficiently managed through the utilization of rainwater harvesting infrastructure and mini-water ponds. This harvested water resource is subsequently distributed to the farming operation via a pumping apparatus, thereby sustaining the growth of the cultivated vegetables. Thus, hydroponic farming is creating employment opportunities in poorer communities that significantly contribute to household income and strengthen community resilience.

2.5.2.2 Water Sector

The worsening freshwater crisis, resulting from climate change and its related adverse impacts, is already evident in coastal areas of Bangladesh, and the situation is expected to deteriorate further in the years ahead. The absence of freshwater aquifers at appropriate depths (200–300m) and the elevated salinity levels (854 mg/I) in surface and groundwater have compelled the vulnerable and marginal communities to adopt technologies such as rainwater harvesting (RWH), reverse osmosis (RO), pond sand filters (PSF), deep tube wells, and shallow tube wells (ADB, 2014; Dasgupta et al., 2015; Mahin et al., 2017).

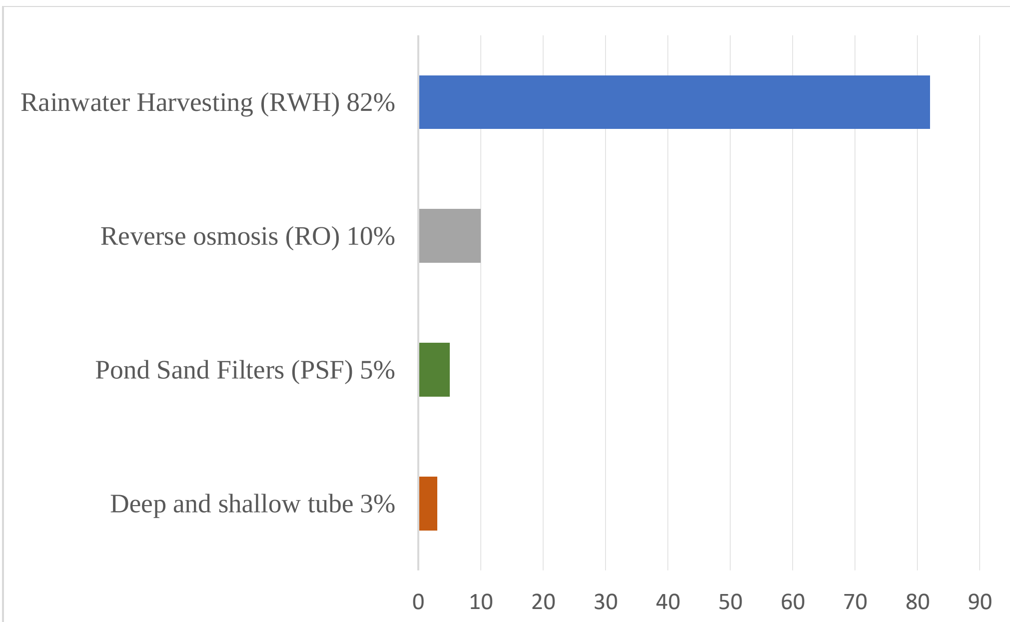

Figure 2.6: Identified water adaptation technologies and communities' adoption rates in both study *Unions*. Source: Field data, 2023.

The findings (see Figure 2.6) underscore that approximately 82% of households have adopted RWH for drinking water and household activities. Among the rest, 10% adopted Reverse Osmosis (RO), 5% adopted Pond Sand Filters (PSF), and 3% adopted deep and shallow tube wells.

For addressing water-related issues, all the above-mentioned technologies were introduced by various stakeholders in Shyamnagar and Kaliganj due to higher salinity in soil and groundwater. Most of these RO plants (7 new and 3 renovated), PSF (6 new and 4 renovated), and RWH systems (about 59.5% of the households use rainwater harvesting systems in the study area) were implemented by local NGOs—including Nawabenki Gonomukhi Foundation, Rupantar, Leaders, World Vision, Satkhira Unnayon Sangstha (SUS), Center for Natural Resource Studies (CNRS), Shushilan, and Friendship—in collaboration with the United Nations Development Programme (UNDP), Department of Public Health and Engineering (DPHE), and other governmental agencies. The field investigation identified that about 60–70% of the total agricultural activities rely heavily on rainwater and 20–25% rely on PSF and shallow tube well water. Currently, they support the communities with sources of pure drinking water, household use, and agricultural activities.

The study found that 96% of RWH drums are located in homestead areas. The size of each RWH drum ranges from 5,000 to 75,000 liters and the setup cost for each RWH varies from BDT 2,000 to BDT 400,000 depending on its size. The rainwater is directly collected from the catchment of the houses using PVC pipes and transported to the RWH drums. Almost all the adopters of such RWH stated that the drums last up to 10 years maximum. Additionally, 99% of PSF and RO are in an open space where the communities have excellent communication systems to transport water.

A local community member elaborated:

I have been residing in this locality since birth, and the underground water here possesses high salinity, rendering it unsuitable for consumption. Historically, we relied on water from the Pond Sand Filtration (PSF) and rainwater collected in household containers for drinking purposes. Nevertheless, during winter or times of natural disasters, procuring and preserving clean potable water proved to be a formidable challenge for us. However, in 2017, a local non-governmental organization (NGO) known as SUS stepped in and provided us with a 10,000-liter Rainwater Harvesting (RWH) drum along with covering the associated setup expenses. Subsequently, my family has been utilizing the RWH system as our primary source of drinking water. This initiative has significantly alleviated our water-related challenges.

On average, the RO plant can withdraw 1,000 liters of underground water per hour. The setting cost of an RO plant is very expensive and ranges from BDT 10,000,000 to BDT 19,000,000 depending on its capacity. In the study *Unions*, it was found that most onRO plants on site withdraw approximately 500 liters of underground water per hour, serving around 300–400 households in the community. Subsequently, households acquire this water at an average cost ranging from BDT 0.25 to BDT 0.50 per unit from on-site sources and if distributed door to door, then the cost increases significantly from BDT 1 to BDT 2 based on the location.

However, a small proportion of community members (8%) still use water from PSF as well as deep and shallow tube wells water, which is unsafe and unhealthy for the human body due to the high proportion of salinity. On average, a PSF house can hold approximately 30,000–50,000 liters of water and can serve 100–150 households. We found that most PSFs are operated by electricity but only 2 of them are powered by solar panels which have a higher establishment cost. The cost per PSF ranges from BDT 350,000 to BDT 500,000 depending on its size and source of power. The water from the deep and shallow tubewells is mostly used for irrigation and household use. However, only a few extremely poor household groups still drink water from these sources because no economic cost is involved in access to it.

Case Study – 2

Women's Empowerment and Water Entrepreneurship

A group of 5 educated rural females is involved in the water entrepreneurship business with the support of a local NGO (*Rupantor*) in Shyamnagar Upazila (see Figure 2.7). In 2020, they established a Reverse Osmosis (RO) water treatment plant, with a total initial investment of BDT 375,000, with Rupantor generously contributing BDT 1,200,000 towards the project. This RO plant withdraws approximately 500 liters of water per hour and serves around 200–350 households, fish farms, and crop fields. The RO plant is operated by using electricity and the submerged pipe extending to a depth of 220 feet. The water is retailed at a rate of BDT 0.50 per liter, with pricing variations occurring when delivered door to door. In 2022, they successfully distributed around 145,000 liters of water to nearby localities and earned a profit of BDT 35,000.

Figure 2.7: RO committee in Shyamnagar

The *Rupantor* has consistently demonstrated its commitment to the sustainability and efficiency of the RO plant venture. They have been conducting workshops and training sessions at regular intervals, with sessions recurring every three months. These training sessions encompass skill development on various RO machinery, optimal operating hours, as well as maintenance and filter replacement procedures. Additionally, the *Rupantor* has taken an active role in promoting the RO plant's services through the distribution of informative leaflets, public announcements, and visually engaging posters. The impact of this 'Water Entrepreneurship' initiative on the rural economy cannot be overstated. It has resulted in the creation of substantial employment opportunities, thereby addressing unemployment issues prevalent in the area. Furthermore, it has successfully tackled the pressing problem of water scarcity, particularly in a region that is highly susceptible to salinity intrusion.

2.5.2.3 Infrastructural Sector

Satkhira's geography is rendered at risk of recurring cyclones, storm surges, tidal flooding, and salinity intrusion as it is adjacent to the Bay of Bengal (Rabbani et al., 2021). According to the IPCC (2015) report, the sea level along the coast of Bangladesh increased at a rate ranging from 6 to 21 mm annually between 1980 and 2010 (Ahmed, 2016). Extreme climatic events severely damage and disrupt coastal livelihood and resources. In the last few decades, the use of Equipment-Oriented adaptation technologies has been saving coastal resources through using increasing structural barriers such as multi-purpose cyclone shelters, sea walls, embankments, sluice gates, culverts, geobags, geosynthetics, and land reclamation projects.

Table 2.7: Identified frequency of community people (Dakshin Sreepur and Padmapukur) relocating to multi-purpose cyclone shelters (MPCS) during climate-induced disasters.

Area (Union)	**Relocating to multi-purpose cyclone shelters (MPCS)** (%)	**Responses regarding level of satisfaction**	
		Satisfaction (%)	**Dissatisfaction** (%)
Dakshin Sreepur	66	39	61
Padmapukur	98	57	43

Source: Field data, 2023.

In the study area, we identified 6 multi-purpose cyclone shelters (MPCS) supporting local communities during times of cyclones and other climatic disasters. Following the receipt of early warning information from the CPP volunteers and other sources, the communities initiate evacuation procedures, seeking shelter with their valuable belongings and domestic animals at the MPCS, with the extent of evacuation depending on the magnitude of the impending disaster. Approximately 66% of the respondents in Dakshin Sreepur and 98% in Padmapukur informed their willingness to relocate to a cyclone shelter during any emergencies, to protect their lives (see Table 2.8). Nonetheless, within the study area (as indicated in Table 2.7), a majority of the community members (52%) expressed their dissatisfaction and exhibited reluctance to seek shelter in cyclone shelters for various reasons, such as concerns related to sexual abuse, safety deficiencies, insufficient space, and inadequate food supply, among others. Furthermore, on numerous occasions, they have reported incidents where their belongings and domestic animals were subject to theft.

The construction of the six multi-purpose cyclone shelters (MPCS) was facilitated through collaboration between the Local Government Engineering Department (LGED) and donor agencies. The MPCSs are used as elementary schools regularly. These MPCS facilities typically consist of robust, multi-story concrete buildings, ranging from 4 to 5 stories in height. Importantly, they are designed to be inclusive, ensuring accessibility for individuals with disabilities as well as those with reduced mobility, including elderly and pregnant women. To safeguard against floodwater and storm surges, the ground floor of the building is intentionally left unoccupied and elevated to a height of 2 meters above the plinth level. This design includes a ramp to ensure universal access to the ground floor, a staircase for access to the upper floors, a dedicated medical emergency room, restrooms situated on one side, and a designated plinth area for housing livestock animals. Within the facility, there are distinct rooms allocated for males and females, equipped with a limited number of toilet facilities and a kitchen.

During disaster situations, food preparation primarily takes place in this kitchen due to reduced accessibility. It is important to note that the entire ground floor is exclusively designated for the accommodation of livestock animals. Each of these MPCS facilities can accommodate 300 to 500 people. Notably, in recent times, these facilities have been equipped with solar energy systems and a reliable water supply through Rainwater Harvesting Systems (RWHS), allowing them to store drinking water for use during emergencies.

A local community member explained and stated:

Throughout my life, I have borne witness to the devastating impact of climatic disasters, including the Bangladesh cyclone in 1991, cyclone SIDR in 2007, cyclone AILA in 2009, and cyclone Bulbul in 2020. In 1991, our locality lacked dedicated cyclone shelters, compelling us to embark on a 15-kilometer journey to seek shelter in a primary school. Thousands of people crammed into a two-story building, struggling to safeguard their lives without access to food and relief supplies, resulting in immense suffering. However, a significant change occurred following cyclone AILA in 2009 when we had two multi-purpose cyclone shelters (MPCS) established in our area. This development made it relatively easier for local residents to find shelter during cyclones *and other climatic disasters. Nonetheless, certain issues persist within these shelter facilities, such as concerns related to sexual harassment and safety.*

The study area has a substantial array of coastal embankment facilities, including approximately 1.5 km of seawalls and 4.1 km of geosynthetic embankments. The per-meter cost for each embankment segment ranges from BDT 500,000 to BDT 600,000, with an additional placement cost of BDT 100,000 for each block. Additionally, there are 16 km of geobags and geosynthetic installations. The cost for each geobag varies from BDT 40,000 to BDT 45,000, with a placement cost of BDT 12,000 each. These measures employ geotextiles, geomembranes, and flood drainage systems, and are particularly useful for creating flood barriers, river control, and mitigating coastal erosion. Geosynthetic bags are reserved mostly for emergency use as part of temporary measures. These coastal embankment initiatives are undertaken to bolster and fortify the overall resilience of the coastal population. Furthermore, there are approximately 8 sluice gates strategically placed for drainage purposes, helping to manage water-logging issues in the region.

A local resident, sharing his observation, stated that:

In 2009 Cyclone Aila, our Union experienced significant infrastructural damage, with approximately 17 km of roads and 3 km of embankment facilities completely destroyed. Additionally, the cyclone inflicted partial damage upon 3 sluice gates, 4 culverts, and 1 multi-purpose cyclone shelter (MPCS).

2.6 Discussions

2.6.1 Community mobilization through DRR innovations

The findings of the present study signify the prominent role of Cyclone Preparedness Programme (CPP) volunteers in transmitting early warning signals to the community members in both study *Unions*. The preparedness program and warning system ensures timely communication in vulnerable communities, prompting them to relocate to multipurpose cyclone shelters (MPCS) and respond appropriately with better preparation. These actions involve swiftly returning from deep-sea fishing activities, preserving dry food supplies, reducing outdoor activities, and securing shelter for livestock animals before the onset of any climatic disasters.

In this regard, Ahsan et al. (2020) and Lejano et al. (2022) have asserted that the early warning system (EWS) provides not only critical information but also empowers local communities to formulate preparedness plans and strategies aimed at reducing livelihood risks. For instance, during the 2009 cyclone Aila in Bangladesh, the EWS played a crucial role in mitigating its impacts. The warning information about cyclone Aila was analyzed and shared a full 36 hours ahead of its landfall. The advanced warnings provided local authorities with the opportunity to fortify their preparedness measures and evacuation procedures (Akhand, 2003; Saha & Pittock, 2021). Haque et al. (2022) and Quader (2023) cited that one of the noteworthy characteristics of the CPP is its unwavering dedication to community-based disaster risk management (CBDRM) within the coastal regions of Bangladesh.

In the study area, we observed that the CBDRM empowers community people and creates a participatory platform for the community and various stakeholders. Collaboratively, communities engage in the identification and mitigation of local disaster risks, crafting an Inclusive Risk Reduction Action Plan (IRRAP) in partnership with government agencies and non-governmental organizations (NGOs) (Shahidullah & Haque, 2016; also see Azad et al., 2019). However, Nasreen et al. (2014) found that influential individuals within the community can disrupt the process and “push down” the marginalized and vulnerable populations. The Azad et al. (2019) study also found that the distribution of benefits from the implementation of the CBDRM approach were uneven among the community members in coastal Bangladesh.

Despite such challenges, the observations indicate that the community members actively share valuable local and indigenous knowledge on the platform, including reading and understanding the warning signals, vulnerable locations, shelter options, past experiences, survival strategies, and social connections. Institutions in the Caribbean regions have similarly achieved notable success by adopting the CBDRM approach, emphasizing "climate-proofing" through integrating climate resilience and promoting sustainable livelihoods (Meira & Bello, 2020). In Thailand, a community-based approach to flood management, wherein a proactive stance was adopted to enhance community preparedness and resilience was quite successful (Tripathi, 2018). The creation of a community-based flood management committee, trained in early warning systems, search and rescue operations, evacuation procedures, relief efforts, and first aid, marked a remarkable shift toward proactive measures in supporting vulnerable communities.

Using CBDRM approaches, vulnerable communities in both study *Unions* have actively contributed to the creation of hazard maps. These visual representations of vulnerable areas aid in informed decision-making to address climate risks. The formulation of the 2018 hazard maps for Padmapukur *Union*, Shyamnagar identified communities' vulnerability and infrastructures at risk and served as the cornerstone for formulating appropriate policies and strategies aimed at reducing risks and implementing mitigation measures that eventually strengthen the resilience of coastal people.

Collectively, these components create a synergistic framework for community mobilization, enhancing the resilience of coastal communities in Bangladesh to withstand and respond effectively to climate-related hazards. The success of this integrated approach lies in its ability to engage communities actively, bridging the gap between traditional practices and modern technologies for disaster resilience.

2.6.2 Livelihood recovery through financial credit systems

In Bangladesh's coastal region, financial capital through microfinancing institutions (MFI) has been a critical asset in enhancing resilience and reconstructing community people's livelihood. In this regard, the households in the present study reveal that a considerable proportion, specifically 92% of households, acquire loans or credit from various microfinance institutions (MFIs) to "bounce back" from the impact of any climate-induced disaster. The credit/loan obtained from MFIs thus significantly supports the poorer and more vulnerable groups by providing them with the means to repair and restore their livelihood activities. However, the households frequently find themselves in a 'poverty trap' resulting in borrowing simultaneously from multiple MFIs (also see Faruqee & Khalily, 2011; Uddin et al., 2021) and alleviating poverty through income-generating activities (Abdullah & Uddin, 2013).

The study observed that the MFIs prefer females when it comes to providing credits, which is often rooted in a combination of economic, social, and cultural factors. In coastal Bangladesh, with its patriarchal societal structure, women frequently encounter barriers to accessing financial services (Kelkar et al., 2004; Debnath et al., 2019). Thus, MFIs recognizing this gender inequality, specifically target women to address it, thereby promoting social inclusivity, gender balance, and promoting women's entrepreneurship. Additionally, women are often perceived as more reliable borrowers due to their commitment to improving their family's welfare.

However, the findings of the study reveal that microcredit has had a limited impact on women's empowerment. This limitation is attributed to high interest rates and lack of financial literacy and awareness. Diro and Regasa (2014) in Ethiopia, Ukanwa et al. (2018) in Sub-Saharan Africa, Al-shami et al. (2021) in Yemen, and Rathnayaka and Silva (2023) in Sri Lanka also identified similar factors limiting women’s empowerment. Furthermore, the empirical investigation has identified a concerning issue that has surfaced as most males take away the borrowed funds from the females, resulting in the victimization of the female members within families. Due to the deficiency in repayment and accountability, female members continuously face a treadmill of borrowing from multiple MFIs, further exacerbating their marginalization. Conversely, the results of the study are consistent with the findings of Uddin et al. (2021) and Rathnayaka and Silva (2023), indicating that microcredit significantly influences the financial status of household income and post-disaster recovery in coastal communities. In Nepal, Dhakal et al. (2019) reported that, following the devastating 2015 earthquake in the country, the affected community received credit ranging from NRs36,000 to NRs64,000 (US$270–$480) from various MFIs to restore their livelihood activities. The majority of these beneficiaries invested in livestock and agriculture during the post-disaster recovery period as income-generating activities, which corroborates with our findings in both study *Unions* following any climatic disaster.

2.6.3 Livelihood security and resilience building: response to crisis by adopting alternative techniques, disaster management, and economic development

In the coastal regions of Bangladesh, communities grapple with the dual challenges of climatic vulnerabilities and economic insecurities and achieving livelihood security requires a nuanced approach that integrates alternative techniques, robust disaster management, and sustained economic development. In response to these challenges, widespread adoption of sustainable agricultural practices including climate-resilient crops, hydroponic and aquaponic farming practices, integrated farm management (IFM), dyke cropping, and other strategies were registered. These practices demonstrate significant potential in minimizing climate risks and strengthening community resilience. Notably, farming communities utilize technologies to improve their adaptive capacity. Hussain and Saha (2019), Arús (2020), and Tong et al. (2023), also observed that the adoption of such adaptation technologies minimizes the vulnerability of marginalized communities, enhances income-generating opportunities, ensures food security through increased crop production, and contributes to the overall resilience system on a larger scale.

However, the findings underscore that adaptation technologies in the agricultural sector encounter substantial challenges and barriers. Limited access to capital and credit facilities poses a hurdle for small-scale farmers, impeding their ability to invest in expensive technologies like mechanized equipment or improved irrigation systems. The lack of access to quality seeds and insufficient knowledge and training among rural farmers about the benefits and proper utilization of new crop varieties and technologies hinder the adoption process.

Structural barriers, including block embankments, sea walls, geobags, and multi-purpose cyclone shelters (MPCS), emerge as highly effective in shielding settlements and infrastructure from climatic disasters like cyclones, storm surges, floods, and erosion in the study area. For instance, MPCS serves as a shelter place for vulnerable communities during emergencies, offering protection for human lives and farm animals. Moreover, the study's observations align with Miyaji et al.'s (2020) findings, indicating that while these shelters have successfully saved lives, they face challenges in accommodating all inhabitants in vulnerable areas within coastal deltas. Further, the implementation of these measures often suffers from insufficient operational and maintenance activities with governance issues (Mostajabdaveh et al., 2018; Opdyke et al., 2021). The present study observed that a significant number of infrastructural projects lack effective oversight by the relevant authorities, thereby seriously impeding the ongoing upkeep and repair activities. Furthermore, conflicts among diverse livelihood groups and government agencies hinder the efficacy of coastal embankment projects, corroborating research findings by Saha et al. (2016) on infrastructural development initiatives in coastal Bangladesh.

The empirical investigation unveils that, in response to climate stress challenges and livelihood disruption, local communities draw valuable lessons from past disaster experiences. Communities are seen to be actively diversifying their livelihood sources, participating in community-based organizations (CBOs) meetings, and developing effective coping mechanisms by adopting adaptation technologies to address future climate risks. For example, farmers are adopting climate-resilient rice and crop varieties. Age-old traditional adaptive measures, such as the utilization of rainwater harvesting (RWH) for household and agricultural activities, are consistent with findings of several previous studies, including those by Pachpute et al. (2009), Masum et al. (2018), and Ghosh and Ahmed (2022). These studies cited the importance of RWH in addressing potable water requirements and achieving notable increases in crop yields, ranging from 30% to 50%, particularly in coastal Bangladesh as the areas are constrained by salinity and turbidity in ground and surface water sources.

2.6.4 Drivers of innovation and adaptation technologies

A synthesis of the drivers of innovation and adaptation technologies and their corresponding outcomes in the context of climate-induced disasters is presented in Table 2.8. It underscores the importance of leveraging technological advancements, fostering international cooperation and partnership, and implementing location-specific solutions to protect lives, resources, and the environment in the coastal region of Bangladesh. Further, these drivers influence the adoption of specific innovation and adaptation technologies to address the challenges posed by climate-related hazards.

Table 2.8: Interactions between different innovation and adaptation technologies with their drivers and outcomes to climate-induced disasters.

Drivers	Innovation and Adaptation Technologies	Outcomes
• Increased frequency of climate-induced disasters • Colossal human death • Technological advancement • International co-operation and partnership	Early Warning System	• Awareness raising • Rapid evacuation • Saving human lives
• Increased frequency of climate-induced disasters • Technological Advancement • Need for detailed information.	Geographic Information Systems and Remote Sensing	• Enhancement in detailed plans for ensuring both structural and non-structural measures for any climatic disaster. • Protecting resources

• International co-operation and partnership • Protecting nature and environment		
• Bridging community and institutions	Community-Based Disaster Risk Management and Hazzard Mapping	• Strengthening community capacity and local resources. • Creating partnerships among community, government organizations, and other various stakeholders.
• Increased frequency of climate-induced disasters • Colossal human death • Unaware of disaster warning signals	Cyclone Preparedness Programme (CPP)	• Awareness building • Strengthening community people's capacity to tackle any disaster. • Developing kinship among community people.
• Unforeseen monetary crisis. • Climate-induced disaster loss	Micro Financing Institutions	• Enhances individual capacity in coping and adapting to the devastation.
• Food security • Higher salinity intrusion, waterlogging, flood • Rapid changes in climatic conditions • Self-sufficiency	Agricultural Sector Biotechnology: Genetically modifying crops (saline-tolerant such as *BRRI*-52, 47, 67, and 72, and *BINA*-10; flood-tolerant such as *BRRI*-55, 68, 73, and 87; and other climate stress-tolerant such as *BRII*-27, and 10). Hydroponic and aquaponic agricultural practices; dyke cropping; vermi and organic composting; vertical towering; mulching methods; agricultural practices using gunny bags, concrete pots, or cork boxes; integrated farm management (IFM); and crop diversification based on seasons.	• Ensuring food supply • Means of income-generating option. • Meeting nutrition requirements.
• Higher salinity • Unavailability of fresh water • Technological advancement	Water Resources (Drinking and Irrigation) Reverse Osmosis (RO), Pond Sand Filters (PSF), Deep and Shallow Tube wells, and Rainwater Harvesting (RWH).	• Freshwater availability for drinking, irrigation, and household activities.

• Increased frequency of climate-induced disasters • Technological advancement • International cooperation and partnership	Infrastructural Sector Multi-purpose cyclone shelter, Sea walls, Block embankments, Sluice gates, Polder, Culverts, Geobags, and Geosynthetics.	• Mitigating climate-induced disasters • Protecting property, business, nature, and environment.

Through empirical investigations, the research has discerned the pivotal role played by various innovation and adaptation technologies in enhancing preparedness and their potential to ameliorate the dire consequences of climate-induced disasters. This study primarily focuses on the motivating factors and outcomes associated with the adoption and implementation of robust innovation and adaptation technology systems. Examining these approaches and technologies, we have identified five major drivers that have been instrumental in initiating this comprehensive process:

- Increased Frequency of Climate-Induced Disasters and Rapid Climate Change: The rising occurrence of climate-induced disasters and the urgency posed by rapid climate change have been the primary catalysts for action.
- Colossal Human Loss: The devastating impact of climate-induced disasters, resulting in significant human casualties, has spurred efforts to develop mitigation strategies.
- Technological Advancement: Advancements in technology have provided new tools and solutions for addressing climate-related challenges.
- International Cooperation and Partnerships: Collaborative efforts on an international scale have played a crucial role in mobilizing resources and expertise to combat climate risks.
- Environmental Protection: The imperative to safeguard the environment and natural ecosystems has been a driving force for proactive measures to mitigate climate risks and protect vulnerable populations.

All these critical elements have collectively instigated significant changes, fostering proactive measures aimed at mitigating climate risks and safeguarding at-risk communities. In the context of coastal Bangladesh, these drivers often involve participatory management that engages multiple stakeholders, strengthening the effectiveness and efficiency of the grassroots-level measures. Furthermore, facilitating knowledge sharing, resource allocation, and collaborative efforts has progressed the development and implementation of innovation and adaptation technologies to address climate risks.

The outcomes resulting from the application of the above-mentioned measures are threefold. Firstly, they contribute to saving lives and fostering awareness within at-risk communities and individuals, ensuring they are well-informed about potential hazards and the necessary precautionary actions. Secondly, these measures emphasize the importance of safeguarding resources, enhancing partnerships among stakeholders, strengthening capacity, and utilizing local resources effectively. This enables the prompt and efficient relocation of affected populations to safer areas, thereby saving lives, reducing casualties, and mitigating the overall societal impact of climate-induced disasters. Lastly, it highlights the significance of ensuring a stable food supply, providing income-generating opportunities, ensuring access to clean water, and protecting the environment and local businesses. These measures empower communities to minimize the adverse impacts of climate-induced disasters and protect the natural environment, fostering resilience in the face of climate change challenges.

Enhancing community resilience involves all the above-mentioned structural and non-structural measures and strategies. These measures offer communities the resources to anticipate and prepare for potential climate consequences, effectively reduce climate risk, and build adaptive capacities. Further, they empower the communities to enhance resilience toward adverse climatic events. It is evident that coping with and adapting to the new conditions brought about by climatic disasters often necessitates transformation as an essential component of the process of building resilience. In other words, embracing change and implementing transformative actions play a significant role in enhancing the ability to withstand and recover from the impacts of climate risk. Therefore, we can highlight that disasters may create a "*window of opportunity*" to foster innovation and adaptation technologies helping vulnerable societies to minimize climate-induced disaster impacts and strengthening community resilience at the local level (Shaw et al., 2016; Brundiers & Eakin, 2018; Izmui et al., 2019a; Davidsson, 2020). The success of utilizing such opportunities depends on the characteristics of multiple factors such as agency, leadership, and self-organizing capacity.

2.7 Conclusion

In coastal Bangladesh, the significance of various innovation and adaptation technologies in mitigating climate risk and enhancing community resilience is noticeable. In this research, I have explored how various approaches and strategies serve as indispensable tools in addressing the multifaceted challenges posed by climate change. By fostering a synergy between cutting-edge innovations and technologies, and locally informed knowledge, communities can harness the power of adaptation technologies to adapt to changing climatic conditions.

From early warning systems to community-based disaster risk management, and resilient infrastructure to climate-smart agricultural practices, these measures offer practical solutions to safeguard communities from the adverse impacts of climate risk. Moreover, their ability to improve resource efficiency, reduce vulnerability, and enhance disaster preparedness underscores their significance in building sustainable and climate-resilient communities. A wide range of drivers including the high frequency of climatic disasters, protecting human lives and the natural environment, technological advancement, and multi-level cooperation among stakeholders and parties have significantly influenced the adoption of innovation and adaptation technologies at the local level. The convergence of these crucial factors has encouraged substantial transformations, prompting proactive initiatives designed to mitigate climate-related risks and protect vulnerable communities. However, it is important to acknowledge that the successful application of these measures must be coupled with a commitment to inclusivity and equity in social conditions. Vulnerable populations must be at the forefront of any adaptation efforts, ensuring that the benefits of innovation and adaptation technologies are accessible to all. Moreover, continued research, development, and dissemination of these measures are imperative to staying ahead of evolving climate challenges.

Overall, the present study signifies that the interplay between innovation, adaptation technologies, and community resilience is a dynamic and evolving process. It demands sustained collaboration between stakeholders, a commitment to equitable distribution, and a steadfast dedication to the principles of sustainability. Through these collective efforts, we can navigate the uncertain climate landscape and strengthen communities to thrive in the face of climate-induced disasters.

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CHAPTER 3

Role of Multi-level Institutions in Facilitating Innovation and Adaptation Technologies for Climatic Risk and Impact Mitigation: Evidence from Coastal Communities of Bangladesh[1]

Abstract

While the role of innovation and adaptation technology in reducing climatic risks is widely recognized, few studies have investigated the role of formal, quasi-formal, and informal institutions in facilitating the adoption of such technology at the local level. In this study, a mixed-methods research technique was employed to empirically examine how local institutions in two coastal communities in Bangladesh facilitate the innovation and implementation of adaptation technology to minimize the impacts of climate hazards. Primary data are collected via 300 household surveys, 26 key informant interviews, and 2 focus group discussions. The findings reveal that local institutions (i.e., formal, quasi-formal, and informal) are actively involved in various partnership-building processes and actions to promote innovation and adaptation technologies at the community level. However, significant institutional fragmentation remains a major barrier to the sustainable implementation of various programs/initiatives related to climatic hazards. For institutions to play their roles sustainably, it is recommended that national policies place greater emphasis on nurturing partnerships among regional stakeholders, as well as facilitating collective action for climate-induced disaster risk reduction and participatory community development.

KEYWORDS: Climate change; institutions; disaster risk reduction; agriculture; water; Bangladesh.

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[1] This Chapter is under review in the *International Journal of Disaster Risk Reduction*.

3.1 Introduction

Institutional structure and relationships play a pivotal role in enhancing the human and financial resource capacity of climate victims to systematically address the underlying factors of climate risk (Adger et al., 2005; Agrawal, 2010). Here, institutions are conceptualized as entities that encompass laws and regulations influencing behavior and learning processes (Grønning, 2008). As Azad (2020) asserts, institutions act *"as systems of rules, decision-making procedures, and programmes that shape social practices, assign roles to the participants in these practices, and direct interactions among the actors with assigned roles*" (p 71). Institutions can take various forms, including formal, semi-formal (quasi-formal), and informal (Gupta et al., 2010; Uddin et al., 2020; Azad et al., 2021). "Formal" institutions are distinguished from "quasi-formal" institutions by their comparatively greater tangible contributions to governance and administrative frameworks, while "informal" institutions are predicated on the intricate incorporation of nuanced perceptions and cultural norms (Agrawal, 2010; Abass et al., 2018; Bekele et al., 2020). This classification approach aims to underscore aggregate measures by engaging diverse parties within the community (Gupta et al., 2010; Agrawal et al, 2013; Abass et al., 2018).

Institutions can bolster resilience and foster collaboration within communities to mitigate climate risk and the impacts of climate-induced disasters, largely through their ability to shape innovation and climate change adaptation technologies (Agrawal, 2010). This influence is most often manifested via the establishment of connections between communities and resources, collaborative actions, the identification of external supports, and the integration of vulnerable communities into local developmental initiatives (Yaro et al., 2015; Berkes, 2017; Wittmayer et al., 2017). The collaborative synergy of formal, quasi-formal, and informal institutions is instrumental in addressing risks, making decisions, and implementing innovation and adaptation technologies in climate risk mitigation strategies and initiatives across all levels (Wilbanks & Kates, 1999; Agrawal, 2010). Following Islam and Nursey-Bray (2017), I posit that institutions also function as intermediaries, facilitating interactions between state actors, non-governmental organizations (NGOs), community-based organizations (CBOs), and various local occupational groups, such as farmers and fishermen. This intermediary role highlights the importance of institutions in orchestrating coordinated efforts among diverse stakeholders for effective climate risk management.

In addressing the vulnerability of local communities, numerous researchers have underscored the significance of integrating local knowledge and cultural aspects into the institutional structure to enhance the efficacy of the fostering process (Naess et al., 2005; Rabbani, 2010; Choudhury et al., 2019). However, several investigations have revealed that institutional barriers function as major impediments to effective climatic risk reduction measures (Naess et al., 2005; Fünfgeld, 2010; Glaas et al., 2010; Lebel et al., 2010). Glaas et al. (2010), and Lebel et al. (2010) argue that institutional "traps," such as fragmentation, can exacerbate issues related to various topics affecting the fostering process, including: the reluctance to nurture collaboration and partnership; reactive responses; the top-heavy concentration of authority; and an over-reliance on established pathways. Numerous studies have also identified key constraints on institutional actions, including inadequate funding, lack of mutual trust and transparency, and maladaptive practices (Van Niekerk & Wisner, 2014; Fan, 2015; Uddin et al., 2020). Collectively, these critical challenges increase the risk of failure for local-level initiatives related to innovation and adaptation technologies. Local communities face serious challenges in effectively adopting adaptation measures due to contextual barriers (e.g., culture) and the lack of resources required to sustainably implement such initiatives. Therefore, it is critical to address these institutional shortcomings, as doing so will ensure the success and sustainability of local-level initiatives aimed at enhancing climate resilience and adaptation.

Over the past three decades, formal and quasi-formal institutions (i.e., *Union Parishads* (councils), the Project Implementation Office, the Bangladesh Water Development Board, local government engineering departments, *Union* disaster management committees, *Union* agriculture offices, the Cyclone Preparedness Program, NGOs, and MFIs) and informal institutions (i.e., village development committees, CBOs, faith-based committees, union leaders, farmers' associations, and community members) have actively engaged in collaborative efforts at the grassroots level aimed at promoting and strengthening climate resilience in Bangladesh's coastal areas (Uddin et al., 2020; Azad et al., 2021). Despite this rich history of engagement, the specific roles of formal, quasi-formal, and informal institutions in facilitating innovation and adaptation technologies have been largely overlooked. Thus, empirical research aimed at yielding a comprehensive understanding of the roles and dynamics of these institutions is urgently needed. Indeed, such research is essential to elucidating the nuanced contributions and interactions of these entities with respect to reducing climatic risks and promoting resilience in Bangladesh's coastal areas.

The ongoing effects of climate change on the lives and livelihoods of Bangladesh's coastal population is a pressing policy concern (Ahmed & Eklund, 2021), especially given these regions' heightened susceptibility to climate extremes (Kabir et al., 2016). Bangladesh's coastal belt is exposed to substantial climate risks, mainly in the form of fluctuations in the intensity and frequency of climate-induced disasters, including cyclones, storm surges, floods, and river erosion (Uddin et al., 2019). Despite concerted efforts to implement risk-reduction strategies, the toll of extreme climate events continues to escalate, resulting in economic and human losses (Islam, 2018; UNDRR, 2019).

The agricultural and water sectors are particularly vulnerable to climatic risks due to challenges such as rising sea levels, salinity intrusion, recurrent storm surges, and the persistent threats of land degradation and erosion (Ahmed and Eklund, 2021). The present research analyzes the intricate dynamics of climatic risks faced by vulnerable communities in coastal Bangladesh and the pivotal role played by formal, quasi-formal, and informal institutions in mitigating these risks.

The specific objectives of this chapter are as follows: i) to examine the role of institutions in reducing climate-induced-disaster risks and enhancing resilience by facilitating innovation and adaptation technology at the local community level; and ii) to analyze the nature of institutional relations and fragmentation and how this may hinder the adoption processes.

3.2 Methods and Study Area

The District of Satkhira, located in the southwestern coastal zone of Bangladesh, was selected as the study area for the empirical portion of this research, as it is one of the most susceptible regions worldwide to the adverse effects of climate change (Shaw et al., 2022). Over the past few decades, recurrent climate-related disasters, including tropical cyclones, tidal surges, floods, river erosion, and increased salinity, have significantly impacted the infrastructure and the natural environment of southwestern Bangladesh and southeastern India (Fenton et al., 2017). During this time, Satkhira District has been among the most severely affected areas; for instance, Cyclone Sidr (2007) and Cyclone Aila (2009) resulted in approximately 350 deaths, 12,000 injuries, and the destruction of thousands of acres of cropland, properties, and critical infrastructure in this region (Mallick et al., 2017; Sadik et al., 2018; Parvin et al., 2019). Similarly, Cyclone Bulbul (2019) and Cyclone Amphan (2020) also wrought considerable devastation upon the region (Rahaman & Esraz-Ul-Zannat, 2021).

The water and agriculture sectors in the study area are acutely vulnerable to climate change risks and their impacts, as rising sea levels and increased salinity intrusion pose significant threats to the freshwater sources that are essential for drinking, household activities, and irrigation (Abedin et al., 2018; Hadi, 2019). Researchers have observed that changing climate patterns, including erratic rainfall and extreme weather events, disrupt traditional agricultural practices and jeopardize crop yields (Hoque et al., 2019). For instance, Cyclone Amphan (2020) damaged 368,187 acres of croplands in coastal Bangladesh (Jakariya et al., 2020; Rabbani et al., 2021). Thus, the proximity of agricultural land to the Bay of Bengal exacerbates such challenges, impacting staple crops like rice and compromising food security.

The field investigations were conducted from December 2022 to February 2023 in two selected *Unions* (Padmapukur in Shymnagar *Upazila* and Dakhin Sreepur in Kaliganj *Upazila*) in Satkhira District (See Figure 3.1). This portion of the research took place over 27 days (about 4 weeks), with data being collected by a team of 5 enumerators. Given the scope and objective of this research, I employed a "mixed method" approach as it allows the integration of both qualitative and quantitative data for analysis of the results. Primary data were collected via a household survey (semi-structured interviews), key informant interviews (KIIs), and focus group discussions (FGDs) (see Table 3.1).

For the survey, a sample of 300 households was obtained using a simple random sampling technique. Each survey was completed by the household head and took between 45 and 60 minutes to complete. A total of 26 KIIs were conducted with the representatives of various regional and local institutions (i.e., formal, quasi-formal, and informal). See Table 3.1 for a breakdown of the KII participants. Each KII lasted between 30 and 40 minutes and consisted of having participants respond to guided questions. Finally, one FGD was conducted in each study *Union.* to obtain a better understanding of institutional roles and facilitating processes. Each FGD session consisted of 6-8 participants and typically lasted 60 to 90 minutes. With the participants' consent, all interviews were recorded in the local *Bengali* language and subsequently transcribed into English. Secondary data were accumulated from research papers, journals, reports, and document reviews.

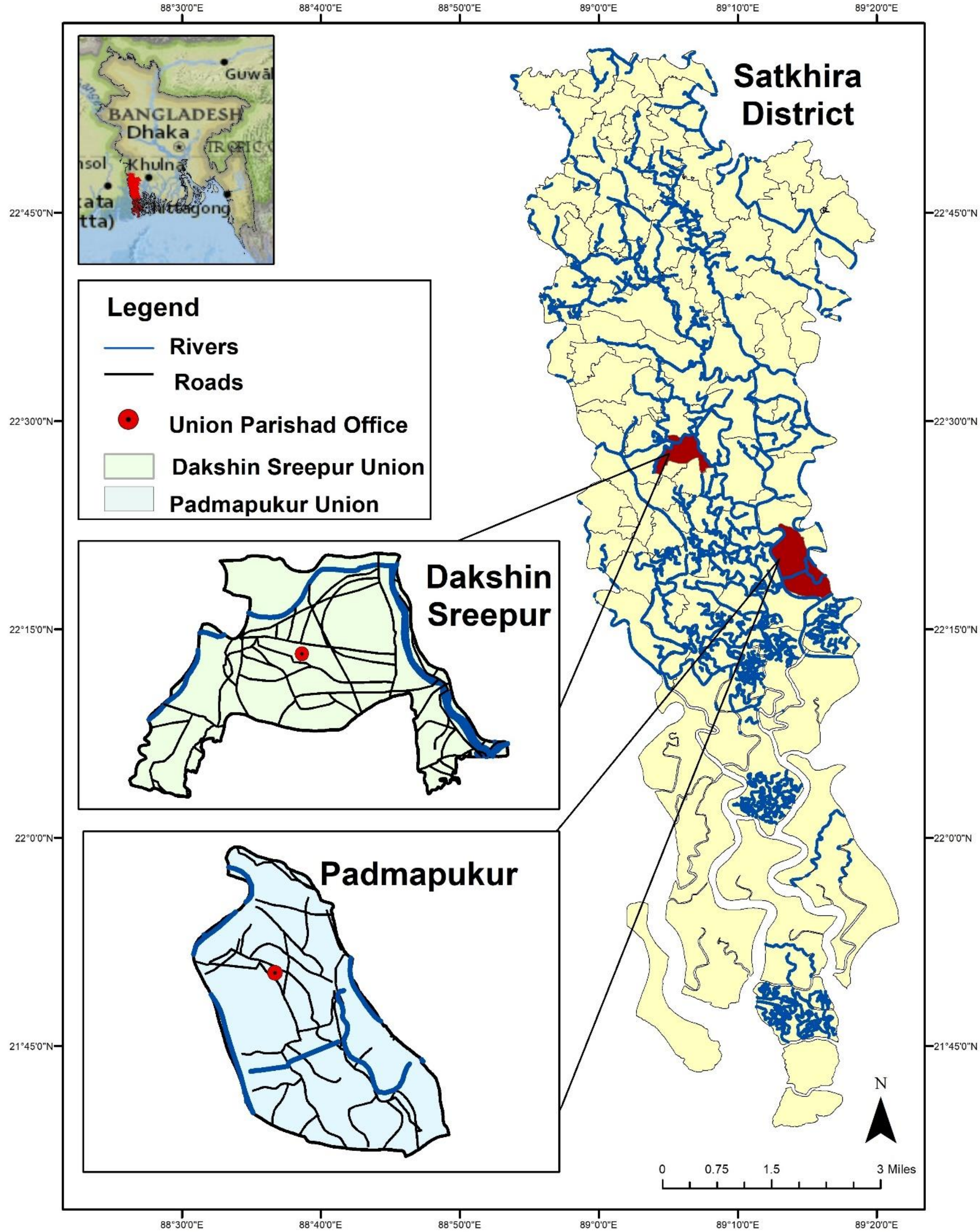

Figure 3.1: Map of the study area.

Table 3.1: Method, and sample size of the field data collection.

Tool/Instrument	Participants	Sample Size
Household Survey	Household Heads	300
Key Informant Interviews (KII)	*Union Parishad* officials (2) Cyclone Preparedness Programme officials, and volunteers (3) Bangladesh Water Development Board (1) Local Government Engineering Department (LGED) (2) *Union* Disaster Management Committee (2) Project Implementation Office for Disaster Management (2) Department of Public Health Engineering (1) *Union* Agricultural Officer (1) local chairman (1) MFIs representatives (2) NGO representatives (2) Reverse-Osmosis Committee (1) Community leaders (2) Local elites (2) Religious institution leaders (2)	26
Focus Group Discussions (FGD)	Farmer groups (1) Mixed occupational group including farmers, community people, Reverse-Osmosis committee, Cyclone Preparedness Programme volunteers, and fishermen (1)	2

A triangulation technique (Creswell, 2009) was employed during data analysis to help identify distinct issues and streamline themes, which allowed for the simultaneous analysis of the qualitative and quantitative data and their integration into the overall interpretation process. The research in this work was approved by the University of Manitoba (Canada) Joint Research Ethics Committee (Protocol # HE 2022-0206).

3.3 Results

In Bangladesh's coastal communities, numerous formal and quasi-formal institutions (i.e., *Union Parishads*, the Project Implementation Office for Disaster Management, the Bangladesh Water Development Board, Local Government Engineering Departments, *Union* Disaster Management Committees, *Union* Agriculture Offices, Cyclone Preparedness Programme (CPP), NGOs, and microfinancing institutions (MFIs) and several informal institutions (i.e., the village development committee (VDC), community-based organizations (CBOs), faith-based committees, *Union* leaders, farmers associations, and community members) have long been engaged in climate-induced disaster risk reduction (DRR) and other economic development sectors. The extent to which these institutions serve their local communities was reflected in the responses of the community members in the study *Unions*. As shown in Figure 2, more than 81% of respondents reported having relationships with local NGOs (i.e., quasi-formal institutions), which provide community members with credit support, livelihood-skill advice, and training.

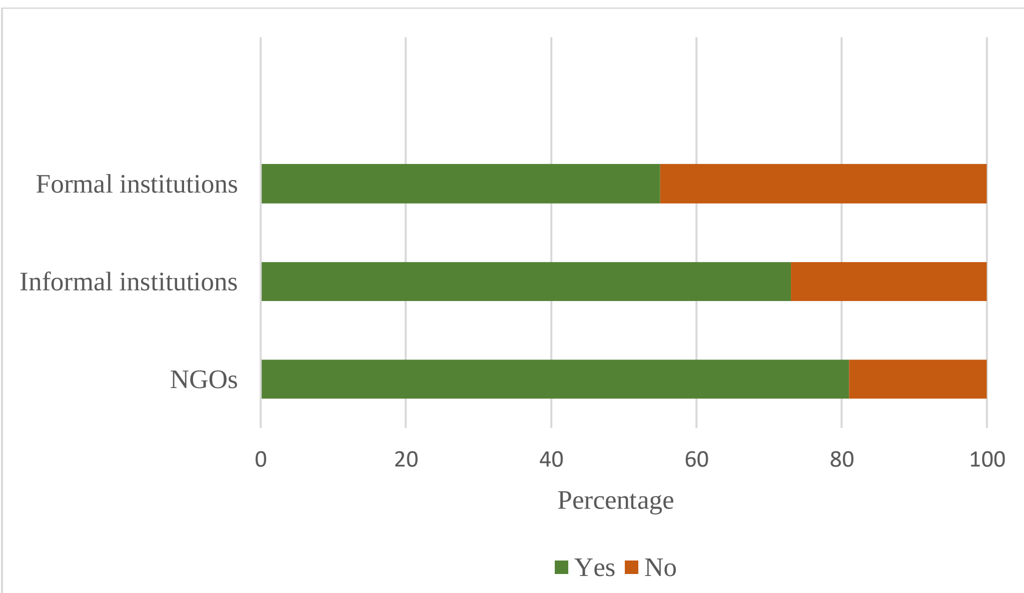

Figure 3.2: Formal, informal institutions and NGOs support for community people (n = 300). Source: Field data, 2023.

These organizations also function as bridging institutions between local communities and formal government departments. Nearly three-quarters (73%) of respondents reported receiving support from informal institutions, as these entities are firmly embedded within Bangladesh's rural communities. Although a majority of community members (55%) had some form of relationship with formal institutions (Figure 3.2) via the receipt of subsidies, grants, and extension services, local people still faced various barriers to accessing these supports.

3.3.1 Community Access to Formal and Quasi-Formal Institutions

The field data revealed that various formal and quasi-formal institutions were actively engaged in mainstreaming innovation and adaptation technologies at the community level. These institutions, operating at the grassroots level, collaborated with regional and national agencies, primarily benefiting from technical advice and support.

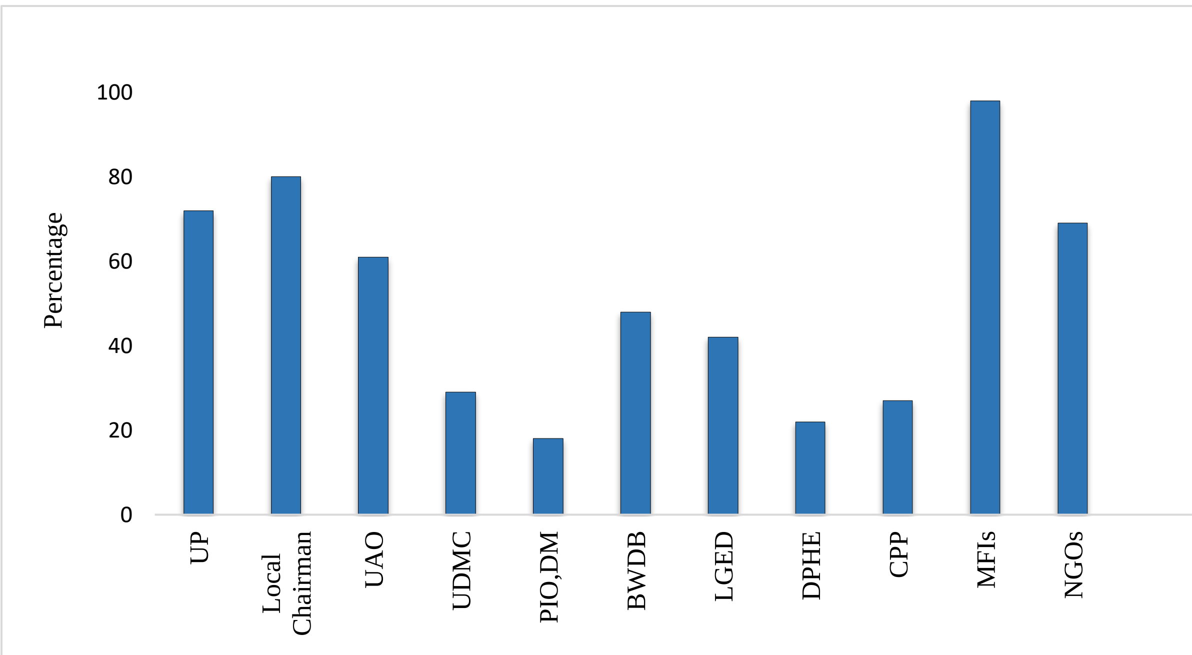

Figure 3.3: Access to formal and quasi-formal institutions at the community level.
Source: Field data, 2023.

The community members reported having access to a range of institutions simultaneously (Figure 3.3). Among these institutions, microfinancing institutions accounted for the most interactions (98% of respondents), followed by the local chairman's office (80%), the *Union Parishad* office (72%), the *Union* Agricultural Office (61%), and NGOs (69%). In contrast, access to institutions such as the *Union* Disaster Management Committee, the Project Implementation Office for Disaster Management, the Bangladesh Water Development Board, the Local Government Engineering Department, and the Cyclone Preparedness Programme was more limited, ranging between 18% and 48%. These findings confirm that a considerable proportion of community members are involved with and participate in various programs offered by the formal and quasi-formal institutions within the study area.

3.3.1.1 Formal and quasi-formal institutions in disaster risk reduction (DRR)

Both formal and quasi-formal institutions were actively involved in addressing the myriad challenges faced by local communities, especially in mitigating their vulnerability to climate-induced disasters (Table 3.2). Two notable examples of this were the Early Warning System and the Cyclone Preparedness Programme, wherein formal and quasi-formal institutions serve as crucial bridging organizations. The Bangladesh Meteorological Department provides weather forecasting information to local institutions, which is immediately disseminated to communities via organizations such as the Project Implementation Office for Disaster Management, the Cyclone Preparedness Programme, the *Union Parishad*, the *Union* Disaster Management Committee, the Ward Disaster Management Committee, and various NGOs engaged in disaster management and resilience efforts. These local organizations then collaborate to identify potentially vulnerable communities and ensure the timely dissemination of early warning information.

Both KII respondents and FGD outcomes revealed that formal and quasi-formal institutions had extensively engaged in capacity-building initiatives for DRR strategies, including early warning system training programs, risk management, mock drills, strengthening local capacities, and knowledge- and awareness-building efforts. However, the survey data contradicted these findings, with 80% of respondents (n=300) reporting having never received any such training or assistance. Indeed, only 5% said they had received moderate training and/or assistance, albeit several years prior.

The respondents alleged that the local government and non-government institutions employed a top-down approach in developing and delivering DRR programs and other community development initiatives. As a result, community members do not have easy access to information and resources. With regards to training, a group of community disaster management volunteers reported that, in 2017, 30 of them participated in a comprehensive training program on disaster management. However, one KII respondent reported:

> *I took part in a comprehensive training program on disaster management, encompassing the vital components of early warning signal dissemination, mock drills, evacuation procedures, and awareness promotion, facilitated by the Project*

Implementation Office for Disaster Management. It was a 2-day long training course. However, regrettably, since then, no subsequent or analogous training initiative has been undertaken in our community.

Table 3.2: Innovative programs pursued by formal and quasi-formal institutions in climate-induced disaster risk reduction.

Institutions	Key issues of concern	Innovation	Implications of such initiatives
– Bangladesh Meteorological Department – Project Implementation Office for Disaster Management – Cyclone Preparedness Program Committee – *Union Parishad* – *Union* Disaster Management Committee – Ward Disaster Management Committee – Local Chairman – Sajida Foundation – World Vision – Nawabenki Gonomukhi Foundation (Affiliated with Palli Karma Sahayak Foundation) – Friendship – Uttaran – Shushilon – Islamic Relief	– Provide weather data to *Upazila*, *Union Parishad*, and the CPP committee. – Dissemination of early warning signals. – Disaster Management.	Early Warning System (EWS) and Cyclone Preparedness Programme (CPP)	– Rapid dissemination of warning information, allowing affected community members to evacuate to safer locations/cyclone shelters. – Enhanced awareness and disaster anticipation capacity. – Ensures proactive disaster preparedness plan/strategies. – Effective search and rescue operations.
– Project Implementation Office for Disaster Management – Cyclone Preparedness Programme Committee – *Union Parishad* – *Union* Disaster Management Committee – Ward Disaster Management Committee – Local Chairman – Local NGOs	– Recognizing potentially vulnerable communities to climate-induced disaster. – Hazard mapping. – Disaster management.	Community-based disaster risk management (CBDRM)	– Community risk assessment. – Community empowerment through proactive measures to mitigate climate risk and enable effective response. – Preparedness plans such as identifying safe evacuation routes and establishing alternative communication systems. – Promoting local and Indigenous knowledge on

			weather patterns, disaster indicators, and traditional coping mechanisms. – Diversifying livelihood activities.
– Space Research and Remote Sensing Organization – Centre for Environmental and Geographical Information Services – Local government engineering departments – *Union Parishad*	– Spatial database for protecting rural infrastructure.	Geographic information systems (GIS) and remote sensing (RS)	– Precise disaster risk map for identifying vulnerable areas, the impact of potential disasters, and formulating effective disaster management strategies. – Help to identify suitable locations for cyclone shelters, roads, and other infrastructural projects.
– Bangladesh Bank – Grameen Bank – ASA – Ektee Bari Ektee Khamar project – Shushilan – Satkhira Unnayan Sangstha – Uttaran – Nawabenki Gonomukhi Foundation (Affiliated with Palli Karma Sahayak Foundation) – Sonakhali Bohumukhi Somobay Somity – BK Social Safety Net	– Credit facility to the vulnerable community.	DRR-informed micro-credit	– Poverty alleviation through income-generating activities and improved standard of living. – Resilience building through the repair and reconstruction of houses and businesses. – Reduced livelihood risks via the diversification of livelihood activities.

Source: Field data, 2023.

Community-based disaster risk management (CBDRM) is a contemporary approach that has been employed to address the multifaceted challenges posed by climatic disasters in coastal Bangladesh since the 1990s. CBDRM was first developed by the United Nations Development Programme (UNDP) before being adopted and scaled up by the Government of Bangladesh. This approach connects formal, quasi-formal, and informal institutions, including the Project Implementation Office for Disaster Management, the Cyclone Preparedness Programme, the *Union Parishad,* the *Union* Disaster Management Committee, the Ward Disaster Management Committee, the local chairman, NGOs, and mostly community people. By fostering collaboration, CBDRM creates an inclusive framework that enhances the resilience of vulnerable communities, operating as a proactive strategy to reduce the devastating consequences of climatic disasters.

In the field study, it was observed that formal and quasi-formal institutions foster strengthened community resilience by providing the necessary policy framework, resources, training facilities, and infrastructure. The CBDRM approach is based on involving local-level informal networks during the decision-making process. Here, participatory mechanisms allow community members and local CBOs to actively engage with formal and quasi-formal institutions to identify vulnerabilities, assess risks, and co-create solutions to existing and future disasters. Indeed, these entities are deeply embedded within the fabric of local communities, which gives them a particularly nuanced understanding of the socio-cultural dynamics and allows them to bridge the gap between levels of institutions at the local level. CBDRM encourages the establishment of community-based early warning systems, evacuation plans, and resilient infrastructure, which are all crucial to mitigating the adverse impacts of climate-induced disasters. By empowering the local community across the entire disaster management cycle—from risk assessment to response and recovery—formal and quasi-formal institutions can mobilize multi-level institutions and people from various socioeconomic groups.

The study also examined community members' knowledge and perceptions of innovative approaches to DRR, finding that respondents in both *Unions* had a high rate of reception, understanding, and use of early warning systems (89% in Dakshin Sreepur *Union*, and 98% in Padmapukur *Union*) (Figure 3.4). While nearly all respondents also recognized the Cyclone Preparedness Programme (81% in Dakshin Sreepur *Union* and 100% in Padmapukur *Union)* and MFIs (71% Dakshin Sreepur *Union* and 92% in Padmapukur *Union*) (Figure 4), capacity deficiencies in the implementation of CBDRM activities and hazard mapping adoption rates underscored the need for nuanced, community-specific strategies.

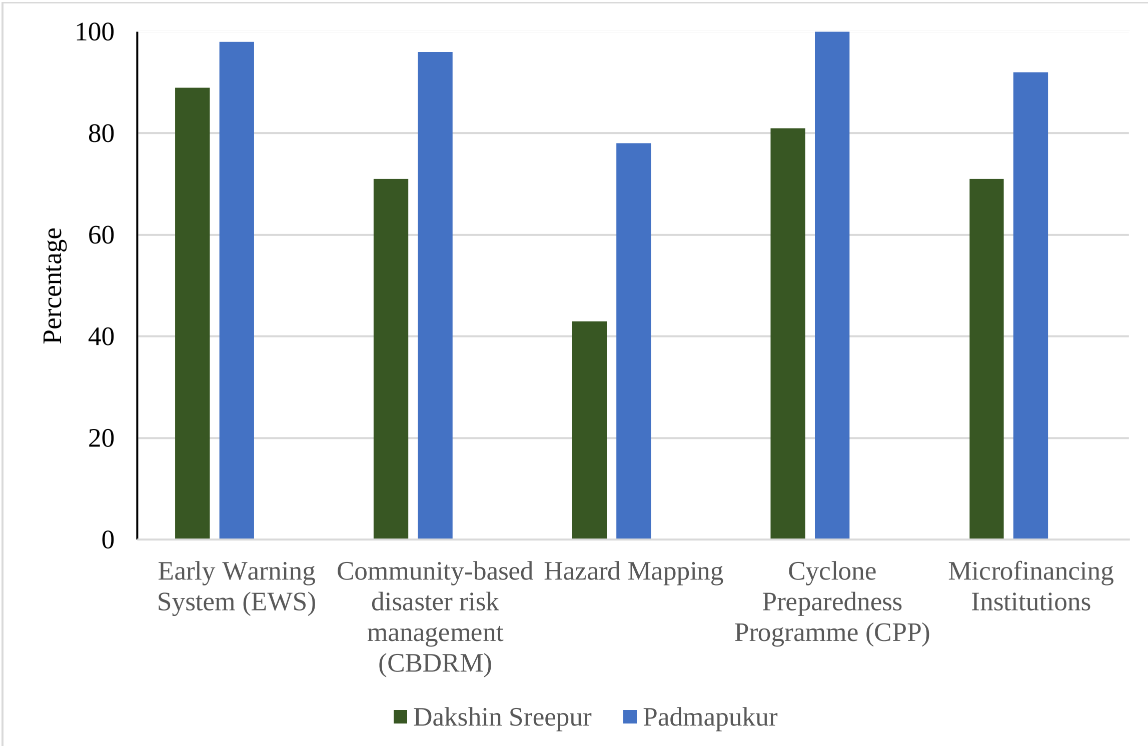

Figure 3.4: Community members' knowledge and perception of innovative approaches to DRR strategies (n=300).
Source: Field data, 2023.

Nonetheless, the findings showed that, in many instances, such institutional efforts fell short of effectively integrating community perspectives and local knowledge into the resultant DRR initiatives, resulting in limited community mobilization at the local level. As noted above, the top-down approach employed by formal institutions in facilitating DRR innovations within vulnerable communities does not help residents develop a "sense of ownership" of DRR programs and their associated activities. Furthermore, the protracted bureaucratic protocols present a challenge to the local formal networks. As one community leader explained,

The implementation of DRR strategies in our locality is often delayed due to the overly bureaucratic attitude of formal institutions such as the Union Parishads, Project Implementation Office for Disaster Management, and Upazila Nirbahi Offices. This kind of approach undermines the long-term viability of these initiatives, rendering our area more susceptible to climatic risk.

Entities such as *Union Parishads*, local government engineering departments, and the Bangladesh Water Development Board receive extensive geographic information systems (GIS) and remote sensing (RS) databases from the Bangladesh Space Research and Remote Sensing Organization (SPARRSO) and Centre for Environmental and Geographical Information Services (CEGIS), which is based in the capital city of Dhaka. These databases are invaluable resources for local authorities, providing them with the means to proactively address ongoing and imminent climate challenges, including information on potential cyclones, rises in sea levels, and flooding. GIS is recognized as a powerful tool that enables the accurate mapping of vulnerable areas, thereby facilitating the identification of high-risk zones and densely populated centers susceptible to climatic risks. However, the field data relating to GIS and RS revealed limited vertical (national-regional-local) and horizontal (among the local community-based institutions) collaboration. Furthermore, the findings showed that the involvement of local community stakeholders in the project planning phases was also nominal, thus limiting the scope of the actual application of GIS-based tools and outputs in local disaster management and planning.

In the micro-credit sector, the formal and quasi-formal institutions (i.e., Bangladesh Bank and MFIs) were found to be actively engaged in efforts to eradicate poverty and reduce vulnerability to livelihood security. While MFIs are primarily concerned with poverty alleviation, the increased frequency of climate-change-induced disasters has led them to incorporate DRR components into their institutional portfolio. As a result, MFIs and their programs significantly assist vulnerable communities in coping with and adapting to climate risks at the local level. Numerous microfinancing institutions (e.g., Grameen Bank, ASA, Ektee Bari Ektee Khamar, Shushilan, Satkhira Unnayan Sangstha, Uttaran, Nawabenki Gonomukhi Foundation (affiliated with the Palli Karma Sahayak Foundation), Sonakhali Bohumukhi Somobay Somity, and the BK Social Safety Net) operate within the study area, providing credit to local communities with manageable repayment terms (i.e., most offer annual interest rates ranging from 4% to 24% and operate under the regulatory oversight of the Bangladesh Bank).

The findings indicated that a significant portion of residents in the study area access these MFIs for credit, which is crucial to helping communities recover from climate-induced disasters. In terms of credit usage, 34% of survey respondents reported that they had used the funds to install rainwater harvesting systems to ensure access to clean drinking water. Notably, 21% of farmers reported that, following Cyclone Bulbul (2020), access to institutional credit facilities enabled them to successfully restore their agricultural activities. One local MFI manager shared that,

> *Amidst Cyclone Bulbul in 2020, we extended credit amounting to Bangladeshi Taka (BDT) 13,00,000 to the community adversely impacted by the disaster, at an exceptionally low interest rate of 2%. Most beneficiaries were farmers, who were driven by the aspiration to revive their agricultural pursuits. As a local MFI, we made a serious commitment to aid these farmers, encompassing guidance and mentorship across diverse farming techniques. These included integrated farming management, strategies for pest control, and the advocacy of hydroponic agricultural practices.*

3.3.1.2. Formal and quasi-formal institutions in the agricultural sector

In the study area, the Department of Agricultural Extension (DAE) of the Government of Bangladesh was the most proficient formal agency facilitating climate change-related agricultural adaptation practices (Table 3.3). Operating at the grassroots level, the DAE leverages institutional programs and the expertise of highly trained staff to implement projects aimed at mainstreaming agricultural technologies to address climate change challenges. Additionally, institutions such as the Bangladesh Agricultural Research Institution, the Bangladesh Rice Research Institute, and the Bangladesh Institute of Nuclear Agriculture primarily focus on research and the development of crop varieties, production techniques, and technological transfer at the national and regional levels. In contrast, field-level initiatives are spearheaded by institutions like the *Union* Agriculture Office, the *Union Parishad* office, and NGOs such as Rupantor, the Nawabenki Gonomukhi Foundation (affiliated with the Palli Karma Sahayak Foundation), the Centre for Natural Resource Studies, Uttaran, the Sajida Foundation, and World Vision. These organizations are actively engaged in programs relating to seed distribution, information and knowledge dissemination, agricultural training for farmers, and providing irrigation facilities.

The survey results revealed that formal and quasi-formal institutions have implemented numerous interventions and projects in the agricultural sector, including climate-smart initiatives, which have been conducted via seminars and training facilities at the national and local levels. These endeavors were designed to develop efficient manpower for agricultural climate change adaptation practices, enhance farmers' skills, and build capacity for climate-smart technologies related to crop varieties, pest management, and irrigation. Significantly, these institutions also contribute to the supply of agricultural inputs, machinery, and equipment. Thus, such initiatives increase crop productivity and enhance food security in vulnerable communities at the local level. To illustrate, the DAE and *Union* Agriculture Office collaborate to assist farmers in adopting climate-resilient rice variants such as *BRRI*-47, 52, 55, 67, 68, and 72, as well as *BINA*-10. These varieties are specifically chosen for their suitability in changing climate scenarios, requiring fewer irrigation facilities and contributing to the overall resilience of agricultural practices. One local farmer detailed the benefits of this program as follows:

> *This year, I have received 50kg of BRRI-52 seeds and 25kg of BINA-10 seeds at no cost from the Union Agriculture Office. Additionally, the Department of Agricultural Extension and the Union Agricultural Office collaborated to introduce innovative crop rotation practices that resulted in a twofold increase in crop production while substantially reducing our production costs. This strategic intervention led to a substantial enhancement in profit margins.*

However, it is noteworthy that 68% of survey respondents deemed the support and interventions provided by these institutions as insufficient for addressing the needs of their communities. They also pointed out that the locals, especially marginalized farmers, faced challenges in accessing agricultural information and resources from the regional government offices. As one such marginalized farmer shared,

> *Over the past decade, I have consistently faced challenges in accessing subsidies for adopting agricultural technologies provided by various governmental projects. These types of sanctions stemmed from the differences between my political views and the views of the local government officials (i.e., the local chairman and members). In addition, other institutional representatives also have actively influenced local authorities to exclude my participation from all agricultural initiatives in our locality.*

Table 3.3: Adaptation programs pursued by formal and quasi-formal institutions in the agricultural sector.

Institutions	Key issues of concern	Adaptation technology	Implications of such initiatives
– Bangladesh Agricultural Research Institute – Bangladesh Rice Research Institute – Bangladesh Institute of Nuclear Agriculture – Department of Agricultural Extension – *Upazila* Agriculture Office – *Union Parishad* – Rupantor – The Nawabenki Gonomukhi Foundation (affiliated with the Palli Karma Sahayak Foundation) – Center for Natural Resource Studies – Uttaran – The Sajida Foundation – World Vision	– Provision of climate-smart agricultural information. – Developing farmers' skills and building capacity for climate-resilient agricultural technologies. – Supply of seeds, seedlings, and fertilizers to farmers' groups.	Agricultural sector Biotechnology: Genetically modifying crops (saline-tolerant such as *BRRI*-52, 47, 67, and 72, and *BINA*-10; flood-tolerant such as *BRRI*-55, 68, 73, and 87; and other climate stress-tolerant such as *BRII*-27, and 10). Hydroponic and aquaponic agricultural practices; dyke cropping; vermi and organic composting; vertical towering; mulching methods; agricultural practices using gunny bags, concrete pots, or cork boxes; integrated farm management; and crop diversification based on seasons.	– Adaptation to climate vulnerability. – Increased crop productivity and food security. – Income-generating activities. – Promoting sustainable agricultural practices that increase soil health, reduce the number of irrigation facilities, and minimize dependency on chemical fertilizers.

Source: Field data, 2023.

3.3.1.3. *Formal and quasi-formal institutions in the water and infrastructural sector*

Climate change has contributed to a freshwater crisis that is projected to escalate without significant interventions (Abedin et al., 2018). In response, the Government of Bangladesh and various other non-governmental entities have launched projects focused on the use of technological advances to improve access to fresh water for drinking and irrigation purposes in the southwestern regions of the country (see Table 3.4). In line with such initiatives, and with the support and management of the Bangladesh Water Development Board, the study communities have progressively embraced a range of technologies in response to evolving climate conditions. These technologies include rainwater harvesting systems, reverse-osmosis systems, pond sand filtration, and deep and shallow tube wells.

The research showed that the Bangladesh Water Development Board introduces innovative technologies to local communities and offers technical support in collaboration with the Department of Public Health Engineering. Local institutions, such as local government engineering departments, the Project Implementation Office, the DAE, and the *Union Parishad* Office work collaboratively to implement projects initiated by the Bangladesh Water Development Board and the Department of Public Health Engineering. These collaborative efforts entail developing coordinated action plans and sharing expertise at the local level, particularly via training initiatives aimed at equipping local authorities with the skills needed to efficiently operate and maintain various water technologies. Such capacity enhancement programs are critical, as they ensure the sustained functionality of water supply systems, help to secure financial resources for water-related projects and promote the responsible and sustainable use of local resources.

Several NGOs and INGOs, including Rupantor, the Sajida Foundation, World Vision, the Nawabenki Gonomukhi Foundation, Friendship, Shushilon, and Satkhira Unnayan Sangstha, actively support water-related projects by securing funding from external sources. Despite these positive initiatives, the respondents also noted several key challenges. For instance, 68% of respondents expressed concerns about the high price of water from reverse-osmosis plants, as the cost of reverse-osmosis water constituted a significant portion of many families' monthly expenses. Furthermore, as marginalized households simply could not afford water from reverse-osmosis plants, these households had little to no access to such technologies.

Nonetheless, NGOs, namely, Rupantor, Friendship, and the Nawabenki Gonomukhi Foundation are promoting "water entrepreneurship" by installing reverse-osmosis plants and empowering community members to operate water businesses (and thus, generate profits). These NGOs provide comprehensive support, including technical, operational, and maintenance assistance, and conduct quarterly workshops to enhance the proper utilization of the reverse-osmosis plants. The implications of adopting such water technologies further ensure water security through improved drinking water quality and irrigation facilities.

The research findings also revealed that the Bangladesh Water Development Board (BWDB) and Local Government Engineering Department (LGED) are instrumental in implementing and maintaining critical infrastructure projects, particularly those aimed at safeguarding communities against climate-change-induced disasters. The Bangladesh Water Development Board focuses on coastal embankment projects, conceptualizing and constructing protective barriers to shield coastal areas from the adverse effects of cyclones, tidal surges, floods, and storms. These barriers include sea walls, sluice gates, polders, culverts, geobags, and geosynthetics. The LGED concentrates on local-level infrastructures, including cyclone shelters designed to provide “safe havens” during severe weather events. They also oversee the construction of such infrastructures and ensure facilities are equipped for emergencies. As one *Union* BWDB engineer shared:

> *During the previous year, we secured approximately $2 million in funding from the Asian Development Bank to execute a 3-kilometer-long embankment project -- spanning the regions of Kaliganj and Shaymnagar. In addition to the financial assistance rendered, the ADB facilitated a comprehensive series of training sessions for five days, concentrating on technological methodologies and the upkeeping of the recently established embankment initiatives. These training sessions proved instrumental in providing us with an extensive knowledge base, enriched by insights from preeminent specialists in this field.*

During primary data collection, it has been observed that the Bangladesh Water Development Board and the local government engineering departments maintained a collaborative relationship with one another and with local government authorities such as the *Union Parishad* office, the Project Implementation Office for Disaster Management, the *Union* Disaster Management Committee, and local community organizations. This collaborative approach is essential for ensuring a comprehensive strategy for disaster resilience. The Bangladesh Water Development Board's specialization in embankments and sluice gates is complemented by the local government engineering departments’ focus on community-oriented infrastructure, such as cyclone shelters. Such collaboration ensures that coastal communities benefit from a multi-layered defense against nature-triggered calamities. However, this institutional involvement extends beyond construction and maintenance; it also extends training to local authorities in disaster preparedness, evacuation procedures, and the maintenance of climate-resilient infrastructure.

Table 3.4: Adaptation programs by formal and quasi-formal institutions in the water and infrastructural sectors.

Institutions	Key issues of concern	Adaptation technology	Implications of such initiatives
– Bangladesh Water Development Board – Department of Public Health Engineering – Project Implementation Office for Disaster Management – Local Government Engineering Departments – Department of Agricultural Extension – *Union Parishad* – Sajida Foundation – World Vision – The Nawabenki Gonomukhi Foundation (affiliated with the Palli Karma Sahayak Foundation) – Friendship – Rupantor – Satkhira Unnayan Sangstha – Shushilon	– Establishing reverse osmosis, pond sand filtration, deep and shallow tube wells, and rainwater harvesting technologies. – Maintenance of water adaptation technologies. – Irrigation facilities.	Water resources (drinking and irrigation) Reverse osmosis, pond sand filtration, deep and shallow tube wells, and rainwater harvesting.	– Limits water security. – Improves drinking water quality. – Enhances irrigation practices. – Creates the possibility for income generation via water business.
– Local government engineering departments – Bangladesh Water Development Board – Project Implementation Office for Disaster Management – *Union Parishad* – *Union* Disaster Management Committee	– Identifying major vulnerable areas. – Establishing various infrastructural projects at the coastal level. – Protecting and maintaining embankments.	Infrastructural Sector Multi-purpose cyclone shelters, sea walls, block embankments, sluice gates, polders, culverts, geobags, and geosynthetics.	– Protecting lives, resources, and critical infrastructures.

Source: Field data, 2023.

3.3.2 Informal Institutions

3.3.2.1 Informal institutions and climate-induced disaster risk reduction

The study identified various informal institutions in the study communities, including CBOs, faith-based organizations, village development committees (VDCs), and indigenous knowledge-based institutions (see Table 3.5). These entities collaborate to safeguard community resources and assets from extreme climatic events and foster capacity building through the adoption of diverse innovation and adaptation technologies at the local level. This collaboration among informal institutions significantly bolsters the community's self-reliance and mobilizing capacity, thus reducing its dependence on external sources.

CBOs play a pivotal role in organizing courtyard meetings, which involve members from diverse groups such as VDCs, school committees, and faith-based groups, as well as community leaders, politicians, elites, local Cyclone Preparedness Programme (CPP) volunteers, farmers, and fishermen. These forums provide community members with a platform to discuss existing vulnerabilities and challenges, explore surrogate measures, and adopt innovation and adaptation technologies to mitigate the impacts of climate-induced disasters. The exchange of experiences during these meetings is crucial for generating knowledge that can fortify the resilience-building process among community members, underscoring the importance of dialogue and interaction among local stakeholders. This collaborative knowledge-creation process is detailed in Table 3.5.

Residents in the study communities had made a concerted effort to reduce their reliance on external sources and enhance their self-sufficiency by safeguarding shared resources and bolstering their community's resilience against the risks posed by climatic disasters. The adoption of a CBDRM approach was instrumental in achieving these ends, as it brings together local community members, Cyclone Preparedness Programme (CPP) volunteers, *Union* and Village leaders, politicians, and religious leaders in order to identify potential climatic disasters, develop hazard maps, conduct community risk assessments, formulate contingency plans, and disseminate early warning information. CBDRM activities include organizing workshops, gatherings, and motivational sessions that focus on ways of reading and understanding different warning signs. In addition, practice exercises are conducted, which promote local community members' engagement in the CBDRM approach. This approach also fosters a sense of community ownership, enhances social networks, and promotes collective action. These forums extend beyond immediate disaster activities and include a focus on long-term initiatives aimed at building adaptive capacity. The effectiveness of such collaborative endeavors was evident during Cyclone Bulbul (2020), as community members were well-prepared to confront its adverse effects. Indeed, the community's response to this disaster was both timely and robust, which was perhaps best exemplified by its timely dissemination of warning signals in the lead-up to the cyclone's landfall.

Through the empirical investigation, it was found that before the 2000s, there was a growing concern about misinformation that infiltrated these efforts. Religious and traditionally fatalist groups played influential roles in shaping the narrative surrounding (i.e., beliefs, behaviors, and norms) DRR strategies by incorporating innovation and adaptation technologies at the local levels. Unfortunately, their well-intentioned advice has sometimes been tainted by misinformation, leading to misguided decisions in disaster situations. For example, there have been instances where religious leaders and traditional fatalists propagated the notion that certain disasters were "divine punishments" or "acts of god", discouraging communities from adhering to scientifically proven evacuation plans, strategies, or the use of various early warning systems (Weichselgartner & Bertens, 2000; Kempe, 2003; Nasreen, 2004; Jensen et al., 2022). This blending of religious doctrine with disaster response has undermined the effectiveness of preparedness efforts and hindered the adoption of innovation and adaptation technologies in the past.

However, the local communities have witnessed notable changes in the early 2000s, reflecting some positive shifts towards the improvement of narratives and socially corrected communications. The post-2000 era has seen a concerted effort to address the challenges posed by misinformation, recognizing the increasing need for accurate information dissemination in the face of increasing climate-related risks. Religious and community leaders, along with political influencers, began to willingly collaborate with scientific communities and local authorities. This shift has not only contributed to aligning community beliefs with proven strategies but has also fostered a more harmonious relationship between traditional values and contemporary scientific knowledge.

Table 3.5: Innovative programs related to climate-induced disaster risk reduction offered by informal institutions.

Institutions	Key issues of concern	Meeting arena	Innovation	Implications of such initiatives
– Village Development Committee – Community-based organizations – Cyclone Protection Programme volunteers – *Union* and Village leaders – Local community people – Politicians and members of elite groups – Religious institutions such as mosques, churches, and temples	– Identifying and addressing potential vulnerabilities through interactive discussions. – Disseminating early warning information at the local level. – Transferring of local knowledge.	Courtyard meetings and faith-based group meetings.	Early Warning System and Community-based disaster risk management (CBDRM)	– Promotes local and Indigenous knowledge regarding local hazards and coping mechanisms. – Fosters community ownership and participation. – Enhances community mobilization and social cohesion. – Develop hazard mapping. – Develop risk-reduction action and contingency plan.

Source: Field data, 2023.

3.3.2.2 Informal institutions and the agricultural sector

Within the agricultural sector, we observed effective collaboration between farmers' associations and the Village Development Committees (VDC), *Union* and Village leaders, and representatives from local agri-businesses (see Table 3.6). These groups worked together to identify suitable crops based on the prevailing soil characteristics and fertility, ultimately focusing on high-yielding varieties resilient to salinity and flooding. As a result of these collaborations, rice varieties such as *BRRI*-10, 27, 47, 52, 55, 67, 68, 72, 73, 87, and *BINA*-10 were identified as optimal for the farmers in the region. Additionally, these collective efforts generated a comprehensive body of information regarding crop cultivation techniques and sustainable agricultural practices, including hydroponics and aquaponics, dyke cropping, integrated farming management, vermi and organic composting, and vertical towering, which local farmers could draw upon.

The study results revealed that informal institutions promoted agricultural technologies through local mobilization. For example, they frequently organize community gatherings to discuss targeted crop cultivation, distribute seeds and plants to farmers, and ensure that farmers are receiving sufficient technical assistance, irrigation resources, and pest control measures. One notable example of such an informal institution is the "*Krishok Sheba Shonghoton*" farmers' association, which was established in 2006. This association is actively involved in rice seed breeding research, focusing on saline-tolerant varieties that are primarily cultivated during the *aman* (rainy) season. They also organize an annual rice festival (*Chal Utshob*) to promote different rice varieties among local farmers. At the festival, seeds are made available for purchase or exchange with other suitable local varieties. The association also provides local farmers with critical support in the form of information and guidelines for cultivating specific rice varieties. When needed, the association extends technical assistance—including artificial light traps for pest management, tractors for plowing, tilling, sowing, and harrowing, power tillers for soil preparation and planting, combine harvesters for rice harvesting, and reaper machines for cutting rice paddy—often at a minimal rental fee for local farmers. This multifaceted support contributes significantly to the agricultural resilience and sustainability of the local farming community. One local farmer described their experiences with the farmers' association as follows:

> *In 2021, I collected BRRI-52 rice seeds from the "Krishok Sheba Shonghoton" with a minimum cash payment. They provided me with all the support needed from germination*

to harvesting the rice. With their advice, rice production has increased twofold since the previous year. Additionally, I availed myself of the option to rent a tractor and power tiller from them, culminating in a substantial reduction of production expenses associated with the crop.

The findings of the empirical investigation confirmed that the implementation of such initiatives by informal institutions promotes sustainable agricultural practice at the grassroots level. These sustainable practices focus on enhancing soil health, optimizing irrigation facilities, reducing dependency on chemical fertilizers, and improving crop productivity, which in turn promotes overall food security, especially for vulnerable populations. Moreover, the implementation of these practices creates income-generating opportunities for local farmers. For instance, it was found that the agricultural practice through dyke cropping as well as hydroponics enables the local farmers to meet their family's nutrition needs. Additionally, they can sell the surplus to the local market and thereby contribute to their household income.

Table 3.6: Adaptation programs by informal institutions in the agricultural sector.

Institutions	Key issues of concern	Meeting arena	Adaptation technology	Implications of such initiatives
– Village Development Committee – Community-based organizations – Farmers' associations – *Union* and Village leaders – Representatives from local agri-business	– Identifying potential crops based on soil characteristics and fertility, such as saline and flood-tolerant varieties, high-yielding crops, and many others. – Providing information services regarding various crop cultivation techniques such as hydroponics, aquaponics, vertical gardening, integrated farm management, dyke cropping, and crop diversification.	Courtyard meetings and faith-based group meetings.	Agricultural Sector Biotechnology: Genetically modifying crops (saline-tolerant such as *BRRI*-52, 47, 67, and 72, and *BINA*-10; flood-tolerant such as *BRRI*-55, 68, 73, and 87; and other climate stress-tolerant such as *BRII*-27, and 10). Hydroponic and aquaponic agricultural practices; dyke cropping; vermi and organic composting; vertical towering; mulching methods; agricultural practices using gunny bags, concrete pots, or cork boxes; integrated farm management; and crop diversification based on seasons.	– Adaptation to climate vulnerability. – Increased crop productivity and greater food security. – Income-generating activities. – Promotion of sustainable agricultural practices aimed at increasing soil health, reducing irrigation facilities, and minimizing dependency on chemical fertilizers. – Encourages the diversification of crops and farming practices.

Source: Field data, 2023

3.3.2.3 Informal institutions and the water sector

In addressing livelihood vulnerabilities and focusing on water resources (both for drinking and irrigation) and infrastructure, two key areas of emphasis were identified. First, there is a need for the widespread dissemination of information about water technologies such as reverse osmosis, rainwater harvesting, pond sand filtration, and shallow and deep tube wells. Second, there is an urgent need to assess and support the development of critical infrastructure at the grassroots level.

The research findings underscore the pivotal role played by informal institutions (e.g., the VDC, CBOs, *Union* and village leaders, community members, and representatives of local water businesses) at the local level in addressing water-related issues (see Table 3.7). These entities serve as valuable collaborators for local government bodies, including the Bangladesh Water Development Board and the Department of Public Health Engineering, as they are instrumental in disseminating information about available water sources within local communities. This objective is typically achieved through courtyard meetings and advocacy initiatives facilitated by local religious leaders. This collaborative approach not only fosters community mobilization, but it also reduces the community's reliance on governmental entities such as the Bangladesh Water Development Board.

CBO members were found to be actively involved in setting up water infrastructure (e.g., pond sand filtration and shallow and deep tube wells) for household activities and irrigation purposes. For instance, during 2018-19, the local youth organization, "*Jubo Shongho,*" spearheaded the construction of four deep tube wells and one pond sand filtration system. This initiative aimed to support economically disadvantaged communities by providing them with access to water for daily activities, including irrigating agricultural land and fish farming. Such community-led initiatives highlight the effectiveness of collaborative efforts in addressing water-related challenges and promoting sustainable solutions for both household and agricultural needs. One local farmer reflected on this initiative thusly:

> *Earlier, we had to depend mainly on rainwater for irrigation on the agricultural land, but the deep tube well from "Jubo Shongho" is helping us in a big way with the irrigation facility at just a nominal cost.*

Table 3.7: Adaptation programs initiated by informal institutions in the water sector.

Institutions	Key issues of concern	Meeting arena	Adaptation technology	Implications of such initiatives
– Village Development Committee – Community-based organizations – Farmers' associations – *Union* and Village leaders – Local community members – Representatives from local water resource businesses	– Information provision and the promotion of reverse osmosis, rainwater harvesting, pond sand filtration, and shallow and deep tube wells.	Courtyard meetings and faith-based group meetings	Water Resources (Drinking and Irrigation) Reverse osmosis, pond sand filters, deep and shallow tube wells, and rainwater harvesting.	– Limited water security. – Improved drinking water quality. – Enhanced irrigation practices. – Community involvement and ownership in water technologies.

Source: Field data, 2023.

Local institutions help to foster social cohesion among community members by actively engaging in conflict resolution and facilitating negotiations between diverse groups within the community. This is a crucial function, as conflicts often arise between various stakeholders, including agricultural landowners, farm-based fishermen, and local government authorities. The study findings revealed specific conflicts between fish-farm proprietors and the local government engineering department. In particular, the engineering departments were resistant to the fish-farm proprietors' desire to use PVC pipes to enable saltwater intrusion, as doing so would result in substantial embankment degradation.

Furthermore, the field data showed that various community organizations had established a learning platform to address conflicts among local groups, which has since become an integral part of the negotiation process. This platform brings community members together to identify potential strategies for preventing the breaching of embankments. In instances where conflicts persist, fines ranging from BDT 30,000 to 100,000 are imposed, depending on the extent of damage to the embankment. This collaborative approach not only facilitates conflict resolution but also establishes a framework for sustainable coexistence and responsible resource management within the community. As one local community leader explained,

> *During July, a group of 4 fish-farm owners destroyed approximately 0.5 km of embankment in our area to allow saltwater drainage into their fish farms. This resulted in a massive conflict between the owners and local government authorities (i.e., the local government engineering department and the Bangladesh Water Development Board). However, due to successful mediation by the community organizations, no legal actions were taken, but they were fined BDT 50,000 each*.

3.4 Discussions

In this section, I delineate the three main contributions of this study and highlight their significance in promoting the adoption of innovation and adaptation technologies to address climate-related challenges and enhance resilience at the local level. First, collaborative interaction and synergy among institutions are critical to facilitating the uptake of innovation and adaptation technologies for DRR and climate risk reduction in the agriculture and water sectors. Second, the implementation of adaptation technologies in the agriculture and water sectors must be inclusive and equitable to ensure they also enhance the capacities and resilience of vulnerable communities.

And third, participation and continued learning on the part of local institutions are key for facilitating meaningful community engagement, thus emphasizing the significance of establishing collaborative partnerships with informal institutions.

In terms of DRR, the empirical investigation found that formal and quasi-formal institutions oversee new and innovative practices and technologies, governance systems, policies, training facilities, funding, and collaboration activities at the local level. In the study areas, all local-level DRR-related projects must be approved by the *Union Parishad* office, which engages various other regional organizations and stakeholders (e.g., the Project Implementation Office for Disaster Management, the *Union* Disaster Management Committee, the Ward Disaster Management Committee, Cyclone Preparedness Programme (CPP) volunteers, community members, and CBOs) in formulating DRR plans, developing hazard maps, and establishing vulnerability indices. The formal and quasi-formal institutions in the study area adopted a CBDRM approach for such mobilization. The study of communities in coastal Bangladesh captured the collaborative efforts of multi-level institutions to address emerging climate challenges and to empower vulnerable communities. These institutions worked together to disseminate disaster warning messages, strengthen social networks, and foster collective actions to minimize climate-induced disaster impacts, thereby enhancing resilience at the community level. Similarly, recent research revealed that in Thailand, community and village-level institutions had played a crucial role in developing adaptation and mitigation strategies against flood risks in the Chao Phraya Basin (ADB, 2020).

In addition, the findings of the study showed that MFIs played a significant role in the DRR strategies by helping vulnerable communities mitigate livelihood security risks and recover from damage from natural disasters. This aligns with other work recognizing MFIs as key recovery tools in risk reduction approaches aimed at assisting at-risk communities and individuals impacted by disasters (Kumar & Newport, 2005; Becchetti & Castriota, 2011). During Cyclone Sidr (2007) and Cyclone Aila (2009), MFIs, such as BRAC and Grameen Bank, provided grants and reduced-interest loans to affected people, which were instrumental in allowing them to repair and rebuild their homes and restore their agricultural and livelihood activities (Faruqee & Khalily, 2011; Islam, 2018).

In the uptake of adopting agricultural technologies, it was found that institutional arrangements consistently supported communities in accessing agricultural technologies. The initiatives undertaken by formal and quasi-formal institutions to introduce and promote agricultural technologies in this region have the potential to address key challenges faced by local farmers, such as the impacts of climate change, soil salinity, and water scarcity. Furthermore, the support offered by these institutions extends to raising awareness and technical support through information services, providing access to credit facilities, protecting critical infrastructures, and ensuring access to irrigation facilities and subsidies. For example, regional-level entities such as the *Union* Agricultural Office partnered with NGOs and community-based groups to facilitate the adoption of climate-resilient rice varieties and low-irrigation agricultural practices among local farmers. To this end, these entities work together to offer free seeds, information, and training to local farmers, with the ultimate goal of enhancing their capacity for climate change adaptation practices.

The collaborative involvement of regional stakeholders and agencies, including the *Union Parishad*, the Bangladesh Water Development Board, the Department of Public Health and Engineering, the local government engineering departments, and community-based groups, underscores the importance of a collective and coordinated approach to addressing water-related challenges. This collaboration not only acknowledges that finding solutions for these challenges is a shared responsibility, but it also emphasizes the interconnectedness of the various agencies involved in such endeavors. The multifunctional role of water technologies, along with their ability to ensure access to fresh water for drinking, livelihood, and irrigation activities, highlights the importance of an integrated and sustainable water management approach that addresses the diverse requirements of communities. These results concur with those reported by Greenlee et al. (2009), Freni and Liuzzo (2019), Parkinson et al. (2019), and Garcia et al. (2023), thus confirming the importance of collaborating with localized institutions and using multifaceted strategies to ensure water security and resilience. It was observed that formal and quasi-formal institution initiatives mostly involved introducing and installing water technologies in the study communities, along with their maintenance activities. In these initiatives, informal institutions (e.g., community-based groups) significantly assisted in the adoption process and community mobilization, thus establishing synergy between multi-level stakeholders in the adoption of these technologies at the grassroots level.

Nonetheless, the inclusiveness and equitability of these initiatives remain unclear and contingent upon several factors, such as the ability to access information and resources related to DRR and agricultural and water technologies. The study findings indicated that, while formal institutions designed their programs to reach communities more broadly, their top-down approach to program implementation resulted in disparities in access to information, which often undermined their inclusiveness. Other factors, such as education, socioeconomic status, and political influence, further restricted marginalized communities' ability to access and learn about the benefits of new technologies (Lovell & Masson et al., 2014; Lewis & Hossain, 2017; Uddin et al., 2020; Sajid et al., 2022). With regards to agriculture, 64% of survey respondents reported receiving limited assistance from formal and quasi-formal institutions—a finding that aligns with prior studies conducted in coastal Bangladesh (Islam & Nursey-Bray, 2017; Kundu et al., 2020; Paparrizos et al., 2021), Tanzania (Lwoga et al., 2011), and Thailand (Raungpaka & Savetpanuvong, 2017).

It was found that certain underprivileged groups were at greater risk of exclusion due to the non-uniform distribution of resources and benefits. These findings concurred with those of Lewis and Hossain (2017) and Uddin et al. (2020) in that technological interventions tended to favor wealthier or politically connected individuals and groups (albeit usually inadvertently), thus leaving marginalized groups at a disadvantage. For example, marginalized farmers often lack access to institutional resources due to power dynamics and the political influence of local stakeholders, who largely target specific interest groups when distributing agricultural resources such as specific crop varieties, power tillers, tractors, subsidies, and credit facilities. Similar patterns relating to political influence were observed in both study *Unions;* for instance, nepotism or bias towards groups with better connections to the ruling political party was observed in the distribution of crop seeds and rainwater harvesting drums. These findings align with those previously reported by Ainuddin et al. (2013), Hermansson (2019), Lewis and Hossain (2019), and Choudhury et al. (2021a).

The affordability of agricultural and water technologies can be a barrier to access, further exacerbating existing social and economic inequalities (Islam & Nursey-Bray, 2017; Puppala et al., 2023). Moreover, gender relations can complicate the process. For instance, although women are often primarily responsible for water-related activities, their involvement in decision-making processes regarding technology adoption is typically quite limited. This lack of involvement was previously illustrated by Sajid et al. (2022) in their study of water technology in Pakistan. Therefore, formal institutions must prioritize making these technologies financially accessible, perhaps through subsidies or low-interest credit programs, and efforts must be made to ensure the decision-making process is more gender-inclusive, as such measures will ensure that small-scale farmers and vulnerable populations benefit from these technologies equitably.

The study findings further revealed that DRR, agricultural, and water-related programs run by formal institutions often fall short in terms of inclusivity. Specifically, these institutions' implementation of water technologies, such as rainwater harvesting systems, reverse osmosis, pond sand filtration, and deep and shallow tube wells, has largely been strategically directed toward climate change-affected communities at large, which ignores the unique water-related burdens faced by underprivileged groups.

The informal institutions mobilized local communities by organizing community meetings and gatherings, which empowered vulnerable communities to collectively engage in crop harvesting, safeguard critical resources, and enhance community awareness of extreme climatic events. These institutional processes allow Indigenous knowledge, beliefs, and practices to become catalysts for fostering community resilience and capacity-building in the face of climate-induced disasters (Armitage et al., 2008; Murti & Mathez-Stiefel, 2019; Choudhury et al., 2021b; Haque et al., 2022). Such community-driven initiatives, rooted in indigenous wisdom, can significantly contribute to building adaptive capacities and fortifying communities against the impacts of climate change.

The power dynamics and authoritarian approach often employed by formal institutions were found to hinder community mobilization for DRR and the adoption of agricultural and water adaptation technologies. Specifically, It was found that informal institutional networks were more effective at disseminating warning information, community mobilization, and connecting vulnerable communities with agencies such as the *Union Parishad*, the Cyclone Preparedness Programme (CPP), and other formal and quasi-formal institutions throughout the risk management process. These outcomes align with Azad et al.'s (2021) conclusions regarding the strength of informal networks in Bangladesh's coastal region. The coordination of multi-sectoral institutions creates the opportunity to identify local vulnerabilities to protect community resources and build capacity against climate stressors.

The findings of this study emphasize the significance of power and resource sharing through effective institutional mechanisms (Tang et al., 2009; Keys et al., 2014). One of the primary issues stemming from the dominance of formal institutions is the imposition of lengthy bureaucratic protocols due to their top-down approach. Numerous researchers (e.g., Ahrens & Rudolph, 2006; Maes et al., 2018; Uddin et al., 2020; Kalogiannidis et al., 2023) have argued that the prevalence of top-down approaches revealed in less developed countries is typically due to the limited autonomy of regional entities. Similarly, it was observed that, in coastal Bangladesh, decision-making processes within the formal network often involved intricate procedures and multiple layers of approval, causing delays and inefficiencies in implementing innovation and adaptation technologies. This aligns with Barnett et al.'s (2015) findings related to barriers to climate change adaptation and Azhon et al.'s (2017) findings regarding institutional barriers to the adoption of water technologies in India.

Finally, it was found that, in their role as intermediaries, formal institutions did not effectively establish the essential connection between quasi-formal and informal networks in coastal Bangladesh. This inability was due to their failure to adequately incorporate culture and the community into initiatives focused on innovation and adaptation technologies. Therefore, greater focus should be placed on incorporating cultural norms and values and promoting community participation throughout the adaptation process, as doing so will improve the efficacy of formal institutional mechanisms. In such conditions, empowering local stakeholders by delegating authority and responsibility to them can enhance the adaptability and flexibility of governance frameworks, thereby forging more effective connections between formal, quasi-formal, and informal networks at the grassroots level.

3.5 Conclusion

The results of this study provide several valuable insights into the pivotal role of multi-level institutions in facilitating the adoption of innovation and adaptation technologies to mitigate climatic risks at the local level. For instance, I observed that institutions foster a multi-dimensional approach to resilience-building in climate-vulnerable communities by integrating innovation and adaptation technologies at the community and individual household levels. Findings such as these demonstrate that supportive institutional environments can be key in catalyzing the development and dissemination of climate-resilient technologies.

The findings further affirm that the success of institutional initiatives in DRR and the adoption of agriculture and water technologies at the local level in coastal Bangladesh hinges on factors such as community engagement, inclusivity, and cultural sensitivity. In addition, I show that it is essential to strike a balance between targeted interventions for vulnerable community members and a broader inclusive approach to involve all stakeholders. Furthermore, it is critical for formal and quasi-formal institutions to nurture capacity-building by partnering with informal networks, as this will ensure that local communities are equipped with the knowledge and skills required to cope with and adapt to climate risks. Moreover, policymakers and institutions must continually assess and adapt their strategies to ensure that their benefits are shared equitably and that no community is left behind in the pursuit of sustainable risk reduction management.

This research also identifies significant institutional deficiencies and barriers that hinder progress, including inadequate partnerships, authoritarian operating procedures, lengthy bureaucratic processes, and a lack of inclusivity and equitability at the local level. Addressing these challenges will require substantial improvements to governance structures and practices, which will ensure proactive measures in institutional activities. Additionally, fostering a cohesive and collaborative approach to formulating community initiatives and national policy that involves stakeholders from all institutional levels will be essential for effective innovation and technology adoption.

The findings of this study highlighted the importance of flexibility and adaptability within institutional dynamics, confirming their essential role in sustained climate risk reduction programs. As climate change continues to evolve, institutions must remain dynamic and responsive to emerging challenges. To this end, it will be imperative for formal institutions to integrate cultural mechanisms, take collective action, develop social networks, and establish collaborations with informal and quasi-formal institutions at the grassroots level. Adaptive governance structures that incorporate feedback loops, continuous monitoring, and evaluation mechanisms will also be vital for ensuring the long-term effectiveness of climate resilience efforts.

The mainstreaming of innovation and adaptation technologies via institutional processes that involve all major stakeholders will be crucial to enhancing climate risk reduction and resilience to disasters. Such mainstreaming will allow Bangladesh's coastal communities to work collectively toward ensuring a more resilient, sustainable, and secure future.

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CHAPTER 4

Discussion and Conclusion

4.1 Introduction

Climate-induced disasters in Bangladesh have become increasingly prevalent and devastating in recent years, revealing the high vulnerability of the region to the negative impacts of climate change (Ahmed & Eklund, 2021). Rising sea levels, more frequent and intense cyclones, prolonged monsoon seasons, and erratic weather patterns have all contributed to a heightened risk of disasters. The impact of climatic disasters extends beyond the immediate loss of life and property, affecting coastal Bangladesh's agriculture, water, infrastructure, and overall socio-economic stability.

Innovation and climate change adaptation technology plays a crucial role in responding to the region's challenges posed by climate change and its susceptibility to climate variability. Such innovations and adaptation technologies (see Chapter 2) not only improve the resilience of communities and protect critical resources but also offer opportunities for economic growth and sustainable development in coastal Bangladesh. As the nation continues to grapple with the impacts of climate change, the role of innovation and adaptation technology remains pivotal in building a more resilient and prosperous future for its coastal regions. In this regard, my thesis research emphasized identifying the role of multi-level institutions (see Chapter 3) in climate disaster risk reduction at the local level.

A number of research efforts have been made on innovation, adaptation technology, and institutions (Huq et al., 2013; Shaw et al., 2016; Islam & Nursey-Bray, 2017; Hussain & Saha, 2019; Izumi et al., 2019; Haque et al., 2022), but they were carried out in an isolated manner, focusing on only one single dimension—namely innovation or adaptation technologies. Moreover, the aspects of integration of innovation and adaptation technology and the role of multi-level institutions in risk reduction and strengthening community resilience towards climate-induced disasters have generally been ignored. Therefore, the main aim of my thesis research is to advance the understanding of the prevailing innovation and adaptation technology in reducing climate-induced disaster impacts in the coastal region of Bangladesh. It also aimed to examine the institutional dynamics in climate risk reduction at the local level.

The specific objectives of this research were: i) to identify the existing innovation and adaptation technology to minimize climate risk impacts and strengthen community resilience ii) to analyze the drivers that promote the adoption of innovation and adaptation technologies and iii) to examine the role of multi-level institutions in reducing climate risk through facilitating innovation and adaptation technologies at the local level.

4.2 Key Findings of the Study

All three of the aforementioned objectives have been achieved, and the associated results and findings have been presented in the preceding two chapters. A synthesis of the key findings are given below:

- **Disaster risk reduction (DRR) has been successfully implemented through the effective use of the Early Warning System (EWS), and Cyclone Preparedness Programme (CPP).**

  In response to the escalating climate challenges, local communities in coastal Bangladesh have emerged as pioneering actors for developing and implementing various innovations in disaster risk reduction (DRR) at the local level (see Section 2.5.1). Innovations in DRR including early warning systems (EWS), and the Cyclone Preparedness Programme (CPP) have played a crucial role in saving countless lives during climatic disasters. This has been achieved through the identification of vulnerable areas, dissemination of early warning information before the onset of any disaster events, and training on disaster preparedness and mitigation activities. Since the early 2000s, the disaster management discourse in Bangladesh had a radical transformation from a reactive to a proactive approach focusing on disaster mitigation.

  The findings of my investigation have revealed that 57% of the population receives warning information directly from the CPP volunteers, who disseminate warning information within 8 minutes at the local level. This rapid dissemination has helped vulnerable populations in evacuation, disaster preparedness, and relocating to nearby cyclone shelters. However, the hesitation of community members to relocate to cyclone shelters, as observed in the present study concurs with the findings of Chakma & Hokugo (2020), which indicated that 38-45% of people are reluctant to relocate due to concerns such as sexual harassment, safety issues, and inadequate space. The CPP further extends its assistance in search and rescue operations, first aid, relief, and rehabilitation activities to disaster-affected communities. Thus, the successful implementation of EWS and CPP has played a significant role in community mobilization to climate-induced disasters.

- **Community-based disaster risk management (CBDRM) approach enhances disaster risk reduction (DRR) strategies through community ownership.**

The CBDRM approach has been widely adopted and was instrumental in enhancing community resilience to DRR in both study *Unions*. This approach follows a bottom-up strategy, emphasizing community-focused climatic disaster management by using available community resources, and heeding community perspectives and values, all while fostering a sense of community ownership to strengthen capacities in minimizing risk and vulnerability. However, Kenney and Phibbs (2015) asserted that the CBDRM approach often ignores community beliefs, norms, and practices, hindering the involvement of local communities in the process.

In contrast to this assertion by Azad (2020), the study observed that, concerning the CBDRM approach, communities are actively involved in identifying their existing risk, utilizing techniques in disseminating early warning information, implementing preparedness mechanisms, and establishing alternative evacuation routes for vulnerable communities. Further, my investigation identified that CBDRM has been a successful approach in creating community ownership through inclusive participation, resource mobilization, and risk reduction strategies at the local level. The CBDRM approach allowed the local stakeholders to develop a 'hazard map' in Padmapukur *Union*, Shyamnagar, identifying vulnerable locations and available resources for local communities. Consequently, our study substantiated that the CBDRM approach creates a 'culture of prevention' and responsibility among the community members to minimize disaster impacts.

- **Micro-credit system has played a crucial role in building the livelihoods of climate-induced disaster victims as well as of vulnerable communities.**

Micro-credit systems through microfinancing institutions (MFIs) have proven to be a key tool in addressing climate vulnerability in coastal Bangladesh. The findings highlight the pivotal role played by the MFIs in empowering communities to rebuild and enhance their economic conditions in climate-induced disasters. In the study, it was revealed that 92% of households access loans/credit from a range of MFIs. Similarly, Becchetti and Castriota (2011) stated that

MFIs are recognized as a key recovery tool in the risk reduction approach to assist communities at risk and individuals impacted by disasters. Nevertheless, the empirical analysis of my study found that 72% of households fall into the ‘poverty trap’ due to loans and/or credit from multiple MFIs, a trend consistent with studies conducted by Faruqee and Khalily (2011) in coastal Bangladesh. This finding also concurs with the results of the Chirambo (2017) study in Africa. In the context of DRR, it was observed that the Bangladesh Rural Advancement Committee (BRAC) and Palli Karma Sahayak Foundation (PKSF) microcredit systems integrate disaster preparedness and risk reduction strategies into their training programs, equipping borrowers with the knowledge and skills needed to navigate and mitigate the effects of climate-induced disasters. For example, they provide training on climate-resilient agricultural practices—such as integrated farming management, and hydroponic agricultural practices, helping borrowers adapt to changing environmental conditions and safeguard their livelihoods.

By providing access to financial resources, the micro-credit system through different MFIs proactively supports the recovery process of vulnerable populations in repairing damaged property and restoring agricultural and livelihood activities. Overall, this financial tool proves instrumental in fostering resilience, enabling individuals and communities to withstand the adverse impacts and work toward building sustainable livelihoods in the face of ongoing climate uncertainties. In this context, Rathnayaka and Silva (2023) argued that microcredit significantly influences the financial status of household income and post-disaster recovery in coastal communities.

- **Adoption of agricultural and infrastructural technologies has lowered the degree of disaster vulnerability and livelihood risk of communities.**

The adoption of adaptation technologies mitigates communities' vulnerabilities to climate risk. In response to climate change, a considerable number of adaptation technologies are being implemented across diverse sectors. Adaptation technologies in the agricultural sector include climate-resistant rice varieties such as *T Aman; BARI dhan*-33, 56, 57, and 62; *BRRI*-55; *BRRI*-68; and *BRRI*-73—all commonly popular among the local farmers for higher production in both study regions. Similarly, Rabbani (2010) also found that climate stress-tolerant rice varieties offer high yields in climate-affected areas in coastal Bangladesh. Other adaptation practices include integrated farm management (IFM), dyke cropping, crop diversification, and hydroponic agricultural practices have emerged as transformative approaches in lowering the intertwined challenges of unemployment, household income, and food security in vulnerable communities. Through this multifaceted strategy, communities adopt a holistic approach that combines various agricultural practices to maximize productivity, sustainability, and resilience. The increased productivity and income generated through these approaches empower vulnerable communities to improve their standard of living, thus reducing associated economic risks at the local level.

As climate change impacts continue to intensify, coastal Bangladesh has undertaken strategic initiatives to protect against extreme climate events. In the uptake of infrastructural technologies, the implementation of protective measures such as sea walls, block embankments, sluice gates, geo bags, and multipurpose cyclone shelters are critically safeguarding both resources and infrastructures. Such measures represent a proactive response to the intensifying threats by cyclones, storm surges, and rising sea levels, not only reducing vulnerability but also fostering long-term sustainability and resilience of coastal communities.

Further, in the context of adaptation technologies in coastal Bangladesh, a key contribution of this research is the identification and description of ways that local knowledge and practices play a pivotal role in enhancing resilience to climate change impacts by adopting diverse adaptation practices. Coastal communities in Bangladesh have developed intricate understandings of their environment over generations, encompassing knowledge of weather patterns, tidal cycles, and ecosystem dynamics. This indigenous wisdom serves as a valuable resource in the design and implementation of adaptation technologies based on local conditions. Incorporating local knowledge ensures that adaptation strategies such as climate stress-tolerant varieties, sustainable agricultural practices (hydroponic, dyke cropping, integrated farming management), rainwater harvesting, and multipurpose cyclone shelters are contextually appropriate, effective, and sustainable. Moreover, it fosters community ownership and participation, thereby promoting the successful adoption and long-term maintenance of adaptation measures.

- **Adoption of water technologies enhanced income-generating opportunities and lowered the freshwater crisis.**

In the study area, due to the impacts of climate change, freshwater crises at the surface and ground level are acutely felt. These have compelled marginalized communities to adopt water technologies such as reverse osmosis (RO), rainwater harvesting (RWH), and pond sand filtration (PSF). These technologies have played a pivotal role in livelihood support and mitigating climate challenges, allowing communities to access clean and potable drinking water and irrigation facilities. The study reveals that 82% of households largely depend on rainwater harvesting (RWH) for drinking and household chores, as the RWH drums are easily available in the local market with minimum setup costs involved. Conversely, the water from the RO plant is expensive as the cost varies from BDT 0.25 to BDT 0.50 per liter.

These water technologies not only address the increasing freshwater crisis and contribute to improved health outcomes but also open a 'window of opportunities' for income generation. For instance, the promotion of women's empowerment through the 'water entrepreneurship' project created income-generating opportunities by addressing the water scarcity and unemployment issues in the study region. Further, communities can engage in aquaculture, agriculture, and other livelihood activities that depend on reliable freshwater sources.

- **Formal institutions have played a pivotal role in establishing the necessary conditions to support the livelihood strategies in risk reduction of local community members.**

The findings of this research revealed that formal and quasi-formal institutions act as connectors between communities and necessary resources, facilitating collaborative actions, identifying external support systems, and ensuring the integration of vulnerable communities into local initiatives (also see Agrawal, 2010; Uddin et al., 2020).

At the local level, formal and quasi-formal institutions engage in various short and long-term interventional activities such as knowledge development, information sharing, financial support, and policy formulation (Naess et al., 2005; Choudhury et al., 2021a; Haque et al., 2022). For example, the *Union* Agricultural office initiates efforts to promote climate-resilient crops in the study area. They offer training and distribute free seeds to local farmers to enhance their ability to adapt to the impacts of climate change. Another notable example in the water sector involves entities like Bangladesh Water Development Board (BWDB) and the

Department of Public Health Engineering (DPHE), which oversee various water-related projects, including rainwater harvesting systems (RWHS), reverse osmosis (RO), pond sand filtration (PSF), and deep and shallow tube wells in coastal Bangladesh. These institutions introduce innovative technologies and provide comprehensive technical assistance, with a specific focus on aspects such as design, construction, operation, and maintenance.

In the context of collective efforts against climate-induced disasters, institutional collaboration proves indispensable for strengthening resilience (Folke et al., 2002). The empirical investigation highlighted that formal, and quasi-formal institutions collaborate effectively and create a '*bridge*' to identify and address existing risks within the community (also see Agrawal, 2010; Islam & Nursey-Bray, 2017). For instance, in the Early Warning System (EWS), formal entities like the Bangladesh Meteorological Department, Cyclone Preparedness Programme (CPP), and *Union* Parishad collaborate with informal institutions such as community and faith-based organizations to disseminate warning information and evacuate vulnerable populations to a safer location. This collaborative partnership allows for the involvement of diverse stakeholders at multiple levels and enhances institutional capacity in mitigating the impacts of climate-induced disasters and strengthening community resilience at the local level (Agrawal et al., 2013; Azad et al., 2021).

- **Informal institutions help reduce disaster risk and foster community resilience at the local level.**

In coastal communities, informal institutions play a crucial role in DRR by adopting diverse innovation and adaptation technologies at the local level. However, I have noticed that formal institutions often face limitations in addressing the dynamic and context-specific nature of climate challenges, leading to the emergence of informal institutions that fill the gaps and contribute to community resilience.

One of the primary ways informal institutions contribute to DRR is through the adoption of various initiatives/measures. These institutions are embracing adaptive technologies to enhance community resilience. Climate-resilient agriculture practices, such as the cultivation of climate stress-tolerant crops and the use of sustainable agricultural techniques, are being promoted by local community groups including community-based organizations (CBOs), village development committees (VDC), farmers associations, and *Union* and village leaders.

The study observed that a local farmers association named "*Krishok Sheba Shonghoton*" assists farmers with information and guidelines on crop varieties, supply of quality seeds, pest management, harvesting techniques, and irrigation facilities. These adaptations not only ensure food security but also contribute to the economic sustainability of the communities, reducing their vulnerability to the adverse effects of climate change. Informal networks disseminate knowledge about these adaptive technologies, in fostering a collaborative approach to disaster risk reduction.

Informal institutions further contribute to disaster risk reduction through community-based initiatives that focus on knowledge sharing and capacity building. Localized groups, often led by community elders or experienced individuals, VDC, and faith-based organizations, disseminate information about traditional coping mechanisms and practices that have proven effective over generations. These informal networks serve as repositories of indigenous knowledge, offering insights into sustainable living and resource management in the face of environmental challenges.

The results of the study also observed that the resilience of coastal communities is enhanced by informal social networks that facilitate collective action during times of crisis. These networks are based on strong social ties and mutual trust, enabling swift and effective response mechanisms. In the aftermath of a disaster, such networks play a crucial role in coordinating rescue efforts, distributing relief materials, and providing emotional support to affected individuals. The sense of community cohesion fostered by these informal institutions not only enhances the overall resilience of the community but also ensures that no one is left behind in the recovery process.

- **Institutional fragmentation often hindered the adoption of innovation and adaptation technologies.**

In this study, it is concluded that ineffective collaboration, lengthy and top-down bureaucratic processes, institutional power dynamics, and issues related to equity often impeded innovation and the adoption of adaptation technologies at the local level, thus limiting opportunities for building resilience.

I observed that in the study *Unions*, the intricate interplay of power dynamics and political influence among local stakeholders poses significant challenges for marginalized communities, particularly concerning disaster risk reduction (DRR), agricultural practices, and water resource management. Being deprived of access to vital information and resources exacerbates the vulnerability of these marginalized groups to natural disasters, such as cyclones and floods. Notably, the current political landscape tends to favor specific interest groups aligned with the ruling party, resulting in the uneven distribution and inefficient utilization of DRR resources. In agriculture, marginalized farmers struggle to adopt climate-resilient practices due to limited access to modern technologies and credit institutions, while political favoritism concentrates support and subsidies among selected groups. These findings concur with the studies by Persson & Poyitkina (2017), Lewis & Hossain (2019), and Kundro et al. (2023).

It has been further observed that various innovation and adaptation projects exacerbate existing socio-economic disparities. In coastal Bangladesh, the issue of equity in adaptation technology presents a complex scenario with distinct winners and losers in terms of resilience outcomes. Those who have benefited from increased resilience often include wealthier landowners, influential community leaders, and government-backed development projects. These groups have been more able to invest in resilient adaptation practices such as DRR strategies, improved agricultural techniques, reverse osmosis, and rainwater harvesting systems, which shield them from the impacts of recurrent cyclones, storm surges, and salinity intrusion, thereby enhancing their resilience to climate-related hazards.

Conversely, marginalized communities and poorer groups such as landless farmers and informal settlers frequently experience weakened resilience despite adaptation efforts or even because of them. These communities often lack access to resources, technology, and decision-making power, leaving them disproportionately vulnerable to the adverse effects of climate change. Interventions like embankments and shrimp farming, intended to mitigate risks, can also inadvertently exacerbate vulnerabilities by altering ecosystems, displacing traditional livelihoods, and intensifying social inequalities. The unequal distribution of resources and benefits disproportionately affects vulnerable communities, widening the inequality gap between vulnerable and wealthy populations in the coastal region. Thus, while adaptation technologies have the potential to enhance resilience in coastal Bangladesh, ensuring equitable distribution and participatory decision-making are crucial to prevent further marginalization and foster sustainable resilience among all segments of the population.

Additionally, a lack of effective cooperation was evident among various stakeholder groups such as UAO, PIO, BWDB, LGED, DPHE, UP, NGOs, and community networks. In this context, the study identified several significant factors that exert influence on the overall process. These include insufficient financial backing, challenges in accountability, and the ramifications of political influence on the decision-making process. It is crucial to systematically analyze and mitigate these negative consequences to ensure that innovation and adaptation technology contribute to sustainable and equitable development in coastal Bangladesh.

4.3 Major Contributions of the Research

The findings of this study made substantial contributions to the following areas:

- The findings contribute to the literature relating to innovation and adaptation technology to minimize the impacts of climate-induced disasters in coastal Bangladesh. While most previous studies focused solely on the use of adaptation technology and overlooked innovative approaches to reduce vulnerabilities and their drivers, the present study attempted to fill in these gaps. This study provides a comprehensive perspective of the existing use of innovation and adaptation technology in the study area.

- This study provides comprehensive insights into multi-level institutions involved in reducing climate risk by promoting innovation and adaptation technology and enhancing community resilience. In disaster studies, substantial research gaps are evident, particularly in understanding how institutional processes and collaboration can effectively cope with and foster the adoption process of climatic risk and resilience-building measures. As in Chapter 3, I have intelligibly mentioned that institutional collaboration and partnership are significant in initiating various projects and initiatives. Although several recent studies have explored institutions and adaptation technology, there remains a noticeable dearth in the examination of the interconnected relationship between innovation, adaptation technology, and institutions in the context of enhancing community resilience to climate-induced disasters.

- This study of innovation, adaptation technologies, and institutional dynamics collectively propels the interdisciplinary paradigm, promoting a holistic approach to further research that transcends traditional disciplinary barriers. It further advances the frontier of interdisciplinary approaches to climate change adaptation through using innovation and technology in the context of Bangladesh.

4.4 Policy Implications

The major policy implications derived from the findings of this study are as follows:

- The findings from this research strongly indicate that sustainable use of innovation and adaptation technologies can be achieved by concentrating on interventions focused on specific regions, needs, and the vulnerability of the community. The adaptation strategies therefore need to pay more attention to these aspects of local communities in Bangladesh.

- In the realm of climate risk reduction, a comprehensive understanding of community perspectives regarding adaptation technologies, as detailed in Table 2.6, underscores the efficacy of certain adaptation technologies. Drawing from both scholarly literature and my own field observations, it becomes evident that climate-resilient crops, sustainable agricultural practices, rainwater harvesting systems, and cyclone shelters stand out as the most impactful measures within the study regions. These technologies have demonstrably reduced vulnerability among communities' and bolstered their capacity to adapt to climate-related challenges. Moreover, they offer opportunities for income generation and employment, ensure food security, and alleviate water scarcity concerns. Therefore, the Government of Bangladesh, non-governmental organizations, local institutions, and other stakeholders must prioritize the effective implementation of these technologies in coastal communities. By doing so, they can foster holistic livelihood development among vulnerable populations.

- In the context of policy development, it is advisable for governmental agencies in Bangladesh to prioritize training facilities, skills, and knowledge development of local vulnerable populations, particularly concerning their capacity building to address climate-related risks.

- The Government of Bangladesh must prioritize the development of concrete policies related to inclusivity and equity of various climate-related projects and interventions carried out by formal and quasi-formal institutions. This initiative is essential to minimize the vulnerability gap and ensure that the benefits are accessible to all at the grassroots level. The policy framework should also incorporate effective fund management and monitoring mechanisms.

- The findings of my thesis emphasize that the crucial role of persistent institutional collaboration and partnership needs to be increased and sustained to effectively address climate challenges and enhance community resilience.

- In conclusion, the Government of Bangladesh must invest in research and development of new and existing innovation and adaptation technologies in coastal Bangladesh to improve the communities' lives, and livelihoods, and protect resources and the natural environment.

4.5 My Reflection on this Thesis Research

The process of doing my Master's thesis on innovation and adaptation technologies in coastal Bangladesh has proven to be a profoundly enlightening experience. As I reflect on the conclusion of my thesis, several key factors and realizations came to the forefront. My educational background in Disaster and Human Security Management has allowed me to investigate the interdisciplinary sectors of climate change and DRR in local communities. This research has identified various innovation and adaptation technologies used in climatic disaster risk reduction in coastal Bangladesh, along with the underlying challenges presented in facts and figures.

Initially, I devoted my time to carrying out, a comprehensive literature review to lay the foundation for refining my understanding of the contextual factors at play in Bangladesh's coastal regions. This exploration revealed the multifaceted nature of climate challenges, making it essential to comprehend these issues to develop effective and sustainable solutions.

The fieldwork conducted for the thesis provided me with invaluable firsthand insights. Interacting with local communities allowed me to grasp the resilience and adaptability inherent in the coastal region of Bangladesh. Through interviews and observations, I have witnessed the dynamic ways in which individuals and communities were adopting innovation and adaptation technologies to respond to and cope with the adverse impacts of climate change. As I explored the complexity of this research, it was evident that the issue extends beyond the scientific domain and affects the lives of individuals and communities that are coping with both the tangible and intangible effects of climate change. From the early warning systems (EWS) to the Cyclone Preparedness Programme (CPP), and from climate-resilient agricultural practices to the implementation of critical infrastructures, these innovations and adaptation measures were evidently instrumental in climatic disaster risk reduction and fostering community resilience.

Through this investigation, I realized that innovation and adaptation technologies are not isolated solutions but integral components of a broader strategy. Coastal Bangladesh, with its increasing climate effects, serves as a microcosm of the global struggle against climate change.

My research findings identify the existing innovation and adaptation technologies in the study region (see Chapter 2). The adoption of EWS is crucial for vulnerable communities and offers timely alerts about impending disasters. These systems, utilizing advanced technologies like satellite imagery and GIS, empower communities with CPP volunteers on critical information that enables them to develop effective risk reduction strategies. The importance of such tools becomes evident when considering the unpredictable nature of climate-induced disasters, emphasizing the need for preparedness and swift responses. Micro-credit systems through microfinancing institutions (MFIs) have emerged as a key tool to reduce climatic vulnerabilities. Households obtain loans/credit from various MFIs to repair and rebuild properties and for livelihood recovery through agriculture, fish farming, rearing livestock, and other businesses. However, I noticed that these credit systems can be counter-productive or ineffective and push toward 'poverty' due to multiple borrowings from different MFIs.

Another major finding of this research highlights the role of multi-level institutions (i.e., formal, quasi-formal, and informal) in facilitating innovation and adaptation technologies at the local level (see Chapter 3). The multifaceted institutional approach not only ensures the relevance of such measures but also empowers communities in sustainable development, emphasizing the importance of inclusivity and collaboration in climate risk reduction and building adaptive capacities. Institutions promote these innovation and adaptation technologies through knowledge and skill development, information services, training facilities, resource mobilization, and proper fund allocations for implementing various projects/initiatives at the grassroots level. Collaboration and partnership among diverse stakeholders have emerged as the key tools for addressing such initiatives. However, I have observed that institutional fragmentation often hinders the implementation and adoption process, significantly raising tension and increasing socio-economic disparities among the vulnerable population.

Through interviews, observation, data analysis, and case studies, it became evident that successful adoption is often rooted in a combination of traditional knowledge and modern technology. Local knowledge and understandings passed down through generations were integrated with modern technology to maximize the effectiveness of these measures. Furthermore, the thesis sheds light on the need for policy frameworks that foster innovation and adoption of adaptation technologies, creating a favorable environment at both community and institutional levels.

In conclusion, the process of writing this master's thesis has been both intellectually and emotionally fascinating. It highlights the significance of innovation and adaptation technologies in addressing the adverse climate effects in coastal Bangladesh. As I reflect on the transformative potential of the findings, I hope that this research contributes to the academic discourse and practical implementation that enhances the resilience and adaptive capacity of coastal communities to climate-induced disasters.

4.6 Further Research

- Further research should prioritize a rigorous scientific examination of the efficacy of innovation and adaptation technologies within coastal Bangladesh, a dimension that remained unexplored in the present study.

- In my research, I have concentrated on institutional dynamics mostly at the microscale (i.e., local level) in the implementation of climate projects and interventions. However, further research must address the institutional role at the national level and the analysis of diverse policies related to the adoption of innovation and adaptation technologies and their impact.

4.7 Major Limitations of the Study

- In my research, I focused on two small *Unions* of coastal Bangladesh. Therefore, the study may not necessarily reflect the comprehensive situation of coastal communities in Bangladesh. This is because the dynamics of innovation and adaptation technology can differ significantly based on the region and vulnerability to climate risk. Consequently, any attempt to generalize the findings from this study should be approached with caution. It is therefore recommended that comparable studies should be pursued in similar climatic hazard prone regions of Bangladesh so that their findings can be generalized and adopted in national policies on climate risk reduction and adaptation.

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APPENDIX 1: Research Ethics and Compliance from the University of Manitoba

University of Manitoba | Research Ethics and Compliance

Human Ethics - Fort Garry
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PROTOCOL APPROVAL

Effective: November 22, 2022 Expiry: November 21, 2023

Principal Investigator:	Sabbir Ahmed Khan
Advisor:	C. Emdad Haque
Protocol Number:	HE2022-0206
Protocol Title:	*The role of innovation and adaptation technologies in reducing climate-induced disaster impacts and enhancing resilience in Satkhira communities of Bangladesh*

Andrea L Szwajcer, Chair, REB2

Research Ethics Board 2 has reviewed and approved the above research. The Human Ethics Office (HEO) is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans*- TCPS 2 (2018).

This approval is subject to the following conditions:

i. Approval is granted for the research and purposes described in the protocol only.

ii. Any changes to the protocol or research materials must be approved by the HEO before implementation.

iii. Any deviations to the research or adverse events must be reported to the HEO immediately through an REB Event.

iv. This approval is valid for one year only. A Renewal Request must be submitted and approved prior to the above expiry date.

v. A Protocol Closure must be submitted to the HEO when the research is complete or if the research is terminated.

vi. The University of Manitoba may request to audit your research documentation to confirm compliance with this approved protocol, and with the UM *Ethics of Research Involving Humans*Ethics of Research Involving Humans policies and procedures.

APPENDIX 2: TCPS 2 CORE Certification

PANEL ON RESEARCH ETHICS

Navigating the ethics of human research

TCPS 2: CORE 2022

Certificate of Completion

This document certifies that

Sabbir Ahmed Khan

successfully completed the Course on Research Ethics based on the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2: CORE 2022)

Certificate # 0000816058 **20 May, 2022**

APPENDIX-3

Household Survey Questionnaire

District:
Upazila:
Village:

Section – 1 (Socio-demographic Characteristics)

1. Name of the respondent:
2. Age (in years):
3. Sex: ☐ Male ☐ Female
4. Religion: ☐ Islam ☐ Hinduism ☐ Buddhism ☐ Christianity ☐ Others______
5. Educational qualification:

   ☐ Illiterate ☐ Primary ☐ Secondary ☐ SSC ☐ HSC
   ☐ Diploma ☐ Bachelor Degree ☐ Master Degree
   ☐ Others_________

6. Primary occupation:
7. Secondary occupation? If any:
8. Monthly household income (BDT) ☐ Below 5,000 ☐ 5,001-10,000 ☐10,001-20,000 ☐20,001-30,000 ☐ Above 30,000
9. Total family members:

Male	Female
Total	

10. Are you the household head? ☐ 1=Yes ☐ 2=No

    10.1. If not, what is your relationship with the household head:

11. Which climate-induced disaster affected you most?
    i. Cyclone SIDR
    ii. Cyclone Aila
    iii. Other extreme events (specify)

12. Who helps you to bounce back after every disaster? How?

13. Did you receive any training on disaster management □ 1=Yes □ 2=No

If yes, from which organization and list of training?

Section – 2 (Innovation, Adaptation Technology, and Institutions)

1. Do you know and use these innovations in climatic disasters?

Innovation	1=Yes	2=No
Early Warning System		
Community-based disaster risk management (CBDRM)		
Hazard Mapping		
Cyclone Preparedness Programme (CPP)		
Microfinancing Institutions		

2. Do you receive any early warning information for climate-induced disasters?

   If yes, then what was the first source of that early warning?

Source of early warning	1=Yes	2=No
CPP Volunteers		
Interactive voice response (Cellphone)		
Faith-based institutions		
Relative/Neighbors		
Electronic Media (Television/radio)		
Print Media (Newspaper)		

3. Are you familiar with CPP warning signal flags?

   ☐ 1=Yes ☐ 2=No

4. Have you borrowed money from any MFIs?

   ☐ 1=Yes ☐ 2=No

   If Yes, then from how many MFIs have you borrowed money?

   _______________(Specify)

5. Could you rank this adaptation technology based on your understanding and uses in your area?

Adaptation Technology	Level of Quality				
	1=Poor	2=Fair	3=Good	4=Very Good	5=Excellent
Biotechnology: Genetically modifying crops (saline tolerant, flood-tolerant, and climate stress)					
Hydroponic and aquaponic agricultural practices, homestead gardening, vermi and organic compost, vertical towering, mulching method, agricultural practices using gunny bag, concrete pot, or cork box, integrated farm management (IFM)					
Reverse Osmosis (RO)					
Pond Sand Filters (PSF)					
Deep Tube well, and Shallow Tube well					
Rainwater Harvesting (RWH)					
Multipurpose Cyclone Shelters (MPCS)					
Sea walls					
Block embankment					
Sluice gates					
Polders and Culverts					
Geobags and Geosynthetic					

Early warning (Interactive Voice Response)					

6. What is the main source of drinking water for your household? (Multiple responses)

   Water Technologies

   1=Rainwater Harvesting (RWH)
   2=Deep Shallow tube-well
   3=Reverse Osmosis (RO)
   4=Pond Sand Filtration (PSF)

7. Do you relocate to a Multipurpose Cyclone Shelter during a disaster?

   □ 1=Yes   □ 2=No

   If Yes, then are you satisfied or dissatisfied with Cyclone Shelter conditions?

   □ 1=Satisfied □ 2=Dissatisfied

8. Do you have access to the following formal and quasi-formal institutions?

   1=Union Parishad
   2=Local Chairman
   3=Union Agricultural Office (UAO)
   4=Union Disaster Management Committee (UDMC)
   5=Project Implementation Office, Disaster Management
   6=Bangladesh Water Development Board (BWDB)
   7=Local Government Engineering Department (LGED)
   8=Department of Public Health and Engineering (DPHE)
   9=Cyclone Preparedness Programme (CPP)
   10=Microfinancing Institutions (MFIs)
   11=NGOs

9. Are you satisfied with the services provided by these institutions?

   □ 1=Satisfied □ 2=Dissatisfied

10. Did you get any support from any formal institutions (GO, union, upazila, wards and others) to incorporate these innovation and adaptation technologies to reduce disaster impacts? □ 1=Yes □ 2=No

If yes, what kind of support?

11. Did you get any support from any NGOs for incorporating these innovation and adaptation technologies to reduce disaster impacts? □ 1=Yes □ 2=No

    If yes, what kind of support?

12. Did you get any support from any informal institutions (CBO, VDO, social network groups, and faith-based organizations) to incorporate these innovation and adaptation technologies to reduce disaster impacts? □ 1=Yes □ 2=No

    If yes, what kind of support?

13. How are these innovation and adaptation technologies benefiting you to reduce vulnerabilities?

14. Did you get any training, information and funds from any (i) government (ii) NGOs (iii) CBO (iv) Other informal institutions (religious institutions, clubs, and social network groups) for using such approaches and technologies? □ 1=Yes □ 2=No

    If yes, what type of training did you get?

15. What challenges and barriers do you think affect the implementation and maintenance of innovation and adaptation technologies in coastal Bangladesh?

    i. Social, and why?
    ii. Economic, and why?
    iii. Institutional, and why?

APPENDIX-4

Guidelines for Key Informant Interviews (KII)

Date:

Union:

Unique identification number:

1. Which climatic disaster impacts the most in your area? What type of community resources have been damaged due to the last 10 years of climate-induced disasters? How do people cope, adapt, and reconstruct their livelihood?
2. What types of innovation (product, approach, and institution) prevail in this community/ area?
3. What types of adaptation technologies prevail in this community/ area?
4. How do people adapt to such innovation and adaptation technology? What strategies do they follow in the adoption process?
5. Do you think the existing innovation and adaptation technologies support vulnerable groups to minimize disaster impacts, building adaptive capacity and community resilience? If yes, then how does it work?
6. Which institution (formal or informal) takes the leading role in introducing and supporting the overall process of innovation and adaptation technologies in your community/ area? Furthermore, how do they accumulate?
7. How do formal institutions foster innovation and adaptation technology in your community/ area? What type of training or activities do these institutions conduct or organize in the adoption process in the vulnerable community?
8. How do informal institutions help to foster innovation and adaptation technology in your community/ area? What type of training or activities do these institutions conduct or organize in the adoption process in the vulnerable community?
9. How do formal institutions engage informal institutions and other local shareholders for collective action?
10. What are the existing challenges and barriers in promoting innovation and adaptation technology to foster community resilience and capacity building? Social, Economic, and Institutional?

APPENDIX-5

Guidelines for Focus Group Discussions (FGD)

Date:

Union:

Unique identification number:

1. What was the loss and damage from previous climate-induced disasters (Cyclone SIDR, cyclone Aila and other extreme events in the last 10 years)?
2. Who helps you the most in any climatic events and How?

Table: Guided questions for FGDs

Focused Area	Key Questions
Community-based organizations, social network groups, credit borrowers from MFIs, RO committee, CPP volunteers, community people and disaster-affected communities	1. What type of innovation and adaptation technologies are used in this community/area? And why? 2. What are the views and perspectives of community people in such cases? 3. How do you promote innovation and adaptation technology at the community level? 4. What types of training or awareness programs do you organize? 5. What type of funding, technical support and facilities do you ensure in fostering such approaches and technologies in building adaptive capacity and resilience? 6. What type of support do you get from formal institutions? 7. How do the community people adapt to such approaches and technologies? 8. What are the barriers to incorporating formal and informal institutions in the overall process? 9. What are the resource constraints and barriers in the implementation and maintenance process at the grassroots level?
Farmers	1. What type of innovation and adaptation technologies do you use in crop cultivation? Why?

	2. How do these practices differ from traditional approaches? 3. How does it benefits you? 4. What challenges do you face in the adoption process? 5. How do formal institutions help the adoption process? 6. How do informal institutions help the adoption process? 7. How does it help to promote adaptive capacity and resilience to climate-induced disaster? 8. What could be the appropriate help and support strategies from both formal and informal institutions in the overall implementation process?
Fisherman	1. What type of innovation and adaptation technologies do you use in fishing activities? Why? 2. How do these practices differ from traditional approaches? 3. How does it benefits you? 4. What challenges do you face in the adoption process? 5. When you go for fishing activities in the deep sea, through which medium do you get the warning signals and communicate with others before the onset of any climatic disaster? 6. How do formal institutions help the adoption process? 7. How do informal institutions help the adoption process? 8. How does it help to promote adaptive capacity and resilience to climate-induced disaster? 9. What could be the appropriate help and support strategies from both formal and informal institutions in the overall implementation process?