Experience and perceptions of climate change-related hazards, and the dynamics of technology-based adaptations in water use in Bangladesh: The case of *Satkhira* communities

by

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Abstract

Climate-change-induced water scarcity has become a major threat to agriculture and livelihoods in low- and middle-income countries. To address this challenge, the adoption and implementation of adaptation measures have emerged as the most effective and viable approach. Individual perception significantly influences the willingness to adopt adaptation measures, where technology-based adaptation measures can mitigate the climate change-induced effects and help to build community resilience. The current study examined the local perceptions of climate change, the factors intensifying climate-induced stress on livelihoods, and the dynamics of technology-based adaptations that affect the availability of water for drinking, domestic, and agricultural purposes in the coastal communities of Bangladesh. *Satkhira*, a coastal district of Bangladesh, was chosen as the primary research location due to its high vulnerability to climate change. Empirical data were collected in *Kaliganj Upazila* of *Satkhira* District by using two participatory rural appraisal tools: key informant interviews and focus group discussions. Additionally, quantitative data were also collected via a household survey. Findings revealed that cyclones, floods, salinity intrusion, and waterlogging were the primary climate-related hazards. Climatic factors coupled with anthropogenic activities resulted in disruptions to the freshwater supply, causing severe water scarcity for drinking and irrigation. Locals are adapting by diversifying crops and growing climate-smart crops based on their experiences and perspectives. Adopting various technologies, including shallow tube wells, deep tube wells, rainwater harvesting, pond sand filters, reverse osmosis, low-lifting pumps, and deep submersible pumps, significantly reduced climate-induced water stress. Community-based organizations, neighboring community members, and electronic media played a critical role in the diffusion of technology. Affordability was identified as the crucial factor for the ability to use such technologies. While existing adaptation approaches fail short in addressing climate-induced stresses, the study emphasizes the importance of community engagement, equitable resource distribution, community-level knowledge enhancement in policy formulation, and equitable access to technology by all socioeconomic groups to achieve the desired outcomes of adaptation in coastal communities.

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I extend my gratitude for the unwavering blessings bestowed upon me by the Almighty. During moments of agitation and on the brink of giving up, those around me played a crucial role in helping me regain composure. To the individuals and organizations that offered invaluable assistance throughout my research journey, I am eternally thankful.

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Dedication

This thesis is dedicated to my mother Sheuli Akter
and my late father M Mostafa Kamal

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Acronyms

AL	Adding Larvae
BBS	Bangladesh Bureau of Statistics
BDT	Bangladeshi taka
BMD	Bangladesh Meteorological Department
CCVI	Climate Change Vulnerability Index
CO_2	Carbon Dioxide
CRI	Climate Risk Index
DSP	Deep Submersible Pumps
DTW	Deep Tube Wells
F	Flowering
FAO	Food and Agriculture Organization
FGDs	Focus Group Discussions
FS	Fruit Stage
G	Growth
GDP	Gross Domestic Product
GoB	Government of Bangladesh
GOs	Government Organizations
H	Harvesting
HDX	Humanitarian Data Exchange
HH	Household
INGOs	International Non-Governmental Organizations
IPCC	Intergovernmental Panel on Climate Change
KIIs	Key Informant Interviews
LLP	Low-Lifting pumps
LMICs	Low- and-Middle Income Countries
LP	Land Processing
NGOs	Non-Governmental Organizations
PRA	Participatory Research Appraisal
PSF	Pond Sand Filters
RO	Reverse Osmosis
RVCC	Reducing Vulnerability to Climate Change
RWH	Rainwater Harvesting

S	Sowing
SD	Standard Deviation
STW	Shallow Tube Wells
UNFCCC	Nations Framework Convention on Climate Change
WV	World Vision

Chapter 1: Introduction

1.1 Background and Rationale

The rapid acceleration and adverse consequences of climate change in recent decades have emerged as a pressing concern for global leaders and policymakers. The continuous upward trend in the emission of greenhouse gases has resulted in a substantial increase in the annual average atmospheric level of carbon dioxide (CO_2), with concentrations climbing from 393 parts per million (ppm) to 410 ppm throughout the period from 2011 to 2021 (Intergovernmental Panel on Climate Change [IPCC], (2021); Baumann et al., 2011). This substantially influences climate change-related hazards, including increasing temperature, changing precipitation patterns, rising sea level, increasing drought, flooding, cyclones, coastal erosion, and salinity intrusion (IPCC, 2021; Dore, 2005; Roebeling et al., 2013). Countries all over the world are currently dealing with the multifaceted repercussions of climate change to varying degrees, with low-lying coastal areas around the world being particularly vulnerable to these adverse effects (Toimil et al., 2020). Prominent consequences resulting from climate change are observed in several geographical locations, including Latin America (Silva et al., 2014), South Africa (Matikinca et al., 2020), coastal regions in Europe (Roebeling et al., 2013), and South Asia (Sivakumar & Stefanski, 2010). These extreme climatic events have an enormous effect on the availability of freshwater resources, leading to substantial disturbances in social stability. The situation is particularly dire for millions of people residing in the coastal regions of low- and-middle income countries (LMICs), where agriculture acts as a fundamental source of livelihoods. The complex impacts of climate change on water-related ecosystem services and agricultural production render vulnerable communities at increased risk of climate change-related impacts to their livelihoods.

Adopting and implementing climate change adaptation measures is identified as the viable policy approach in Bangladesh to reduce the effects of climate change and minimize associated risks to livelihoods (Alam et al., 2018; Chowdhury et al., 2022). The notion of adaptation refers to the process of adjusting to existing, or projected, unpleasant climatic circumstances. Individuals' perceptions play a crucial role in determining their willingness to adopt such adaptation measures (Hansen et al., 2004; Silvestri et al., 2012). These adaptation measures often involve adopting fast-maturing, salinity-resistant, and higher-yielding crop varieties by the farmers in LMICs (Huq et al., 2004; Mondal et al., 2019). Additionally, several studies in India and Pakistan found that the adoption of adaptation measures by farmers was influenced by their memory of previous climatic extremes and their present climate knowledge. Experienced farmers possessed clearer perceptions of climate change-related hazards, which motivated them to act to try to secure their livelihoods. In these households, other members also pursued different economic activities to reduce their reliance on income from sources vulnerable to climate-related risk (Jha et al., 2018). In Pakistan, Shah et al. (2023) observed that farmers' selection of crops, production patterns, and inputs necessary under various climatic stress conditions were shaped by their experiences and perceptions of climate change risks.

Water, among all other natural resources, is widely recognized as the primary medium through which the impacts of climate change can be manifested (Chang & Bonnette, 2016). Using technologies as adaptation measures to alleviate the adverse climate change impacts on water resources is strongly recommended (IPCC, 2014). "Technology" is a broad term which refers to:

> *a form of human cultural activity that applies the principles of science and mechanics to solve problems. It comprises resources, tools, processes, personnel, and systems developed to perform tasks and create immediate, personal, and/or competitive advantages in a given ecological, economic, and social context*. (McOmber, 1999, p. 138)

Other studies define technology as instrumental action, creating a new object, or reducing ambiguity in cause–effect interactions to achieve a desired objective (Rogers, 2003; Sahin, 2006). Since the 2005 United Nations Framework Convention on Climate Change (UNFCCC), the practical application of skills and scientific knowledge through environmentally-sound technologies has received substantial global attention to reduce climate-induced vulnerability and enhance resilience in human societies to deal with climate change (Kim, 2021; UNFCCC, 2005). Technology-based adaptation measures in the water sector can substantially improve the quality of life by building resilience to extreme climate hazards, reducing the contamination of drinking water, and by promoting diversification of water sources and the conservation of water resources. In recent decades, rainwater harvesting, water storage, water reuse, desalination, increasing irrigation efficiency, and effective water use are some major adaptation technologies that have been implemented worldwide (Elliot et al., 2011; IPCC, 2007; Khan & Paul, 2023).

The issues of inequities in resource distribution and access-to-technology are serious concerns in the discourse of climate change. These features of social justice are crucial, as they have the potential to constrain the adaptation process. Numerous studies conducted in LMICs across Africa and South Asia have consistently identified the pervasive problem of inequitable resource distribution and limited access-to-technology, often influenced by favoritism and power dynamics (Nakawuka et al., 2018; Narain, 2014; Yohannes et al., 2017). Inequalities in water distribution and the absence of adequate monitoring by governing authorities regarding the utilization of such technology lead to uneven benefits across communities, where poor and marginalized communities resort to using saline water for both drinking and irrigation. Indeed, these studies highlighted the significance of understanding these key aspects of adaptation but, regrettably, a significant deficiency of scholarly study and comprehensive documentation exists on these issues. The lack of comprehensive understanding of the dynamics of adoption and implementation of technology-based adaptation across different socio-economic groups is a significant challenge for policy-making institutions, with respect to effectively implementing suitable technologies within the water sector to alleviate the impacts of climate-induced water stress.

1.2 The Context of Bangladesh

Bangladesh, a developing country in South Asia, is home to more than 170 million people (World Bank, 2023). With a middle-income economy, the country has made notable economic progress, as shown by a 6.9% growth in its yearly gross domestic product (GDP) in 2021 (World Bank, 2023). Nevertheless, the imminent threat of climate change poses a significant challenge to the nation's ongoing economic development. According to Eckstein et al. (2021), the long-term climate risk index (CRI) ranks Bangladesh as the sixth most vulnerable country in the world to climate-induced hazards. The country's geographic location has made it the third most vulnerable country to emerging threats associated with rising sea levels (Lázár et al., 2015). The coastal region of Bangladesh is globally recognized as a "hotspot" for climate change-related hazards, such as floods, cyclones, tidal surges, droughts, waterlogging, and salinity intrusion (Abdullah et al., 2022; Abedin et al., 2019; Lázár et al., 2015). The country faced 113 climatic disasters between 1991 and 2016, marking a nearly 100% increase compared to the 58 incidents recorded between 1965 and 1990. Notably, the frequency of extreme climatic events has increased by 7% annually in recent years (Mukherjee et al., 2019). This alarming trend is underscored by the economic losses in Bangladesh due to climate change-related hazards, estimated at approximately US$12 billion over the past four decades (World Bank, 2016).

Agriculture plays an enormous role in the economy of Bangladesh, contributing to 14.23% of the gross domestic product (GDP) and employing more than 40% of the overall labor force (Bangladesh Bureau of Statistics [BBS], 2018). A substantial portion of the country's coastal population, comprising approximately 40 million out of a total of 63 million residents, depend on agriculture as their primary means of sustenance (Lázár et al., 2015; Neumann et al., 2015). Shrimp farming, tourism, and collecting forest resources are other major economic activities in the coastal region (Abedin et al., 2019). Approximately 80% of coastal inhabitants live within 5 m of mean sea level (Luetz, 2017). Almost 30% of arable land is located in the coastal low-lying area, where the ongoing impacts of climate change pose a significant and continuous threat to coastal agriculture and the lives of local communities (Hauer et al., 2020; Khanom, 2016). The vulnerability of the coastal region is further intensified by hydrometeorological hazards and fluctuations in climate, such as changes in precipitation patterns and temperature, which have significantly affected water-related ecosystem services and agricultural output (Abdullah et al., 2022). In addition, the rising sea levels and its associated risks have had significant negative impacts on freshwater availability, resulting in severe water scarcity for drinking and irrigation (Lam et al., 2022; Vitousek et al., 2017). The negative consequences of salinity intrusion and the constrained availability of fresh water for crop cultivation compel farmers to excessively utilize fertilizers to optimize yields. This approach has resulted in increased expenses related to agricultural operations and has contributed to the deterioration of soil and the quality of outputs (Akber et al., 2017; Chen & Mueller, 2018; Hauer et al., 2020; Khanom, 2016).

The coastal communities of Bangladesh have made significant progress in adapting to the consequences of climate change. This includes focusing on reducing threats to people's livelihoods and ensuring continuing business (Chowdhury et al., 2022). Research conducted on climate change responses in this coastal region has highlighted common adaptation strategies in the agricultural sector, including crop diversification, integrated farming, cultivating climate-resilient and highly productive crop varieties, and improving irrigation efficiency (Mondal et al., 2019). In addition, technology-based strategies for addressing water scarcity caused by climate change include rainwater harvesting, reverse osmosis pond sand filters, and tube wells (Abedin & Shaw, 2018; Chowdhury et al., 2020; Rahman & Islam, 2013). Conventional knowledge-based water filtration is also widely used to fulfill drinking water demand (Chowdhury et al., 2020).

The successful execution of these adaptation approaches depends on proactive initiatives and collaboration between both public and private entities. In order to effectively disseminate climate adaptation plans and actions within the community, it is imperative to consider the governing structure and factors related to capacity-building. Despite the existence of official documents and policies regarding climate adaptation in Bangladesh, they are deemed inadequate for effectively incorporating climate change adaptation into mainstream activities (Chowdhury et al., 2022). The issue of unequal access to technology and inequities in resource distribution stands as a salient focal point of discussion within the discourse of climate change adaptation. Adaptation research has clearly illustrated the significance of critically understanding people's perceptions of climate change risks in influencing climate adaptation actions and the dynamics of the process of adopting technology as adaptation measures (Alam et al., 2017; Dobbin et al., 2023). However, despite the significance of this issue, limited research has been conducted on the specific topic within the context of Bangladesh.

1.3 Purpose and Objectives of the Research

The purpose of my study is to understand people's perceptions of climate change-related hazards and how these perceptions influence their adaptive actions and thereby adoption of technology-based adaptation within coastal Bangladesh. The present study had two primary objectives, which are to:

1. Examine the perceptions of farmers and shrimp cultivators about climate change-related hazards and its associated effects on livelihoods; and
2. Analyze the dynamics of technology-based adaptation measures in water use for drinking, domestic, and agricultural purposes in coastal communities in Bangladesh.

Each of the two specified objectives has been elaborated into three distinct focal areas, as illustrated in Table 1.1.

Table 1.1 Breakdown of focused areas corresponding to each specific objective.

No.	Objectives of the research	Focused area
1	Examine the perceptions of farmers and shrimp cultivators about climate change-related hazards and its associated effects on livelihoods.	A) Analyze the intensifying stress on crop production and shrimp farming resulting from climate change-related hazards and associated threats. B) Examine the impact of anthropogenic activities in amplifying climate-induced stress on livelihoods. C) Evaluate the underlying motivating factors that drive local communities to adopt and implement adaptation measures.
2	Analyze the dynamics of technology-based adaptation measures in water use for drinking, domestic, and agricultural purposes in coastal communities in Bangladesh.	A) Identify the types, effectiveness, advantages, and limitations of the technology adopted as adaptation measures for drinking, domestic, and irrigation water usages. B) Analyze the adoption process of such technology and roles played by diverse stakeholders in facilitating its implementation. C) Examine the accessibility to such technology for obtaining affordable and safe water services, while addressing disparities in resource distribution.

1.4 Methodological Approaches

1.4.1 The study area

Among the 19 coastal districts in Bangladesh, *Satkhira* stands out as a particularly vulnerable district due to substantial climate-induced risks, including cyclones, rising sea levels, waterlogging, and salinity intrusion (Fenton et al., 2017; Lam et al., 2022; Moniruzzaman, 2011). *Kaliganj Upazila*, a sub-district of *Satkhira* District, was purposively chosen as the primary research site due to its Climate Change Vulnerability Index (CCVI) of 0.66—which indicates vulnerability to the long-term consequences of climate change, and is substantially higher than other *Upazilas* within the *Satkhira* District (Government of Bangladesh [GoB], 2018). Geographically, the study site spans from 22°19’ to 22°33’ north latitudes and 88°58’ to 89°10’ east longitudes, covering an expansive area of 333.78 sq. km (BBS, 2015). The study was conducted in two *Unions* of the *Kaliganj Upazila*, specifically the *Krishnanagar* and *Mathureshpur Unions*, which were selected randomly from a total of 12 *Unions* within *Satkhira*. *Krishnanagar Union* covers 26.65 km^2 and is located only 16 km away from the *Kaliganj Upazila* headquarter (GoB, 2022). Notably, *Krishnanagar Union* is located close to the world's largest mangrove forest, the Sundarbans. *Mathureshpur Union* has an area of 37.79 km^2 and is located 3.6 km from the *Kaliganj Upazila* headquarter (GoB, 2022).

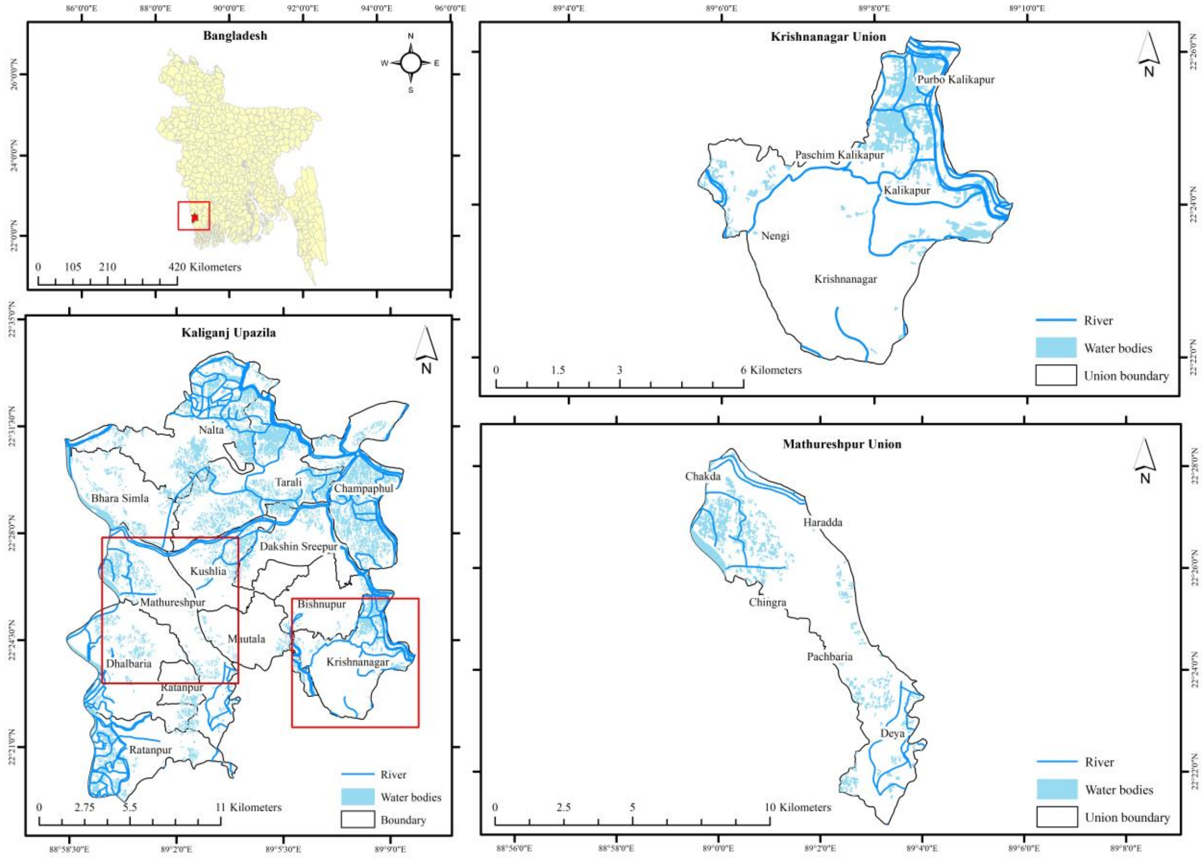

Figure 1.1 The study site for the research.
Data layer source: Humanitarian Data Exchange (HDX) (2022)
Note: The study villages are labelled on each *Union* map.

According to the Bangladesh Bureau of Statistics (BBS), *Krishnanagar Union* and *Mathureshpur Union* accommodate 5573 and 6040 households, respectively (BBS, 2015; GoB, 2022). The major sources of livelihoods in these *Unions* comprise crop production, followed by shrimp farming and day laboring. Throughout the last two decades, crop production has continually maintained a dominant position, establishing itself as the primary occupation and one of the major economic activities in both *Unions*. It is important to mention that shrimp farming has recently become a significant economic activity in response to the increasing salinity intrusion into the inner-coastal area.

1.4.2 Data collection methods

The study has maintained the ‘pragmatic worldview’, which enabled a critical understanding of the focused area, derived from specific objectives, and helped to present a comprehensive analysis (Creswell & Creswell, 2018). A participatory research approach was followed, which emphasises the “bottom-up” technique, prioritizing the perspectives and priorities specified within the local context (Cornwall & Jewkes, 1995). The idea of mixed methods research was used for data collection, incorporating two participatory research appraisal (PRA) tools, namely key informant interviews (KIIs) and focus group discussions (FGDs), alongside a household survey.

The present study received ethics approval from the Research Ethics Board at the University of Manitoba, Fort Garry campus (Protocol Number: HE2022-0207). Following the consent procedure protocol, the household survey, key informant interviews, and focus group discussions were conducted in either Bengali or English, depending on the language preferred by the participants.

1.4.2.1 Key Informant Interviews

A total of 15 key informant interviews (KIIs) were conducted to attain a nuanced understanding of the focused area, derived from specific objectives, through the perspectives of individuals with direct experience and expertise. The KIIs were conducted up to data saturation, aiming at a comprehensive analysis of climate-induced stress, perceptions of climate change, adopted adaptation measures, technology-based adaptation, and the dynamics of technology adoption in the water sector. The interviews were designed using a combination of open-ended and semi-structured questions to elicit detailed and in-depth data on the participants’ views, experiences, and understanding of the research subject. Each interview took the form of a discussion and ensured that the full breadth of the participant’s views, experiences, and understanding of the issues was covered.

The KII participants were purposively selected from different stakeholder groups in the study area, including 3 crop farmers, 2 shrimp cultivator, 1 day laborer, 1 schoolteacher, 2 local leaders, 2 non-governmental organization (NGO) practitioners, and 4 members actively engaged in the governing bodies at *Union* and *Upazila* levels. Five KIIs were performed in *Krishnanagar Union*, 7 KIIs in *Mathureshpur Union*, and 3 KIIs in the greater *Kaliganj Upazila*. Two women were purposefully identified and selected to participate in KIIs, ensuring representation from diverse occupational backgrounds. The average duration required to complete a single KII was around 45 minutes.

1.4.2.2 Focus Group Discussions

Focus group discussion (FGD) provides participants with a platform to share their views and experiences, leading to a comprehensive understanding of reality on a particular topic (Creswell &

Creswell, 2018; Sarantakos, 2013). In this research, 6 FGDs were conducted (3 in each *Union*) to capture the collective views of the stakeholders. The participants were chosen from diverse occupational backgrounds from five villages in each *Union* (Figure 1.1), by using a random sampling method from the pool of prospective participants, who had been previously selected via snowball sampling (Parker et al., 2019). Each FGD contained 12 to 16 participants. In total, 14 women participated in the FGDs (n = 80; 17.5%). In consideration of Bangladesh's patriarchal society (Hossen, 2020; Jaim, 2022) and its related norms, particularly in rural areas, this proportion of women participants is reasonable. The distribution of occupational backgrounds of FGD participants by each *Union* is shown in Table 1.2.

Each FGD was facilitated using semi-structured questions probing the participants' perceptions relating to the following topics: climate change-related hazards and their associated stresses; the implications for agricultural operations and livelihood security; local adaptation efforts; assistance from institutions; disparities in adopting technology as an adaptation approach to reduce water stress; the roles of stakeholders in adopting technology; and constraints and barriers for expanding technology-based adaptation. The average duration allocated for each FGD session was approximately 60 minutes.

Table 1.2 Distribution of occupational backgrounds of FGD participants in *Krishnanagar* and *Mathureshpur Unions*.

Participants	***Krishnanagar Union***	***Mathureshpur Union***
Farmer	20	14
Shrimp cultivator	8	12
Day laborer	5	6
Business (engaged with agricultural product and shrimp)	2	4
Schoolteacher	1	1
Member of community-based organization	3	2
Members of local governing bodies (*Union Parishad* member)	1	1
Total	**40**	**40**

Source: Collected field data 2022.

1.4.2.3 Household Survey

The household survey stands as a pragmatic and extensively used quantitative research method for the assessment of technology-based adaptive measures within the water sector in response to climate change (Mfitumukiza et al., 2020; Voth-Gaeddert et al., 2022). A household survey represents the sample of any targeted population (Wolff, 2015). In order to critically examine the role of technology-based adaptation measures in the water sector, precise data on the communities were needed for a clear understanding of the adoption of technological adaptation measures for drinking, domestic, and irrigation water usages, and its household-level effects in terms of access to resources and benefits, income, and assets.

In the present study, a sample of 300 households was selected through a random sampling method from *Krishnanagar* and *Mathureshpur Unions*. The survey was conducted on the same 5 villages from where FGD participants were selected. These villages were chosen randomly (Figure 1.1). Notably, the heads of the households were interviewed to represent his/her household unit. A structured questionnaire was used in the survey, and was designed to encompass a spectrum of socio-economic attributes, water supply sources, the consequences of climatic variabilities on water sources, the types and effectiveness of adopted technologies as adaptation measures, access-to-technologies, and disparities. The extensive dataset collected through the household survey facilitated a comprehensive analysis from a community perspective (Mfitumukiza et al., 2020; Voth-Gaeddert et al., 2022). The average duration for the completion of each household survey was approximately 30 minutes.

A summary of the methods employed for data collection, as relevant to specific objectives, along with the underlying rationale is presented in Table 1.3.

Table 1.3 Different methods of collection and rationale.

No.	Specific objectives	Methods used for data collection	Participants sample	Rationale
1	Examine the perceptions of farmers and shrimp cultivators about climate change-related hazards and its associated effects on livelihoods.	A) Key informant interview (KII)	15 (12 from *Unions* and 3 from *Upazila*)	• Identifying stress on crop production and shrimp farming resulting from climate change-related hazards and associated threats. • Influence of anthropogenic activities in increasing climate-induced stress on livelihoods. • Evaluate the motivating factors that drive locals to adopt and implement adaptation measures.
		B) Focus group discussion (FDG)	80 (40 from each *Union*)	
2	Analyze the dynamics of technology-based adaptation measures in water use for drinking, domestic, and agricultural purposes in	A) Key informant interview (KII)	15 (12 from *Unions* and 3 from *Upazila*)	• Identify the types of technology-based adaptation, its effectiveness, advantage, and limitations.

coastal communities in Bangladesh.	B) Focus group discussion (FDG)	80 (40 from each *Union*)	- Assess the dynamics involved in the adoption of technology-based adaptation and analyze the varied roles played by stakeholders in facilitating its implementation.
	C) Household survey	300 (144 in *Krishnanagar Union* and 156 in *Mathureshpur Union*)	- Examine the accessibility to technology-based adaptation with a focus on mitigating inequities in resource distribution.

1.4.3 Data Analysis

To address Objective 1, two types of Likert-style scales were used to provide comprehensive analysis of seasonal patterns in the major climate-induced hazards experienced by stakeholders, and assess the magnitude of the damage caused by these hazards. Furthermore, to perform a comparative analysis of the economic losses to local livelihoods resulting from climate-induced hazards and anthropogenic activities, a severity score was derived. This score was calculated as the weighted average of the scores provided by the participants in FGDs, obtained through the aforementioned Likert-style scale for specific issues. Additionally, a two-tailed independent Student's t-test was performed to identify the statistical significance in comparison of the problem score for both *Unions* (Hill, 2006).

For Objective 2, survey data were used to present the socio-economic attributes of the study area. This encompassed an evaluation of the impacts of climatic variability on the availability of water resources, adopted technologies as adaptation measures and their efficacy, and the varied roles played by stakeholders in facilitating the implementation of these measures. Qualitative data played a crucial role in providing a nuanced understanding of the targeted area in alignment with both objectives. Microsoft Excel spreadsheet was used to input quantitative data where the data analysis and other descriptive statistics were calculated, and the responses visualized using bar charts.

1.5 Significance of the Research

Recognizing prevailing research gaps within the context of Bangladesh, the findings of this study presented local stakeholders' perceptions of climate-induced stresses and shocks, their effects on their primary means of subsistence, and adaptation strategies commonly adopted by the local community to deal with climate-induced threats and challenges. This work makes a significant contribution to our understanding of perceptions of climate-induced stress in coastal Bangladesh by presenting novel findings regarding the pivotal role of personal experience and its associated manifestations. It offers critical insights into how climate-related hazards are impacting local livelihoods and the adaptation measures that have been taken to mitigate these effects.

Furthermore, the study also presented a comprehensive analysis of the dynamics of adoption and implementation of technology as adaptation measures to alleviate the climate-induced water crisis (with respect to drinking and domestic water supply, and irrigation purposes) in the coastal communities of Bangladesh. It addresses a significant knowledge deficit by providing valuable insights on the effectiveness of such technology-based adaptation measures to reduce water scarcity, and expanding these adaptive approaches among the coastal communities.

The research findings, along with the derived recommendations, constitute a substantial contribution to the policy domain. The study offers crucial information and guidance for the formulation and implementation of strategies, thereby optimizing the outcome of adaptation measures. In addition to advancing scholarly knowledge, this study reveals practical implications for the development and execution of climate change adaptation.

1.6 Organization of the Thesis

The thesis is organized into four chapters. Chapter 1 offers a comprehensive introduction to the study, including the background, research objectives, methodological approaches, and general structure of the thesis. Expanding upon the results, Chapter 2 and Chapter 3 provide a thorough analysis of the two objectives of the study. Every chapter includes a relevant literature review, methods, key findings, and discussion to address specific objectives. The thesis concludes with Chapter 4, which presents a comprehensive discussion highlighting the major findings of the study, key policy implications, recommendations, and recognition of inherent limits in the study.

The thesis has been prepared according to the “sandwich” or manuscript style format. It consists of two journal manuscripts, including an introduction (Chapter 1) and a discussion and conclusion chapter (Chapter 4). Chapter 2, addressing the first research objective, has been submitted for publication in the journal “*Climatic Change*”, while Chapter 3, addressing the second objective, has been submitted for publication in the journal named “*Mitigation and Adaptation Strategies for Global Change*”.

1.7 Contribution of Authors

In each of the aforementioned publications, I developed the conceptual framework, designed the study, conducted field research, analyzed the data, and drafted the manuscripts. Throughout this process, I benefited from the wonderful assistance given by my co-authors, especially in the areas of peer checking of my data analysis and conceptualizations, and by providing thoughtful comments, as shown in Table 1.4.

It is crucial to emphasize that there is no conflict of interest within the authorship of these submitted manuscripts.

Table 1.4 Authors' contributions to submitted manuscripts for publication.

Chapter No.	**Title**	**Name of the journal**	**Name of the authors**	**Contribution**
Chapter 2	Farmers' experiences and perceptions of climate change-related hazards and their effects on livelihoods, and adaptation actions: Evidence from coastal Bangladesh	Submitted to "*Climatic Change*"	Shehab, M. K.	Conceptualization, design of the research, data collection, data analysis, writing and editing the manuscript
			Haque, C. E.	Supervision
			Faisal, I. M.	Review and editing the manuscript
			Walker, D.	Review and editing the manuscript
Chapter 3	Meeting climate change challenges in coastal Bangladesh: The dynamics of technology-based adaptations in water use in *Kaliganj Upazila*	Submitted to "*Mitigation and Adaptation Strategies for Global Change*"	Haque, C. E.	Supervision
			Shehab, M. K.	Conceptualization, design of the research, data collection, data analysis, writing and editing the manuscript
			Faisal, I. M.	Review and editing the manuscript

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Chapter 2: Farmers' experiences and perceptions of climate change-related hazards and their effects on livelihoods, and adaptation actions: Evidence from coastal Bangladesh

Abstract

The adoption and implementation of adaptation measures has emerged as a central approach to mitigating the impact of climate change and reducing the associated risks to livelihoods. Individual perception significantly influences the willingness to adopt such measures in response to current and anticipated extreme climate conditions. This study analyzes factors intensifying climate-induced stress on livelihoods and the underlying motivations driving the adoption and implementation of adaptation measures in Bangladesh's coastal region. This paper also presents novel findings regarding the pivotal role of personal experience in shaping perceptions of climate change. The *Satkhira* district, a highly vulnerable area in Bangladesh's coastal region, was chosen as the primary research location due to its vulnerability to natural disasters and the long-term consequences of climate change. Two participatory rural appraisal tools—key informant interviews and focus group discussions—were employed for data collection. The findings revealed that cyclones, floods, salinity intrusion, and waterlogging were the primary climate-related hazards experienced by coastal residents. Local stakeholders reported that climatic factors coupled with anthropogenic activities resulted in disruptions to the freshwater supply, causing severe scarcities of water for drinking and irrigation. These experiences and perceptions have motivated locals to adopt and implement adaptation measures, such as crop diversification and the use of climate-smart crop varieties. However, existing adaptation and development strategies remain insufficient for addressing climate-induced stresses in coastal communities. This research underscores that community engagement, equitable resource distribution, and knowledge enhancement at the community level in policy formulation are critical to achieving the desired outcomes of adaptation.

Keywords

Perception of Climate Change, Adaptation Strategy, Climate-Related Hazards, Livelihood, Security, Water Scarcity, Bangladesh.

2.1 Introduction

The rapid acceleration of climate change has become a major policy concern for local, national, and global leaders and policymakers. The relentless increase in greenhouse gas emissions has caused the average yearly atmospheric concentration of carbon dioxide (CO_2) to rise from 393 ppm in 2011 to 410 ppm in 2021 (IPCC, 2021; Baumann et al., 2011). This unprecedented phenomenon has given rise to a wide range of climate change-related hazards, including rising temperatures, changing precipitation patterns, increasing sea levels, droughts, floods, cyclones, coastal erosion, and salinity intrusion (IPCC, 2021; Dore, 2005; Roebeling et al., 2013). Nations around the world are now dealing with the impacts of climate change to varying degrees (Silva et al., 2014; Matikinca et al., 2020), with low-lying coastal regions being particularly vulnerable to the associated hazards and impacts (Toimil et al., 2020; Roebeling et al., 2013). Furthermore, extreme climate events have had highly detrimental effects on freshwater resources, which has contributed to the disruption of social stability. This situation is particularly dire for millions of people residing in coastal regions of low- and middle-income countries (LMICs) (Barbier, 2015). Moreover, as people in LMICs often rely on agriculture as their primary means of subsistence, the complex effects of climate change on water-related ecosystem services and crop production have profound implications for them, especially for their livelihood security.

In LMICs, the adoption and implementation of adaptation practices has emerged as the only viable policy approach for reducing the effects of climate change and minimizing the associated risks to livelihoods. The process of adaptation entails adjusting to actual or anticipated extreme climate conditions, with individual perceptions often playing a critical role in the successful adoption of such measures (Hansen et al., 2004; Silvestri et al., 2012). Indeed, researchers have observed that *perception* acts as the foundation of local adaptation actions, as people who perceive climate change as a threat are usually most likely to embrace adaptation measures. For instance, adaptation research focusing on the relationship between farmers' perceptions of climate change and their adaptation behaviors has demonstrated that, regardless of geographic location, individual experiences significantly influenced the respondents' perceptions of climate change (Hansen et al., 2004; Jha et al., 2018; Shah et al., 2023; Silvestri et al., 2012). Significantly, these findings also reveal a positive association between perception and individual efforts to adopt adaptation measures. Conversely, other studies have yielded mixed or inconclusive findings regarding the influence of human perception on the adoption of adaptation strategies and actions (Albright & Crow, 2019; Shao et al., 2017; Wachinger et al., 2013). Nonetheless, recent findings have emphasized the significance of understanding people's perceptions and insights as factors motivating the adoption and implementation of specific adaptation actions.

Bangladesh is one of the most climate-vulnerable nations in the world, and its coastal regions are an especial hotspot for climate-related hazards (Abdullah et al., 2022; Eckstein et al., 2021). Governing authorities, particularly in LMICs, often lack adequate resources and capacity to fully protect their citizens. Hence, it is essential to understand locals' perceptions, as doing so can foster the adoption of adaptation actions at the individual and community levels, thereby building resilience and reducing climate-related vulnerability. In the present study, we conduct a comprehensive analysis of factors that enhance climate-induced stresses on livelihoods, and we examine the factors that motivate the adoption and implementation of adaptation measures. This work is necessary, as the literature currently lacks systematic studies focusing on how local stakeholders perceive climate-induced stress and how they adapt to climate stresses and shocks in coastal Bangladesh (Kabir et al., 2021; Roy et al., 2022). This study addresses this gap and offers valuable insights for policy development. Specifically, our study of coastal Bangladesh explores and critically examines how farmers perceive climate change-related hazards, their impacts on livelihood security, and common adaptation strategies adopted to address these challenges.

This chapter is divided into seven sections. In Section 2, the existing literature is critically reviewed, with a particular focus on the importance of personal experience and its connection to human perception and adaptive action. Section 3 presents an overview of the geographical and socioeconomic contexts of the study area, as well as the current climate-induced risks and responses. The research methodology is then detailed in Section 4, and the results of the field investigation are presented in Section 5. Section 6 consists of an analysis and discussion of the results and their implications, while Section 7 summarizes the work and presents some concluding remarks.

2.2 Review of existing literature

Studies examining livelihood risks resulting from climate change have emphasized the importance of comprehending how climate-change-related hazards are perceived at the community level, as the advancement of sustainable and successful adaptation measures depends heavily on this knowledge (Dobbin et al., 2023). Researchers underscore the need to critically examine people's perceptions of climate-change-related hazards and to understand the underlying factors driving climate change to develop and implement reasonable and efficient adaptation measures. Such efforts not only help to effectively disseminate knowledge and adaptation practices among local communities, but they can also motivate people to alter their behaviors and accept appropriate adaptation measures (Shi et al., 2015). Conversely, compliance with adaptation policies and the adoption of effective adaptation actions often depends on the support and participation of institutions, elites, and local leaders. In addition, actively involving local communities in the decision-making process and the adoption and implementation of adaptation actions significantly increases the likelihood such measures will be successful (Chen & Mueller, 2018; Hoque et al., 2022). If people do not perceive climate change-related hazards and the associated risks to their livelihood security as real, they are less likely to undertake adaptation actions (Howe et al., 2014; Markowitz & Shariff, 2012).

There has been limited research on perceptions of climate change and its associated livelihood risks in Bangladesh, with most existing studies focusing primarily on the consequences of climate change (Fenton et al., 2017; Alam et al., 2017). Notably, no prior studies have directly examined the varying perceptions of coastal agricultural producers (e.g., rice and shrimp cultivators) regarding the livelihood risks and freshwater insecurity resulting from climate change-induced hazards. In their recent study on perceptions of climate change, Dobbin et al. (2023) highlighted the need to focus on two key issues: 1) the role of personal experience in perceptual mapping, and 2) the effects of experiential learning on motivation to undertake adaptation actions. Dobbin et al. (2023) suggested that experience, learning, and motivation are the most crucial dimensions influencing perceptions of climate change and the subsequent adoption of adaptation actions. We build upon Dobbin et al.'s (2023) work by investigating these two potential factors within the context of climate-change-related livelihood concerns in coastal Bangladesh communities.

2.2.1 The role of personal experience in perceptual mapping and concerns

The concept of "climate change perception" entails identifying the functional characteristics of one's climate and responding to them via cognitive activity, with personal experience as the major driving force (Markowitz & Shariff, 2012; Pageaux, 2016). Such personal experiences are typically acquired via the individual's senses and encompass their knowledge and observations of changes in climate (Howe et al., 2014; Shi et al., 2015). However, experiences of climate change mediated through the media or individuals who are not residents of a particular exposed area cannot by definition be personal (Brügger et al., 2021). Climate-induced events capture people's attention: the frequency and magnitude of such events are crucial factors in determining the retention of such events in memory as past perceptual experiences. People draw upon memory to compare current environmental conditions to those in the past, which in turn shapes their perceptions of climate change (Brügger et al., 2021; Howe et al., 2014).

Numerous studies have investigated the complex link between personal experience and concerns regarding climate change risk (Hansen et al., 2004; Jha et al., 2018; Shah et al., 2023; Silvestri et al., 2012). Most of these studies found that individual perceptions and concerns regarding climate change are largely shaped by one's experiences with climate-induced events (Alam et al., 2017; Ogunbode et al., 2020), although a few have reported mixed (Wachinger et al., 2013) or even contradictory findings (Albright & Crow, 2019; Shao et al., 2017). Individual experiences can significantly influence people's perceptions and adaptive capacity, which in turn influences their sense of urgency and likelihood to proactively adopt measures to alleviate climate-induced risks and threats (Grothmann & Patt, 2005). Individuals who perceive climate change as an important concern have a greater tendency to endorse policies aimed at adapting to it and demonstrate favorable behavioral responses by adopting such measures (Mildenberger et al., 2019).

Sociopolitical factors also help shape human perceptions (Ogunbode et al., 2020), particularly when individuals' experiences of climate-change-related hazards challenge existing social norms and beliefs (Adger et al., 2009). Howe et al.'s (2019) review of 73 studies examining how experiences with climate-induced events influence human perceptions of climate change revealed a strong link between climate concerns and self-reported experiences. The overwhelming majority of the studies in the literature recognize the role and importance of human experience and perception in influencing attitudes towards climate change adaptation.

2.2.2 The effects of experience and perception on climate adaptation actions

Existing research on climate-change-related concerns has identified three major core elements that shape human perceptions of climate-change-related hazards: 1) recognizing the reality of climate change, 2) identifying its underlying causes, and 3) acknowledging its consequences (van Valkengoed et al., 2022). These core elements reflect human attitudes towards adopting and implementing adaptation actions (Dobbin et al., 2023; van Valkengoed et al., 2022); that is, people who acknowledge these elements are more likely to support climate adaptation measures and related policies (Mildenberger et al., 2019). However, people's adaptation actions may vary depending on the local context, sociopolitical structure, conditions, and individual traits.

Several studies in India and Pakistan found that the adoption of adaptation measures by farmers was influenced by their memory of previous climatic extremes and their present climate knowledge. Experienced farmers possessed clearer perceptions of climate-change-related hazards, which motivated them to act to try to secure their livelihoods. In these households, other members also pursued different economic activities to reduce their reliance on income from sources vulnerable to climate-related risk (Jha et al., 2018). In Pakistan, Shah et al. (2023) observed that farmers' selection of crops, production patterns, and inputs necessary under various climatic stress conditions were shaped by their experiences and perceptions of climate-change risks.

Guy et al. (2014) examined the psychological factors influencing human perspectives and ideologies regarding climate change in Australia, finding that individuals with more knowledge and experience in relation to climate change were more likely to believe in its consequences and be willing to adopt adaptation measures. Previously, Hansen et al. (2004) compared perceptions of climate change and decision-making at the farm-level among farmers in the Pampas region of Argentina—which is one of the largest producers of wheat and oilseed—and South Florida in the United States, which is famous for its production and export of vegetables and fruit. Their findings revealed that the farmers' perceptions of the long-term effects of climate change significantly influenced their production goals (Hansen et al., 2004).

Nonetheless, a few empirical studies have cautioned about directly linking perceptions of climate change and related disasters to emergency preparedness and response. For instance, Kreibich (2011) found that, while people in Germany perceived climate change as the major reason for increased flooding over the years, this perception only had a nominal effect on the adoption of essential flood emergency measures. The authors found that socioeconomic factors were likely to hinder people from undertaking flood-mitigation measures (Kreibich, 2011). Similarly, a recent investigation of coastal communities in North Carolina, USA, found that perceptions of climate change had no significant bearing upon people's actions and/or the implementation of adaptation measures to protect their property from extreme climate-change-driven events, such as hurricanes (Javeline et al., 2019).

Despite a minority divergent findings suggesting caution in drawing definitive associations between perceptions of climate change and the adoption of adaptation behaviors, the majority of research in the literature indicates that these two factors are strongly related. Nonetheless, attention to individual personality traits and their sociopolitical and sociocultural contexts should also be considered when making inferences about this relationship.

2.3 Bangladesh case context

Bangladesh, a developing nation in South Asia with a middle-income economy, is home to more than 170 million people (World Bank, 2023a). Although Bangladesh's annual gross domestic product (GDP) increased by a remarkable 6.9% in 2021 (World Bank, 2023a), climate change has become a major concern for its ongoing economic development. According to the long-term climate risk index (CRI), Bangladesh is the seventh most vulnerable country to climate-related events (Eckstein et al., 2021). In addition, Bangladesh's geographic location has made it the third most vulnerable nation to emerging risks related to rising sea levels (Lázár et al., 2015). Moreover, Bangladesh's coastal region is a global "hotspot" for climate-change-related hazards, such as floods, cyclones, tidal surges, droughts, waterlogging, and salinity intrusion (Abdullah et al., 2022; Lázár et al., 2015). Bangladesh experienced 113 climate-based disasters between 1991 and 2016 compared to 58 between 1965 and 1990, an increase of nearly 100%. In recent years, the frequency of extreme climatic events has increased by 7% per year (Mukherjee et al., 2019). This is an alarming trend, as economic losses in Bangladesh due to climate-change-related hazards have been estimated at approximately US$12 billion over the last four decades (World Bank, 2016).

Agriculture plays a crucial role in Bangladesh's economy, contributing 14.23% to the nation's GDP and employing more than 40% of the total labor force (BBS, 2018). Nearly 40 million of Bangladesh's 63 million coastal residents depend on agriculture for their livelihoods (Lázár et al., 2015; Neumann et al., 2015), with shrimp farming, tourism, and collecting forest resources making up the region's other major economic activities. Notably, approximately 80% of coastal inhabitants live within 5 m of mean sea level (Luetz, 2017). Hydrometeorological hazards and climatic variabilities, such as changing rainfall and temperature patterns, have had severe adverse impacts on water-related ecosystem services, which has in turn made the coastal region extremely vulnerable (Abdullah et al., 2022). Furthermore, rising sea levels and associated hazards have had deleterious impacts on freshwater resources, including severe scarcity of water for drinking and irrigation (Lam et al., 2022; Vitousek et al., 2017). The negative impacts of salinity intrusion and limited availability of freshwater for crop production have forced farmers to use excessive amounts of fertilizer to achieve optimal output. This practice has led to increased costs associated with agricultural activities and contributed to the degradation of the soil and the quality of outputs.

In Bangladesh's coastal region, adaptation practices have undergone significant development in response to the impacts of climate change, with a particularly strong focus on reducing livelihood risks (Chowdhury et al., 2022). Several studies on the agricultural sector in Bangladesh's coastal area have found that crop diversification, integrated farming, the cultivation of climate-resilient and high-yield crop varieties, and enhancing irrigation efficiency are the most commonly adopted climate-change adaptation strategies in this region (Mondal et al., 2019). Conversely, adaptation measures for addressing water scarcity caused by climate change include rainwater harvesting, water storage, water reuse, and conventional knowledge-based water filtration (Chowdhury et al., 2020). Ultimately, the successful execution of these adaptation strategies relies on the proactive efforts and engagement of both public and private entities.

2.4 Method

2.4.1 Study area

The *Satkhira* district is among the most vulnerable of Bangladesh's 19 coastal districts (Hoque et al., 2022; Lam et al., 2022*). Kaliganj Upazila*, a sub-district of the *Satkhira* district, was selected as the primary study area due to its high vulnerability to natural catastrophes (vulnerability index: 0.66) and the long-term consequences of climate change (GoB, 2018). Of the 12 *Unions* in *Kaliganj Upazila*, the *Krishnanagar* and

Mathureshpur Unions were randomly selected for the present study. *Krishnanagar Union* covers 26.65 km^2 and is located only 16 km from the *Kaliganj Upazila* headquarter (GoB, 2022a). Notably, *Krishnanagar Union* is located close to the world's largest mangrove forest, the *Sundarbans*. *Mathureshpur Union* has an area of 37.79 km^2 and is located 3.6 km from the *Kaliganj Upazila* headquarter (GoB, 2022a).

According to the Bangladesh Bureau of Statistics, *Krishnanagar Union* and *Mathureshpur Union* have 5573 and 6040 households, respectively (BBS, 2015; GoB, 2022a). The primary livelihood activity in these *Unions* is crop farming, followed by fish farming and day laboring. In both *Unions*, crop cultivation has been the predominant occupation and local economic base for the past two decades. However, shrimp farming has recently emerged as a major economic activity in both *Unions* as a means of adapting to the escalating the intrusion of saline into the inner-coastal zone.

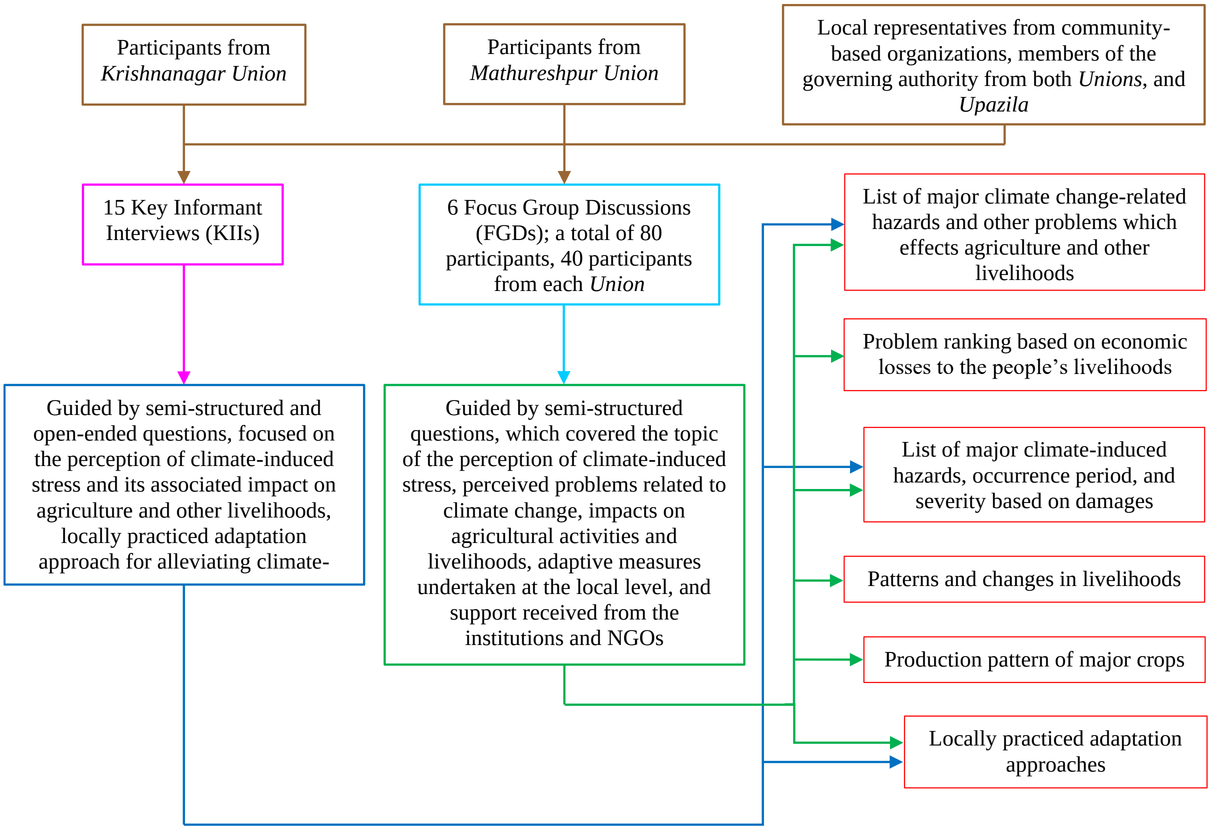


Figure 2.1 Schematic diagram of the research process highlighting the PRA data-collection tools.

2.4.2 Data collection procedure

Data collection was conducted using two participatory rural approaches: key informant interviews (KII) and focus group discussions (FGD). These processes (illustrated in Figure 2.1) incorporated the perspectives of the residents and other stakeholders, including government and non-government organizations, regarding climate-induced stress and shocks and locally driven adaptation strategies. The KIIs and FGDs were conducted in Bengali or English, depending on the respondent's preferred language. The author translated the Bengali interviews into English. To ensure the accuracy and integrity of the translation process, and to mitigate the risk of any possible misinterpretation, the author and research supervisor, who are highly proficient in both Bengali and English, conducted a thorough examination of the translated text. The research and data collection protocol were approved by the Joint Faculty Research Ethics Board at the University of Manitoba, Canada (Protocol Number: HE2022-0207).

2.4.2.1 Key informant interviews (KIIs)

To collect data relating to the objectives of the study, 15 KIIs were conducted with knowledgeable persons in the community using a semi-structured questionnaire. The guiding questions covered topics relating to perceived problems, difficulties caused by climatic variability, and locally driven adaptation efforts in the agricultural and water management sectors. Each interview took the form of a discussion and ensured that the full breadth of the participant's views, experiences, and understanding of the issues was covered. The KII participants were selected from different stakeholder groups in the study area and included farmers, shrimp cultivators, day workers, schoolteachers, local leaders from various community-based groups, members of the local governing bodies (*Union* and *Upazila Parishad*), NGO practitioners, and representatives of local government.

Table 2.1 Distribution of occupational backgrounds of FGD participants in *Krishnanagar* and *Mathureshpur Unions*.

Participants	*Krishnanagar Union*	*Mathureshpur Union*
Farmer	20	14
Shrimp cultivator	8	12
Day labor	5	6
Business (engaged with agricultural product and shrimp)	2	4
Schoolteacher	1	1
Member of community-based organization	3	2
Members of local governing bodies (*Union Parishad* member)	1	1
Total	**40**	**40**

Source: Collected field data 2022.

2.4.2.2 Focus group discussions (FGDs)

Six FGDs were conducted (three in each *Union*) to capture the collective views of the stakeholders. The FDG participants were chosen from five villages in each *Union* (Figure 1.1) using a random sampling method; the pool of prospective participants consisted of stakeholders who had been previously selected via snowball sampling (Parker et al., 2019). Each FGD contained 12 to 16 participants. The distribution of participating stakeholders by *Union* is shown in Table 2.1. Each FGD was facilitated using 11 semi-structured questions probing the participants' perceptions relating to the following topics: climate-change-related hazards and their associated stresses; the implications for agricultural operations and livelihood security; local adaptation efforts; and assistance from institutions.

2.4.3 Data analysis

Seasonal patterns in the major climate-induced hazards experienced by stakeholders in the *Krishnanagar* and *Mathureshpur Unions* were analyzed using a Likert-style temporal scale. During the FGDs, the participants were asked about current (within the last three years) and previous (within the last 10-15 years) patterns relating to major climate-induced hazards. A Likert-style severity scale was employed to ensure a comprehensive analysis of the severity of damage caused by major climate-induced hazards in both study *Unions*. The participants assessed the magnitude of the damage caused by these hazards using a scale of 1 to 5, wherein 1 indicated minimal severity and 5 indicated maximum severity.

Following climate adaptation research (Roy et al., 2022), the FGD outputs were used to perform a comparative analysis of the economic losses to local livelihoods, and to determine the problem severity score for each issue. The problem severity score for a particular issue was based on the weighted average of the scores provided by the participants using the aforementioned Likert-style severity scale (Eq. 1) (minimal damage = 1; minor damage = 2; moderate damage = 3; significant damage = 4; severe damage = 5”), which was determined via Equation 1.

$$P = \frac{1}{N} \sum_{j\,=\,1}^{j\,=\,5} (nD) \qquad (1)$$

where P is the problem severity, N is the total number of participants, j is the severity scale category, and n is the number of participants in the focus group discussions within the ‘jth’ category.

In addition to calculating the problem severity scores, the ranked responses were input into a Microsoft Excel spreadsheet, where the average rankings and other descriptive statistics were calculated, and the responses visualized using bar charts. In addition, a two-tailed independent Student's t-test was performed to identify the statistical significance in comparison of the problem score for both *Unions* (Hill, 2006).

2.5 Results

2.5.1 Experiences and perceptions of climate-change-related hazards and their effects on local livelihoods

In the KIIs, salinity intrusion in soil and water bodies, significant scarcity of water for drinking and irrigation, waterlogging, changing weather patterns, and extreme hydrometeorological events (e.g., floods and cyclones) were identified as the dominant climate-change-related hazards. Similarly, the FGD participants identified a series of problems that have had detrimental effects on their livelihoods. The comparative rankings of the climate-change-related hazards cited in the FGDs are presented in Table 2.2, while the patterns and variations in major livelihoods observed over a 10-to-15-year period are shown in Figure 2.2. The data in Figure 2.2 provides insight into the current main sources of livelihoods, as well as their progression over a 10-to-15-year period, including crop farming, shrimp farming, various forms of fish rearing, and daily wage work, revealing considerable shifts in several livelihood activities.

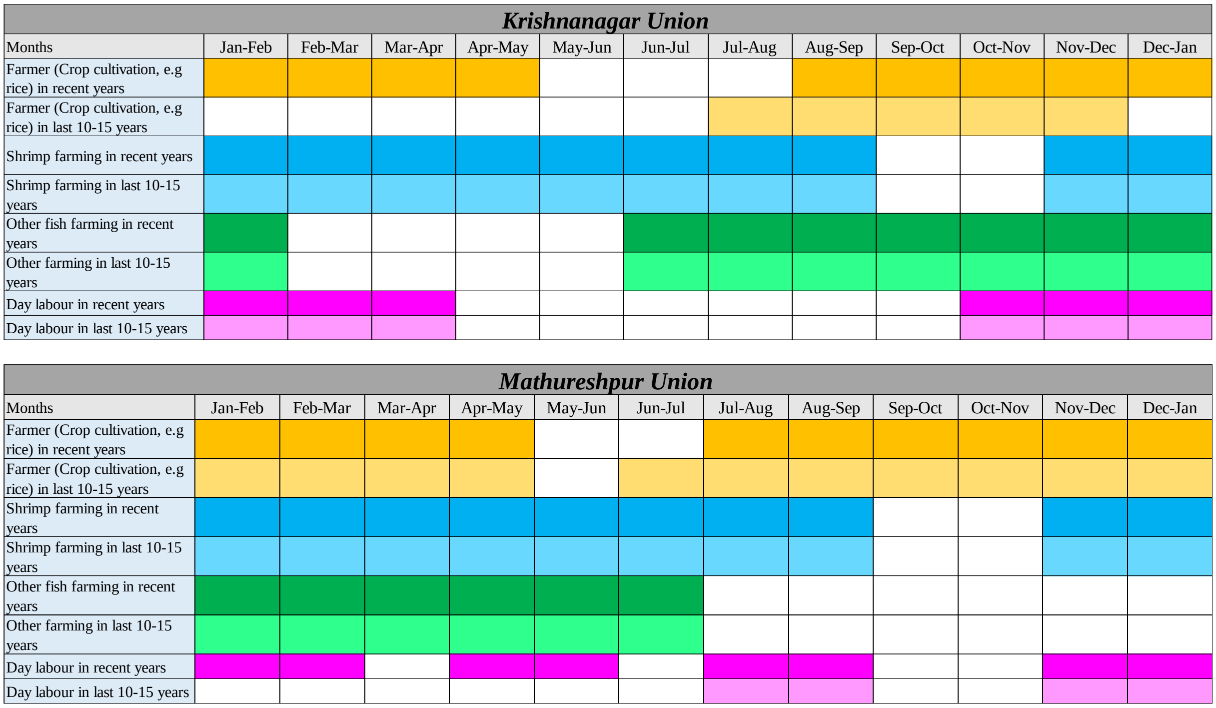
Table 2.2 Perceived problems and their ranking by stakeholders in *Krishnanagar* and *Mathureshpur Unions*.

Perceived problem list	**Problem score in *Krishnanagar Union***	**Ranking**	**Problem score in *Mathureshpur Union***	**Ranking**	**Student's t-test: P value***
Salinity intrusion	4.43	1	3.08	6	0.000002*
Inadequate rainfall	3.05	6	3.80	1	0.008326*
Excessive rainfall	2.68	10	3.05	7	0.961783
Extreme high temperature	3.33	4	3.55	3	1.000000
Waterlogging	3.20	5	3.23	5	1.000000
Safe drinking water scarcity	4.38	2	3.68	2	0.250294
Lack of water supply for irrigation	3.35	3	2.48	11	0.009353*
Water scarcity for domestic use	2.45	12	1.58	14	0.000808*
Weak embankment	2.60	11	2.93	8	1.000000
Lack of availability of good quality seeds	3.03	7	2.50	10	0.279492
Pests attack in rice production	2.98	8	2.65	9	0.509520
Pests attack in vegetables production	2.60	11	2.20	13	0.360072
Virus attack in shrimp farming	2.98	9	3.43	4	0.400450
Virus attack in other fish farming	1.53	13	2.35	12	0.001165*

*Significant at P value 0.05.
Note: Holm method was used for P value adjustment (Dmitrienko & D'Agostino Sr, 2013).
Source: Collected field data 2022.

2.5.1.1 Salinity intrusion

Local stakeholders identified increased salinity intrusion and inadequate rainfall as two of the most serious climate-change-related hazards (Table 2.2). The problem scores for salinity intrusion were 4.43 and 3.08 for *Krishnanagar* and *Mathureshpur Unions*, respectively, while the problem scores for inadequate rainfall were 3.05 and 3.80, respectively. The problem scores and their statistical significance varied between the *Unions*. The detrimental effects of high salinity levels were particularly pronounced in the agricultural sector, with livelihoods in the coastal belt experiencing significant damage compared to those in the inland area. Local farmers observed that, each year, the salinity level increases from December to July, reaching its highest levels between March and May. According to the respondents, the leading causes of salinity intrusion in the study areas included: inadequate rainfall; high temperatures; rising sea levels; the expansion of shrimp farming into lowlands and arable land; allowing saline water from the coastal river to enter farmland through sluice gates controlled by shrimp cultivators and local elites; raising the elevation of tidal water; and the spilling of saline water from rivers due to the overtopping of embankments.



Krishnanagar Union

Months	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan
Farmer (Crop cultivation, e.g rice) in recent years	🟧	🟧	🟧	🟧				🟧	🟧	🟧	🟧	🟧
Farmer (Crop cultivation, e.g rice) in last 10-15 years							🟨	🟨	🟨	🟨	🟨	
Shrimp farming in recent years	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦
Shrimp farming in last 10-15 years	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦
Other fish farming in recent years	🟩					🟩	🟩	🟩	🟩	🟩	🟩	🟩
Other farming in last 10-15 years	🟩					🟩	🟩	🟩	🟩	🟩	🟩	🟩
Day labour in recent years	🟪	🟪	🟪							🟪	🟪	🟪
Day labour in last 10-15 years	🟪	🟪	🟪							🟪	🟪	🟪

Mathureshpur Union

Months	Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan
Farmer (Crop cultivation, e.g rice) in recent years	🟧	🟧	🟧	🟧			🟧	🟧	🟧	🟧	🟧	🟧
Farmer (Crop cultivation, e.g rice) in last 10-15 years	🟨	🟨	🟨	🟨		🟨	🟨	🟨	🟨	🟨	🟨	🟨
Shrimp farming in recent years	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦
Shrimp farming in last 10-15 years	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦
Other fish farming in recent years	🟩	🟩	🟩	🟩	🟩	🟩						
Other farming in last 10-15 years	🟩	🟩	🟩	🟩	🟩	🟩						
Day labour in recent years	🟪	🟪		🟪	🟪		🟪	🟪			🟪	🟪
Day labour in last 10-15 years							🟪	🟪			🟪	🟪

Figure 2.2 Major livelihood calendar and changes to it during the last 10-15 years in the studied *Unions*. Source: Collected field data 2022.

Farmers from both *Unions* expressed their concern about the gradual decrease in crop yields caused by excessive salinity. Furthermore, due to excessive salinity during the dry season (November to February), farmers in certain places in both *Unions* can only produce rice during the monsoon season, which lasts from June to mid-October. Extreme salinity also severely reduces soil fertility, forcing farmers to use more fertilizer to achieve optimum production. Such adjustments not only harm soil quality, but they also result in increased production costs. Consequently, many farmers have abandoned rice cultivation for shrimp farming, which has become a common method of coping with salinity intrusion.

Shrimp aquaculture is now vulnerable to salinity intrusion, which is rapidly worsening. Substantial increases in viral infections (influenced by high salinity) have increased mortality rates for larval shrimp and other fish, resulting in enormous economic losses. The majority of the FGD participants (82% in *Krishnanagar* and 76% in *Mathureshpur*) stated that viral infection in shrimp and other fish farming was generally absent in earlier decades. Studies on aquaculture in Bangladesh (Ahmed & Diana, 2016), Asia (Flegel, 2012), and the rest of the world (Stentiford et al., 2012) have highlighted the proliferation of various pathogenic infections in shrimp and other fish farming, including white spot syndrome virus (WSSV), epizootic ulcerative syndrome (EUS), and infection caused by the parasite, *Hematodinium*, all of which being significantly influenced by climate change. A shrimp cultivator from *Mathureshpur Union* explained the situation as follows:

> "*Rice cultivation was the main livelihood of our ancestors. We had saline soil and water in our tube wells and ponds before the 21st century, but the salinity level became extreme after 2000. Some of our community members started shrimp farming by converting harvesting land into gher* [reconstructed farmland for shrimp farming with dikes around the perimeter]. *They benefited financially more compared to the farmers, who were struggling with rice harvesting due to increasing salinity in soil and water, which influenced some of us to shift our livelihoods from rice harvesting to shrimp farming. Initially, changing livelihood towards shrimp farming appeared as an easy solution to the salinity problem, but high salinity intrusion nowadays causes virus infection and slow growth of shrimp, which causes us immense financial losses.*"

2.5.1.2 Changing weather pattern

The local stakeholders observed that temperature and rainfall patterns had changed significantly over the last 10 to 15 years. In *Mathureshpur* and *Krishnanagar Unions*, inadequate rainfall was ranked as the first and sixth most prominent climate-change-related phenomenon, respectively. The stakeholders' observations are supported by the national precipitation data; for example, in 2022, the annual mean rainfall in Bangladesh was 1762.25 mm, down from 2332.93 mm in 2000 (World Bank, 2023b). Importantly, there was significant disparity in the problem scores for this issue between the two *Unions* (Table 2.2). However, two phenomena—namely, inadequate rainfall during the dry season and excessive, highly intense rainfall over a short period during the monsoon season—were seen as mainly responsible for drought, unforeseen floods, and waterlogging, and consequently, significant damage to crop production. One member of a community-based organization of farmers explained the local people's perceptions of changes in rainfall patterns over the years:

> "*As we are living in a salinity-prone coastal area, precipitation works as a source of irrigational water for rice and other crop cultivation, which acts as a blessing for us. But it becomes a curse when excessive rain with high intensity flushes out the rice grain from the paddy and floods our harvested land, which was not commonly seen in earlier decades.*"

During the FGDs, 82.5% and 90% of respondents from the *Krishnanagar* and *Mathureshpur Unions*, respectively, acknowledged that the temperatures have become extreme, which was something that had not previously happened. While elderly stakeholders noted that they had traditionally endured reasonably high temperatures from the pre-monsoon season to the end of the monsoon season (March to August), they observed that temperatures had become more intense from March to October in recent years. Indeed, in 2000, the maximum recorded temperature in *Satkhira* district was 34.5°C during the month of April; conversely, in 2010, the maximum recorded temperature in April was 36.1°C (Bangladesh Meteorological Department [BMD], 2023). Farmers from both *Unions* believed that extreme temperatures were one of the major reasons for decreasing rice yields and sub-optimal production during the *Aman* season.

2.5.1.3 Waterlogging

Waterlogging in the study area was the product of both climate-induced stress and anthropogenic activities. However, the stakeholders from the two *Unions* held divergent views regarding the causes of this phenomenon. The locals from *Krishnanagar Union* cited the expansion of shrimp production, the illegitimate use of sluice gates, the controlling of the river water by local elites and shrimp cultivators, and the lack of government oversight regarding the proper use and repair of damaged sluice gates as the major causes of waterlogging. In contrast, the participants from *Mathureshpur Union* cited climatic variability (e.g., excessive rainfall), the expansion of rice and shrimp production by local elites via the modification of tributaries and canals, reducing the river depth by depositing sediment, and poor drainage systems as the major factors influencing waterlogging.

Almost three-quarters (72.5%) of FDG participants from both *Unions* said they had incurred moderate to large economic losses due to waterlogging, thus illustrating the widespread impact of this issue. The respondents noted that crop productivity and livelihoods related to agriculture are being adversely affected by dying crops (particularly seedlings), declining soil fertility, and communication breakdowns caused by waterlogging. Moreover, waterlogging has contributed to the loss of freshwater fish in rivers and canals, animal fatalities, and a scarcity of clean drinking water, further exacerbating the misery of the local people.

2.5.1.4 Drinking and irrigation water scarcity

Water scarcity is induced by various climate-change-related hazards, including salinity intrusion, changing weather patterns, and waterlogging. Scarcity of safe drinking water was ranked as the second most important problem in the study area based on the problem scores for both *Unions* (Table 2.2). The majority of FGD participants (87% from *Krishnanagar Union* and 94% from *Mathureshpur Union*) observed that increasing salinity intrusion had significantly affected freshwater sources and groundwater. Efforts to enhance knowledge relating to hygiene and safe drinking water had been successful at changing people's perceptions and caused them to increasingly rely on groundwater as a source of drinking water instead of other surface water bodies like ponds, rivers, and canals. Groundwater use had increased since the 1990s, largely due to increased accessibility due to the construction of more tube wells. During the dry season, drinking water becomes extremely scarce due to inadequate rainfall, declining groundwater levels, and high salinity.

The quality of water used for agricultural irrigation significantly impacts productivity, particularly rice yields. Farmers from *Krishnanagar* and *Mathureshpur Unions* depend heavily on groundwater for agricultural irrigation. The scarcity of suitable water for irrigation is much more severe in *Krishnanagar Union* than in *Mathureshpur Union* due to extreme salinity (Table 2.2). The lack of available freshwater sources, extreme salinity intrusion in groundwater, and insufficient rainfall in the study area have forced farmers to use saline water for rice cultivation, resulting in severe damage to crops and soil fertility. Water scarcity damages agricultural productivity, raises the cost of living, and negatively impacts other local livelihoods. For example, lowered agricultural productivity adversely affects the demand for daily labor, thus increasing the unemployment rate.

2.5.1.5 Experience of major climate-induced disasters and severity of damages

Given its location in the coastal region of Bangladesh, the study area is highly vulnerable to a range of extreme hydrometeorological events and climate-change-related hazards, such as cyclones, floods, storms, and salinity intrusion. To gauge the frequency of these catastrophic events, participants were asked to rate their occurrence period on a temporal scale ranging from 0 to 4. This scale was developed by considering the percentage of participants who responded positively, where 0 = 0%, 1 = 25%, 2 = 50%, 3 = 75%, and 4 = 100%. The calculated frequency intervals for these hazardous events were assessed using a Likert-style temporal scale and are shown in Figure 2.3.

Participants were asked to assess the extent of the severity of the damage due to the extreme climatic events, using a Likert-style severity scale, is presented in Figure 2.4. As the findings show, both *Unions* are highly vulnerable to climate-change-related hazards and their associated stresses. In 2019, 2020, and 2021, the *Kaliganj Upazila* (see Figure 1.1 for location) was devastated by three major cyclones (Cyclone *Bulbul*, Cyclonic *Amphan*, and Cyclone *Yaas*), resulting in total damages of US$25.64 million (GoB, 2022b). Likewise, the *Krishnanagar* and *Mathureshpur Unions* had seen significant losses of life, livelihood, and property as a result of three consecutive cyclones. Moreover, whereas floods were not a common hazard in both *Unions* in earlier decades (Figure 2.3 and Figure 2.4), they experienced a massive flood in 2021 due to excessive precipitation, overflowing river water, and poor drainage infrastructure. Damages from these hazards were comparable in both *Unions*, with 77.5% of respondents in *Krishnanagar* and *Mathureshpur Unions* indicating varied magnitude of the impact on their livelihoods (Figure 2.4).

Figure 2.3 Seasonal patterns of major climate-induced hazards in the studied *Unions*: (A) cyclones, (B) floods, (C) storms, (D) salinity intrusion.

Source: Collected field data 2022.

Note: Temporal scale was used based on the percentage of respondents said “Yes” (0 = 0% respondents; 1 = 25% respondents; 2 = 50% respondents; 3 = 75% respondents; 4 = 100% respondents).

Analysis of the stakeholders’ responses revealed that salinity intrusion is much more severe in *Krishnanagar Union* than in *Mathureshpur Union* (Table 2.2 and Figure 2.3). *Krishnanagar Union*’s close proximity to the sea is likely the major reason for its high salinity levels, as sea water is more able to infiltrate other water bodies in the area. Agriculture is the predominant source of livelihood and most affected economic sector in *Krishnanagar Union*, which explains the heightened awareness of related hazards among respondents from this area (compared to respondents from *Mathureshpur Union*). The increased frequency and intensity of such climate-induced hazards in recent years (Figure 2.3), along with their impacts on water resources and livelihoods, has influenced a significant change in the locals' perceptions of climate change. This, in turn, has intensified their willingness to adopt adaptive measures in response to the increasing challenges posed by such adverse circumstances.

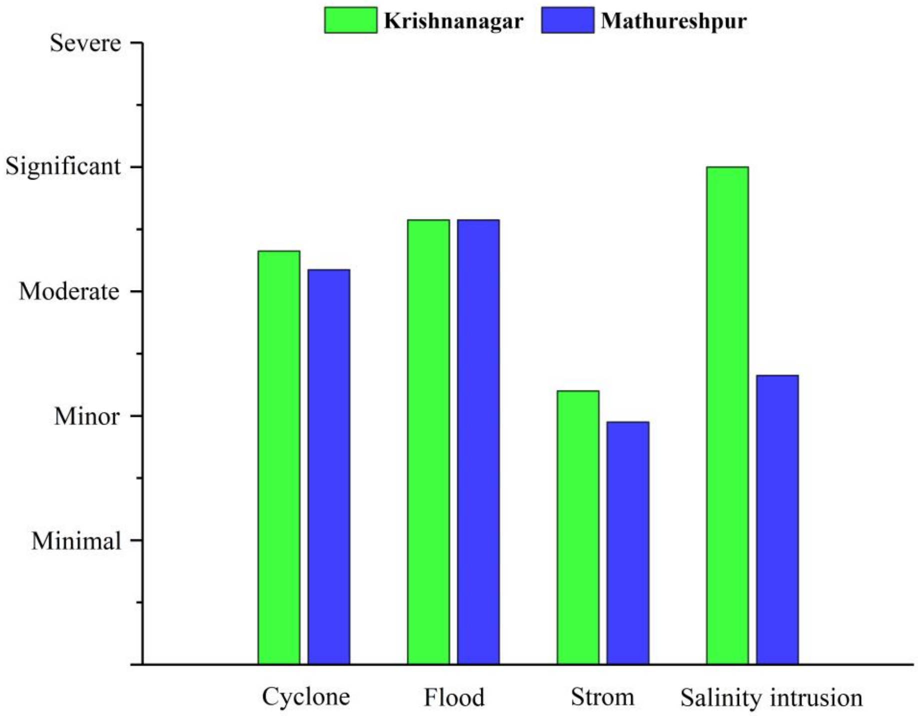


Figure 2.4 Severity of damages from major climate-induced hazards experienced by stakeholders in *Krishnanagar* and *Mathureshpur Unions*.

Source: Collected field data 2022.

Note: A severity scale was used according to the participants' responses (1 = minimal damage, 2 = minor damage, 3 = moderate damage, 4 = significant damage, 5 = severe damage).

2.5.2 Adaptation actions as a response to climate-change-related hazards by farming communities

A visual representation of the harvesting periods for major crops in the studied *Unions* is provided in Figure 2.5. As can be seen, rice production is the main agricultural activity in the study area. *Krishnanagar* and *Mathureshpur Unions* contain 1926 ha and 7025 ha of farmland, respectively, with most farmland in both areas being used for rice production (GoB, 2022c). Early maturing and hybrid rice varieties are cultivated during the *Boro* rice season (December to April), while early maturing and flood-tolerant varieties are cultivated during the *Aman* season (July to November) due to the immense volumes of rain brought by the monsoons. In addition to rice, potatoes are also commonly grown in both *Unions* (Figure 2.5). Jute is the only cash crop not produced in both *Unions*; this crop is exclusive to *Mathureshpur*. The vegetables commonly harvested in both *Unions* are predominantly cultivated through homestead gardening practices.

Farmers that grow cash crops also frequently engage in shrimp farming, particularly tiger prawn (*Penaeus monodon*), which is locally known as *Bagda*. Shrimp farming is much more common in *Mathureshpur Union* than in *Krishnanagar Union*, as the former has around 500 *ghers* (embankments or dikes constructed to create enclosures for shrimp farming), while the latter only has about 300 (GoB, 2022c). Shrimp farming is conducted for about 9 to 10 months of the year, with the remaining months being allocated to land-preparation activities.

Krishnanagar Union

Months		Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan
Major crops	Rice	G	G	G	H				S	G	G	H	S
	Potato	G	G	H								S	G
Fish	Shrimp*	Al H	H	H	Al H	Al H	Al H	H	H		LP	AL	AL
	Others	H						LP	AL	AL			H
Vegetables	Turnip	G	H	H								S	G
	Eggplant	H									S	G	H
	Tomato	H								S	G	G	H
	Cucumber					S	G	G	H				
	Indian spinach	H									S	G	H
	Red spinach	H									S	G	H
	Bitter melon	H	H									S	G
	Okra						S	G	H	H			

Mathureshpur Union

Months		Jan-Feb	Feb-Mar	Mar-Apr	Apr-May	May-Jun	Jun-Jul	Jul-Aug	Aug-Sep	Sep-Oct	Oct-Nov	Nov-Dec	Dec-Jan
Major crops	Rice	G	G	G	H			S	G	G	G	H	S
	Potato	G	H								S	S	G
	Jute				S	G	G	G	H				
Fish	Shrimp*	Al H	H	H	Al H	Al H	Al H	H	H		LP	AL	AL
	Others	Al	Al	Al	G	H	H						
Vegetables	Eggplant	G	H								S	G	G
	Tomato	H								S	G	G	G
	Cucumber						S	G	G	H			
	Indian spinach										S	G	H
	Red spinach	H								S	G	H	
	Bitter melon					S	G	G	H				
	Okra	H				S	G	G	H		S	G	G

Figure 2.5 Graphical representation of harvesting periods for major crops in both studied *Unions*.
Source: Collected field data 2022.
Note: S = Sowing; G = Growth; H = Harvesting; F = Flowering; FS = Fruit stage; LP = Land processing; AL = Adding larvae
*For shrimp production, new larvae are added twice a month. Similarly, shrimp are harvested two times per month.

In addition, genetically-modified, saline-tolerant, early-maturing, and highly productive rice varieties such as *BRRI dhan* 40, 41, and 54 (*Aman* season) and *Binadhan* 10 and *BRRI dhan* 47, 61, and 67 (*Boro* season) are commonly harvested in both study *Unions* due to their resilience to climate-induced stresses and challenges. In addition, different NGOs, GOs, and community-based organizations have been deeply engaged in knowledge sharing; for example, such efforts have included encouraging farmers to use more organic fertilizers and less chemical fertilizers to improve soil fertility. In both *Unions*, the use of integrated pest-management systems (e.g., constructing bird perches in farmlands and using different-colored sticky boards and light traps) has become an increasingly popular approach to minimizing the use of pesticides. Although some farmers thought that adding sugar to fertilizer would aid rice growth in highly salinized soil and water, local agricultural regulatory organizations have discouraged this adaptation measure because it has proven to be detrimental to rice productivity.

Integrated agricultural systems, which are less feasible in areas severely affected by salinity, are often used as an adaptation strategy in areas that are relatively less affected. These systems are predicated on the simultaneous cultivation of rice, vegetables, shrimp, and other fish on the same land, as shown in Figure 2.6. Such adaptation strategies not only ensure food security for those dealing with emerging stresses from changing climate, but they are also beneficial for farmers, both financially and for their means of subsistence.

Crop diversification is another efficient strategy for countering unfavorable weather and climatic stresses commonly used in areas of *Krishnanagar Union* that are affected by high salinity. Indian jujube (*Ziziphus mauritiana*), also known locally as the *Boroi* or *Kul* (Figure 2.6), is becoming increasingly popular in *Krishnanagar Union* due to its low water requirements, high productivity, and the distinctive taste it acquires from being grown in salty soil. These factors influence farmers' perceptions and preferences toward jujube cultivation, as well as their willingness to adopt this adaptation measure at the individual and community levels. Community-based organizations and key stakeholders have been instrumental in promoting and assisting farmers with the implementation of these measures. By adopting such adaptation measures, farmers in the *Krishnanagar Union* have set a remarkable example of resilience in the face of environmental challenges, thus paving the way for sustainable agricultural practices in the *Union*.

Climate change's impact on water resources has directly affected the livelihoods of locals. For instance, 30% of respondents from both *Unions* depend on rain and pond water for their drinking water supply, while 68% rely on groundwater. Furthermore, many households still depend on the ancient filtration technique of purifying pond water with a thin white cloth and potassium alum, locally known as *Fitkari*, to meet their drinking water needs due to severe freshwater scarcity.

Technology-based adaptations play a vital role in the study area, particularly in the form of hand-driven deep tube wells. These tube wells are characterized by their substantial boring depth of over 76 meters. A significant majority of individuals (78% of total respondents) own or have access to a hand-driven deep tube well. Significantly, a considerable number of tube wells in extremely salinity-prone locations had become unsuitable for drinking purposes by the 2000s, primarily due to excessive salinity levels and arsenic contamination. At present, water from these tube wells is used for livestock and municipal purposes. A small portion of financially solvent households (18% of total respondents) had a rainwater harvesting system in place, which helped them meet their short-term water needs for drinking and municipal usage. Additionally, with the assistance of NGOs, rainwater harvesting systems have been set up at the community level in *Mathureshpur Union* and are currently being used for drinking and municipal purposes.

Figure 2.6 Adaptation practices in agriculture and water use in *Krishnanagar* and *Mathureshpur Unions*. (A) Integrated farming system wherein rice, vegetables, fish, and shrimp are cultivated at the same time. (B) Harvesting Indian jujube in extreme saline-prone area. (C) Traditional techniques for collecting rainwater. (D) Reverse osmosis plant.

People in coastal regions have become more dependent on membrane-based reverse osmosis (RO) plants for their drinking water needs since being installed (with assistance from NGOs). Presently, 72% of respondents from *Mathureshpur Union* and 68% from *Krishnanagar Union* depend on RO plants for their drinking water needs. Although RO plants only charge between US$ 0.005–0.009 (equivalent to 0.50–1 BDT) per liter for drinking water, underprivileged people and those living in remote areas still rely on ponds and rivers for their drinking water due to financial barriers. This dependency on untreated water contributes to the rapid spread of water-borne diseases, presenting a substantial health risk to these communities.

In areas less affected by salinity, the excavation of small ponds near arable land is the adaptation strategy typically used to meet agricultural water needs; however, the water from these ponds is mostly used to irrigate rice crops during the *Boro* season. According to 62% of respondents from *Krishnanagar Union* and 78% of respondents from *Mathureshpur Union*, diesel-driven shallow-well pumps are the technical adaptation most frequently used to deliver irrigation water in less saline-prone locations, particularly during the rice growing period in the *Boro* season. Even shrimp cultivators depend on shallow-well pumps to drain out the saline water during the land-preparation process. In contrast, the adoption of a deep-well submersible pump powered by electricity or diesel for irrigation was not common in either *Union*. The respondents cited the lack of good-quality water from groundwater aquifers due to salinity intrusion and high instillation costs as the major obstacle preventing the use of deep-well submersible pumps for irrigation.

2.6 Discussion

2.6.1 Perceived climate-change-related hazards

Climate-change-related hazards and their associated stresses impact the lives and livelihoods of people in coastal Bangladesh in many ways. Notably, precipitation patterns have fluctuated significantly in recent decades, resulting in intense rainfall and massive runoff, which in turn has led to flooding and waterlogging (Chowdhury & Ward, 2007; Shahid, 2011). Our findings align with those of other recent studies examining local perceptions of changing rainfall patterns and their detrimental consequences. In this work, the respondents' perceptions relating to reduced crop yields due to rising temperatures were similar to findings of studies conducted in China (Peng et al., 2009) and Punjab, Pakistan (Abbas & Mayo, 2021).

Our investigation revealed that climate-related concerns are statistically significant in both study *Unions*. The local farmers shared their observations and exhibited a keen understanding of the challenges stemming from the considerable changes in rainfall patterns and their implications for their livelihood security. However, it is worth noting that the locals did not have the technical knowledge or skills to comprehend the effects of rising temperatures on freshwater resources, such as an increase in pH levels, waterborne pathogens, and a decrease in dissolved oxygen (Delpla et al., 2009). These negative effects have the potential to result in catastrophic outcomes and pose a significant threat to the availability of safe water for drinking and aquaculture.

Salinity intrusion due to climate change and anthropogenic activities was one of the most pressing concerns in the study area. Locals viewed inadequate rainfall and rising temperatures as the key factors driving higher evaporation rates and freshwater depletion—consequently resulting in salinization—which is consistent with prior findings (Akter et al., 2020). In addition, the rapid rise of sea levels along the Bay of Bengal coast has contributed to the lateral intrusion of saline water into the groundwater supply, thus shrinking and contaminating fresh groundwater aquifers (Lam et al., 2022; Pethick & Orford, 2013). Farmers expressed concerns about the fragility of embankments, as the spilling of saline water from coastal rivers has also served to limit freshwater availability. Notably, the coastal embankment program implemented by the government has generally failed to reduce saline intrusion and flooding (Masud et al., 2018). In addition, higher dependency and unsustainable groundwater extraction relative to the recharge rate has led to reduced aquifer volumes and increased salinity intrusion (Rahaman & Shehab, 2019; Sharan et al., 2023). The excessive extraction of water from aquifers is compounded by climate-induced stress and poses a significant threat to water ecosystem services and livelihoods in the study area, as well as increasing vulnerability to a severe shortage of freshwater for drinking and irrigation.

2.6.2 Perceived consequences on local livelihoods

Our analysis aligns with Roy et al.'s (2022) study of coastal Bangladesh, which revealed that climate-change-related hazards and their associated stresses had significantly reduced crop productivity. Similarly, Lázár et al. (2015) showed that high salinity had severely reduced rice yields during the *Boro* season. Using the advanced CROPWAT model, the authors predicted a substantial decline in crop productivity in high-saline areas, including the southwest coastal region of Bangladesh, by 2050. Our findings were consistent with Lázár et al.'s (2015), as the respondents in this work also viewed salinity intrusion and water scarcity as key causes for reduced crop yields. The combined effects of climatic stress, lack of quality seeds, and pest attacks (Table 2.2) resulted in persistent economic losses in the agricultural sector, forcing farmers to shift their livelihoods or emigrate (Chen & Mueller, 2018).

Local stakeholders perceived shrimp farming as an expedient solution to the reduced yields and increased stresses caused by salinity intrusion. Morshed et al. (2020) found that locals had increasingly turned to shrimp farming to supplement their incomes, with the number of people involved in this practice growing by 16% between 1990 and 2016. In addition, as of 2016, approximately 36% of the land in *Kaliganj*

Upazila was being used for shrimp production. However, in the current study area, shrimp farming entails converting large arable and rentable land into *gher* by landowners and elites, who control the sluice gates and draw saline water into the land. Crop farmers have raised concerns regarding the unplanned expansion of shrimp production, as it could contribute to salinity intrusion on their land. The concerns expressed by the farmers in our study aligned with Morshed et al.'s (2020) data, as the interviewed farmers perceived shrimp farming as creating adverse external effects on neighboring rice cultivation land. Notably, increased salination causes the price of neighboring rice-growing land to decline, thus facilitating easier acquisition and expansion for shrimp cultivators (Morshed et al., 2020). Although shrimp is the second-largest exported commodity in Bangladesh, expanding shrimp farming operations in the southwestern coastal regions without addressing their adverse consequences has resulted in an alarming rise in salinity levels, which poses a significant threat to rice cultivation in this region (Afroz & Alam, 2013).

2.6.3 The effect of experience and perception on adaptation approaches

A strong association was observed between the meteorological data and the locals' perceptions of how climate-change-related hazards had impacted agriculture and water resources (Hasan & Kumar, 2019) — perceptions which had considerably influenced their adaptative strategies. Coastal communities in Bangladesh are continuously adapting to climate-induced stresses, shocks, and livelihood risks. One example of how local farmers have adapted to the scarcity of freshwater for crop production is their adoption of the practice of shifting the conventional rice production period during the *Aman* season based on seasonality. The farmers' experiences and perceptions played a vital role in developing this strategy. In addition, such water scarcity drives willingness to implement advanced adaptation measures in the agricultural sector, which helps to reduce climatic risks to livelihoods. These measures often involve adopting technological adaptations in agriculture, such as fast-maturing, salinity-resistant, and higher-yielding crop varieties. Huq et al. (2004) also observed similar adaptation measures in their study of LMICs. In our investigation, we observed a variety of adaptation strategies that were prevalent in other parts of Bangladesh, such as: the integrated farming of rice, shrimp, fish, and vegetables; homestead gardening of vegetables and fruits; crop diversification; and integrated pest management. The efficacy of these adaptation strategies in mitigating the challenges presented by climate change has been well documented in the literature (Mondal et al., 2019).

Similarly, recognizing and perceiving the effects of climatic stresses on water resources and their detrimental effects on livelihoods motivated the studied communities to implement adaptation measures within the water sector. These adaptations address important priorities such as enhancing resilience to climate-induced stress, reducing drinking water contamination, and facilitating the diversification and conservation of water resources for agriculture and drinking purposes at both the individual and community levels. Locally-driven adaptation measures like excavating mini-ponds adjacent to arable land to meet agricultural water demands and dredging canals to maintain sufficient water flow were common. These findings conform with those reported by Anik and Khan (2012). The widespread adoption of shallow-well pumps, coupled with increased access to such technology across community levels, has facilitated agricultural expansion (Bell et al., 2015). These adaptation actions have significantly supported local farmers in expanding rice production during the *Boro* season—particularly in salinity-prone areas—by securing a stable water supply for irrigation. Indeed, such adaptation approaches have generated more opportunities for individuals who depend on agricultural-based day labor for their subsistence, marking a notable improvement in standard of living compared to the past.

As in other LMICs, perceptions of climate change and the impacts of climate-induced drinking water crises in coastal Bangladesh have significantly motivated locals, and especially farmers, to embrace technological adaptation measures. These measures primarily involve the utilization of tube wells and rainwater harvesting systems to provide water for drinking and municipal use. Nonetheless, it is important to acknowledge the drawbacks of these technologies. For instance, water from shallow-tube wells is often contaminated with arsenic and excessively saline, thus limiting its usefulness (Ahmad et al., 2018).

The use of rainwater collection systems is also accompanied by a number of difficulties, such as insufficient precipitation, water pollution from dust on rooftops and bird excreta, odor, and design defects that prevent the bypassing of initial foul rainwater (Karim, 2010). These limitations often discourage locals from adopting such technologies. Despite the availability of these technologies, coastal inhabitants largely still rely on traditional knowledge to fulfill their drinking water needs, including cloth filtration, potassium alum-based filtration, and boiling water before drinking. These findings are consistent with those reported by Chowdhury et al. (2020). It is worth noting that the widespread implementation of RO plants in the study area has substantially reduced the inclination to use traditional methods for obtaining clean drinking water.

2.6.4 Factors driving the adoption of adaptation measures

Governmental and non-governmental entities, private investment, and increasing literacy rates play a crucial role in increasing knowledge among the locals and, thus, shaping their perceptions and beliefs. Furthermore, projects like Reducing Vulnerability to Climate Change (RVCC), which was conducted in southwestern Bangladesh from 2005 to 2006, have significantly enhanced food security and household income by disseminating knowledge and promoting community-level participation (Chowhan & Barman, 2005). Some community members have become role models through their adoption of effective adaptation measures, which has transformed adversities into opportunities. Noteworthy examples of this trend include the cultivation of Indian jujube in areas highly affected by salinity (jujube acquires a distinctive taste when grown in salty soil) and integrated farming practices in less saline-affected areas. These adaptation actions have significantly reduced livelihood risks and enhanced financial stability within the community by promoting sustainable agricultural practices. The visible benefits of these adaptation strategies have inspired locals, strengthened community capacity, and motivated climate change adaptation at both the individual and community levels.

Enhanced knowledge relating to hygiene and waterborne diseases significantly influenced locals' perceptions and preferences regarding the adoption of advanced technology such as RO plants to meet their drinking water needs. In 2015, NGOs initiated the implementation of RO plants in the coastal area following a locally owned fee-based business model (World Vision [WV], 2021). Private investment and NGO support led to a substantial increase in the number of RO plants in the study area. The active involvement of financially stable local stakeholders has played a crucial role in this adaptation process and had a remarkable impact on alleviating the climate-induced drinking water crisis. Moreover, these adaptation actions have created employment opportunities for local individuals, particularly women and the poor, who are often involved in the operation and maintenance of these plants.

The dissemination of information and knowledge related to climate change adaptation significantly influences local communities' approach to mitigating climate-induced stress on livelihoods and water resources. By diffusing information about the imperative of adopting diverse adaptation measures, electronic media platforms – such as television, the internet, and radio – have played a crucial role in enhancing awareness levels within communities. These media platforms effectively increase awareness among local communities about the inherent dangers associated with waterborne illnesses and emphasize the need to adopt modern technologies like Reverse Osmosis (RO) systems to ensure the availability of safe drinking water.

2.7 Conclusion

This study examined local stakeholders' perceptions of climate-induced stresses and shocks, their effects on their primary means of subsistence, and adaptation strategies commonly adopted by the local community to deal with climate-induced threats and challenges. This work makes a significant contribution to our understanding of perceptions of climate-induced stress in coastal Bangladesh by presenting novel findings regarding the pivotal role of personal experience and its associated manifestations. The present study offers critical insights into how climate-related hazards are impacting local livelihoods and the adaptation measures that have been taken to mitigate these effects. The findings of this study reveal that coastal inhabitants have frequently experienced extreme climatic events such as cyclones, floods, salinity intrusion, and waterlogging in recent years. An overwhelming majority of the respondents perceived these climatic hazards, which is consistent with hydrometeorological data. In addition, the respondents shared that climatic factors had considerably disrupted local livelihoods, which also matches findings reported in literature. In recent years, the respondents had experienced erratic rainfall patterns and temperatures that exceeded historical averages. Climatic factors, along with anthropogenic activities, were viewed as being primarily responsible for stresses—particularly salinity intrusion and waterlogging—that contributed to significant disruptions in the freshwater supply and severe scarcities of water for drinking and irrigation. These climatic stresses and shocks resulted in damage to the livelihoods of locals, such as decreased crop production and economic losses in shrimp farming.

The respondents' experiences and perceptions of such climatic phenomena influenced their adoption of adaptation measures. Practicing crop diversification, planting climate-smart crop varieties, and employing conventional knowledge-based adaptation measures to satisfy water demand have all significantly alleviated climate-induced stress on livelihoods. Adopting technological measures to alleviate scarcity of water for drinking and irrigation not only reduces people's suffering, but it also creates opportunities for farmers to expand crop production and increases labor opportunities.

While governmental and non-governmental organizations have implemented a wide range of adaptation and development strategies in the coastal region, these actions had limited effects on alleviating climate-induced stresses for those living in Bangladesh's coastal communities. Along with engineering interventions, development approaches and adaptation policies in the coastal region must adopt a bottom-up approach and prioritize community members' preferences and locally practiced adaptation measures. Finally, community engagement in the adaptation process, effective monitoring to eliminate inequity in resource distribution, and the availability of adequate facilities to reduce the knowledge gap at the community level must be considered in policy formulation if the desired outcomes of adaptation actions are to be achieved.

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Chapter 3: Meeting climate change challenges in coastal Bangladesh: The dynamics of technology-based adaptations in water use in *Kaliganj Upazila*

Abstract

Climate-change-induced stress impacting water availability is a major threat to agriculture and livelihoods in low- and middle-income countries. Technology-based adaptation measures, however, can mitigate the effects of such stresses, and help to build community resilience. This study investigates the dynamics of technology-based adaptations that affect the availability of water for drinking, domestic, and agricultural purposes in the coastal communities of Bangladesh. To this end, the efficacies of various technologies, adoption processes, accessibility, and societal resource distribution disparities are examined. Empirical data were collected in *Kaliganj Upazila* of *Satkhira* District—one of most vulnerable areas in Bangladesh—primarily using two participatory rural appraisal tools: key informant interviews and focus group discussions. Data were also collected via a household survey. The findings revealed that shallow tube wells, deep tube wells, rainwater harvesting, pond sand filters, reverse osmosis, low-lifting pumps, and deep submersible pumps were the technologies most often employed to address water-related needs; these measures significantly reduced climate-induced water stress. Community-based organizations, neighboring community members, and electronic media played a critical role in the diffusion of technology, mainly through their ability to raise awareness of these adaptation options, while affordability was identified as being vital to the ability to use technology to access water. This research underscores that advancing technology and deploying it in climate-vulnerable areas is not sufficient for achieving the desired outcomes of technology-based adaptations; rather, it is critical to also ensure equitable access by all socioeconomic groups, as doing so will ensure social equity in water usage.

Keywords

Bangladesh, Climate-related hazards, Coastal community, Technology-based adaptation, Water use.

3.1 Introduction

Climate change has emerged as a pressing global issue and has received substantial attention from world leaders and policymakers. Developing countries are disproportionately affected by the uneven climatic variations and increased frequency of extreme weather events caused by climate change (Altieri et al., 2015). Like other low- and middle-income countries (LMICs), Bangladesh is contending with the effects of climate change, currently being ranked 7th in the long-term Climate Risk Index (CRI) (Eckstein et al., 2021). In addition, Bangladesh has been ranked as the 3rd most vulnerable nation to global-warming-induced increases in sea-levels and the associated hazards (Lázár et al., 2015). At present, Bangladesh is home to over 170 million people (World Bank, 2023). Notably, it is also home to a vast rural population that predominantly relies on an agrarian economy to sustain its livelihood (Mukherjee et al., 2019). Heightened exposure to changing rainfall patterns, floods, cyclones, tidal surges, droughts, waterlogging, rising sea levels, and salinity intrusion has adversely impacted the lives and livelihoods of Bangladesh's population, both directly and indirectly (Abdullah et al., 2022; Lázár et al., 2015). Unfortunately, the occurrence of severe climate events is increasing at a rapid pace. Indeed, Bangladesh experienced 113 climatic disasters between 1991 and 2016 compared to only 58 between 1965 and 1990, an increase of nearly 100% (Mukherjee et al., 2019). Furthermore, it is estimated that climate change has resulted in economic losses of US$12 billion in Bangladesh over the past four decades (World Bank, 2016).

Among natural resources, water is the primary medium through which the impacts of climate change are manifested (Chang & Bonnette, 2016). Due to its location, Bangladesh's coastal area is more exposed to climate-induced geophysical and hydro-meteorological hazards, which can have devastating impacts on water resources (Abedin et al., 2019). Drastic changes in precipitation patterns in these coastal areas, particularly heavy precipitation during the monsoon period, can create massive runoffs, which in turn result in flooding, river erosion, and waterlogging (Lázár et al., 2015; Shahid, 2011). Additionally, considerably low levels of precipitation during the lean period (non-monsoon) pose a threat to freshwater ecosystems and water quality, further exacerbating vulnerabilities in the region. Furthermore, the average temperature in Bangladesh's coastal region is increasing at a rate of 0.023°C per year compared to 0.009°C in its inland areas (Abdullah et al., 2022). The rising temperatures in the coastal region have negatively impacted the freshwater ecosystem and threated the safety of the area's drinking water, as they have resulted in higher pHs and waterborne pathogens, and decreased levels of dissolved oxygen in the water supply (Abdullah et al., 2022; Delpla et al., 2009).

Extreme salinity intrusion is another effect of climate change that significantly threatens social stability in Bangladesh's coastal region. In recent years, increased salinity intrusion into water bodies has resulted into several undesirable features, including higher land surface temperatures and, by extension, higher evaporation rates and more erratic rainfall patterns (Akter et al., 2020; Colombani et al., 2016; Abedin et al., 2019); increased frequency of tropical cyclones and storm surges (Woodruff et al., 2013); and rapid increases in coastal sea levels (Pethick & Orford, 2013).

Rising sea levels drive the long-term lateral intrusion of saline water from the Bay of Bengal into the coastal region's fresh groundwater aquifers and, consequently, their shrinkage and contamination (Lam et al., 2022; Pethick & Orford, 2013). Khanom (2016) found that, between 2000 and 2009, salinity intrusion increased to up to 15 km from the south coast during the monsoon season and up to 160 km during the dry season. This situation has been further exacerbated by the uncontrolled withdrawal of groundwater and the inhabitants' increased dependency on it, as this demand has resulted in the depletion of the fresh groundwater table and contributed to increased salinity intrusion (Rahaman & Shehab, 2019; Sharan et al., 2023). Such climate-induced phenomena have significantly damaged water ecosystem services in Bangladesh's coastal region, causing severe crises regarding the availability of freshwater for drinking and irrigation.

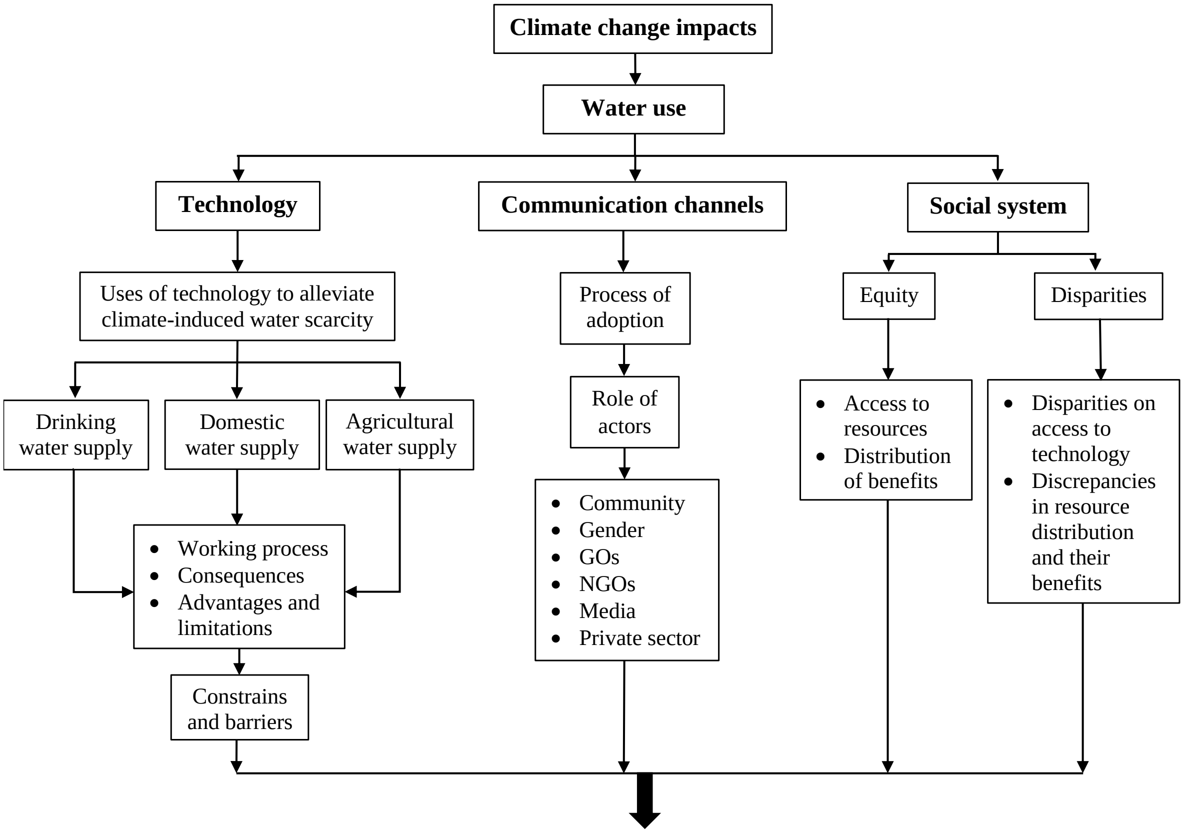
Technology-based adaptations in the water sector can contribute to substantial improvements in quality of life, as they can build resilience to extreme climate hazards, reduce drinking water contamination, and promote the diversification and conservation of water resources. The long-term application of environmentally-sound technology is a highly recommended adaptive measure for alleviating climate-induced stress on water resources (IPCC, 2014). Some of the major adaptation technologies implemented globally in recent decades include rainwater harvesting, water storage, water reuse, desalination, increasing irrigation efficiency, and effective water use. The literature on climate change adaptation in coastal Bangladesh reveals that rainwater harvesting, pond sand filters, and tube wells are the most common hard technologies employed to mitigate climate-induced stresses and address drinking water scarcity (Abedin & Shaw, 2018; Rahman & Islam, 2013). However, inequalities in access to technology and disparities in resource distribution remain major concerns, as these social justice dimensions can impede the adaptation process. Moreover, the scarcity of information relating to the dynamics driving different socioeconomic groups' adoption of such technologies limits the ability of policy-making institutions to deploy effective technology for reducing climate-induced water stress.

This study investigates how coastal communities in Bangladesh employ technology to adapt to climate-related stresses and ensure access to clean water for drinking, domestic, and agricultural purposes. To this end, we investigate critical aspects of different technologies and their efficacy; the adoption process; the ability to access technologies that enable affordable and safe water services; and disparities in resource distribution. This work makes a novel contribution to the literature, as our analysis of the micro-level data relating to these variables identifies effective technology-based adaptation measures for alleviating water scarcity and expanding technology-based adaptive approaches in Bangladesh's coastal communities.

3.2 Conceptual considerations

The diffusion of innovation has been widely researched in various fields, including education, sociology, and healthcare. Rogers et al. (2019) define diffusion as the process through which technology is conveyed to people in a community through certain pathways over time. Rogers' Diffusion of Innovation theory (Rogers, 2003) was incorporated into this study for its ability to provide insights into the adoption and implementation of adaptation approaches in the water resource management sector in Bangladesh's coastal regions. Specifically, we focused on three of the four prime elements of Rogers' theory in designing this study's conceptual framework: 1) technology, 2) communication channels, and 3) the social system (also see Sahin, 2006). In addition to examining the dynamics driving the adoption of technology as an adaptation measure in Bangladesh's water sector, this work also considers the findings of the Food and Agriculture Organization (FAO) study regarding climate change's impact on aquaculture and adaptation management (Bahri et al., 2021). Figure 3.1 illustrates the primary dimensions used to evaluate the three elements of Rogers' theory vis-à-vis the adoption of technology as a climate change adaptation, as well as the consequences of adopting technology-based adaptation based on different scenarios.

The term, "technology," is a broad concept. However, in this paper it will be used to refer to "*a form of human cultural activity that applies the principles of science and mechanics to solve problems. It comprises resources, tools, processes, personnel, and systems developed to perform tasks and create immediate, personal, and/or competitive advantages in a given ecological, economic, and social context*" (McOmber, 1999, p. 138). Other scholars define technology as instrumental action perceived as a new object that reduces ambiguity in cause-effect interactions to achieve a desired objective (Rogers, 2003; Sahin, 2006). Following the 2005 United Nations Framework Convention on Climate Change (UNFCCC), the application of technology-based adaptations to reduce the effects of climate change began to receive significant global attention. The UNFCCC defines technology-based adaptations as the practical application of skills and scientific knowledge via environmentally friendly mechanisms with the aim of building resilience of natural ecosystems or human society to the impacts of climate change (Kim, 2021; UNFCCC, 2005). The study assesses the application of hard technology—defined as, "*manufactured goods or equipment*" (Olhoff, 2015, p. 165)—as an adaptation to climate change in three major water-consumption areas: drinking, domestic, and agricultural.



Climatic adaptation measures	Productivity changes and influences livelihoods	Reduce water vulnerability	Required implementation capacity
Incorporate environmental factors and enhancing efficacy of technology		✓	H
Improve monitoring initiatives using a community-focused strategy	✓	✓	L
Enhance externalities, such as financial facilities and diffusing knowledge	✓	✓	L – H
Enhance and establish effective transparent action to monitor technological facilities and usage of water resources		✓	H
Develop irrigation canals and ensure adequate water supply	✓	✓	H
Adjust conventional cropping period and enhance crop diversification	✓	✓	M
Ensure equitable access-to-technology among all socio-economic groups through community-focused strategy	✓	✓	L – H
Ensure the fair and transparent distribution of institutional resources	✓		L – H

Figure 3.1 A conceptual framework of the diffusion and adoption of adaptation technologies in water use and their outcomes.

Note: Climatic adaptation measures in the water sector are rated according to the capacity required for implementation and are marked as low (L), moderate (M), or high (H)

Communication and diffusion channels are the mechanisms through which information and knowledge generated by individuals or institutions are spread throughout a community (Rogers, 2003; Sahin, 2006). The development and diffusion of scientific-knowledge-based adaptation measures is strongly correlated with communication facilities wherein different actors and institutions play a major role as a mediator (Fuenfschilling & Truffer, 2016; Hovik et al., 2015). A wide variety of factors influencing communication and diffusion channels have been identified in the literature, including: stakeholders' involvement in the community (Adger et al., 2013), role of gender (Pearse, 2017); contributions from government organizations (GOs) (Berrang-Ford et al., 2011) and non-government organizations (NGOs) (Olsson et al., 2015); the diffusion of information through electronic media (Menike & Arachchi, 2016); and private sector engagement (Agrawala et al., 2011). These factors significantly influence adaptation measures, for example, in the form of supportive policies and regulations, capacity building, and public-private partnerships.

The social system consists of a group of connected entities engaged in collective problem-solving to achieve a shared goal (Rogers, 2003; Sahin, 2006). The social system plays a crucial role in ensuring the equitable distribution of resources within a community, which in turn helps to strengthen the community's adaptive capacity (IPCC, 2001). In this work, adaptive capacity will refer to "*the minimum resourcing requirements to successfully implement the adaptation measure and includes human resources, financial resources, technical capacity, and/or the need for supporting institutions or entities*" (Bahri et al., 2021, p. 38). Apart from financial considerations (i.e., affordability), many studies have identified the equitable distribution of resources and facilities within a society as being a major factor influencing the adoption of appropriate adaptation measures (Bahri et al., 2021; Tan et al., 2015; Thomas & Twyman, 2005). Disparities in resource distribution across socio-economic groups not only limit adaptive capacity, but it can also result in disproportionate hardship for marginalized people, thus further exacerbating pre-existing social inequalities (Abebe, 2014; Tan et al., 2015).

3.3 Methodology

3.3.1 Study area

Satkhira is regarded as the most vulnerable of Bangladesh's 19 coastal districts, as it is highly vulnerable to risks such as cyclones, rising sea-level, waterlogging, and saline intrusion (Fenton et al., 2017; Lam et al., 2022). *Kaliganj Upazila* (sub-district) was selected as the study area for this research, as its vulnerability index of 0.66 was significantly higher compared to other *Upazilas* in the *Satkhira* District (GoB, 2018). In terms of geography, *Kaliganj Upazila* is located between 22°19' and 22°33' (north latitudes) and 88°58' and 89°10' (east longitudes) and has a total area of 333.78 sq km (BBS, 2015) The study was conducted in the *Krishnanagar* and *Mathureshpur Unions*, which were selected at random from the 12 *Unions* within the *Satkhira* district. The *Krishnanagar* and *Mathureshpur Unions* encompass total areas of 26.65 sq. km. and 37.79 sq. km, respectively (BBS, 2015; GoB, 2022).

3.3.2 Data collection procedure

Considering the objective of our study, a participatory research approach was employed. Participatory research emphasizes the use of a "bottom-up" technique, which involves privileging perspectives and priorities within a given local context (Cornwall & Jewkes, 1995). Data was collected using a mixed-methods approach comprised of two participatory research appraisal (PRA) tools (i.e., key informant interviews and focus group discussions) and a household survey. The selected approach facilitated a well-rounded understanding of the research questions and responses and allowed for the triangulation of the findings, thus enhancing the reliability and validity of the results (Creswell & Creswell, 2018).

The present study received ethical approval from the Research Ethics Board at the University of Manitoba, Fort Garry campus (Protocol Number: HE2022-0207). The household surveys, key informant interviews, and focus group discussions were conducted in either Bengali or English (depending on the respondents' preferred language) in accordance with the established protocols regarding consent.

3.3.2.1 Household survey

The household survey is a pragmatic and extensively used quantitative method for assessing technology-based adaptive measures in response to climate change within the water sector (Mfitumukiza et al., 2020; Voth-Gaeddert et al., 2022). In the present study, a sample of 300 households from the *Krishnanagar* and *Mathureshpur Unions* was selected using a random sampling method. A total of 5 villages from each *Union* were chosen randomly, with the heads of the selected households being invited to participate in the survey. The survey was a structured questionnaire consisting of questions relating to socioeconomic attributes, water supply sources, the impact of climatic variability on water sources, the types and effectiveness of technologies adopted as adaptation measures, assess-to-technologies, and disparities. On average, the survey took approximately 30 minutes to complete.

3.3.2.2 Key informant interviews (KIIs)

To attain a nuanced understanding of the research questions, a total of 15 key informant interviews (KIIs) were conducted with individuals possessing direct and relevant experience and expertise. The KIIs were conducted up to data saturation to ensure a comprehensive analysis of climate-induced stress, technology-based adaptations, and the dynamics of technology adoption in the water sector. The interviews utilized a combination of open-ended and semi-structured questions to elicit detailed and in-depth data regarding the participants' views, experiences, and understandings of the research subject. Participants were purposively selected from the study area and included 3 crop farmers, 2 shrimp cultivators, 1 day laborer, 1 schoolteacher, 2 local leaders, 2 NGO practitioners, and 4 members actively engaged in the governing bodies at *Union* and *Upazila* levels. Five KIIs were conducted in *Krishnanagar Union*, 7 were conducted in *Mathureshpur Union*, and 3 in *Kaliganj Upazila*. Notably, only 2 women participated in the KIIs due a lack of knowledgeable and literate women in the study communities. Each KIIs took an average of 45 min to complete.

3.3.2.3 Focus group discussions (FGDs)

Focus group discussions (FGDs) provide participants with a platform to share their views and experiences, which yields a comprehensive understanding of their reality with respect to a given research topic. We conducted a total of 6 FGDs (3 in each *Union*), with potential participants being identified through snowball sampling (Parker et al., 2019). From this sample, we randomly selected 12-16 participants for each FGD. The participants came from diverse occupational backgrounds and included farmers, shrimp cultivators, small landowners, teachers, local government officials, community-based organization representatives, and elderly individuals. In total, 14 women participated in the FGDs. The FGDs were conducted using a semi-structured questionnaire that addressed disparities in adopting technology as an adaptation approach to reduce water stress; the roles of stakeholders in adopting technology; and constraints and barriers to expanding technology-based adaptation. Each FGD lasted for approximately 60 minutes.

3.4 Results

3.4.1 Socioeconomic attributes of the study area

The key socioeconomic attributes of the households surveyed in *Krishnanagar* and *Mathureshpur Unions* are presented in Table 3.1. As can be seen, there was a marked distinction in household composition, with *Krishnanagar Union* containing a higher proportion of male-headed households (94.44%) compared to *Mathureshpur Union* (83.33%). With regards to household income, the mean number of earning members was higher in *Krishnanagar Union* compared to *Mathureshpur Union*. Agriculture was identified as the predominant source of livelihood for the majority of households in *Krishnanagar Union*, followed by wage labor and various other professional pursuits, while aquaculture (e.g., collecting shrimp fry, shrimp, and other fish farming) was cited as the primary source of income for most households in *Mathureshpur Union* (Table 3.1).

Rahman et al. (2017) used annual household income to create a socioeconomic profile of Bangladesh's coastal communities. Conversely, other researchers have defined the socioeconomic profiles of LMICs using "per day per capita income," with reference to poverty line values provided by the World Bank (Njie et al., 2023; Voth-Gaeddert et al., 2022; World Bank, 2020a; World Bank, 2020b). In this study, we used per day per capita income data to divide the participants into three socioeconomic groups: extreme poverty (less than or equal to US$1.90 per day); lower middle-income (less than or equal to US$3.20 per day); and upper middle-income (less than or equal to US$5.50 per day). The field data revealed that the majority of households in *Krishnanagar Union* (63.19%) and *Mathureshpur Union* (73.72%) fell within the extreme poverty group (Table 3.1). Additionally, the data showed that *Krishnanagar Union* had a relatively higher proportion of lower-middle income households compared to *Mathureshpur Union*, while only a small proportion of households in both *Unions* fell within the upper middle-income group.

Table 3.1 Characteristics of households surveyed in the study area.

Characteristic	***Krishnanagar Union***	***Mathureshpur Union***
Total number of HH survey	144	156
Male-headed HH	136	130
Women-headed HH	8	26
HH size, mean (SD)	4.74 (1.74)	3.91 (1.52)
HH head age, mean (SD)	49.49 (11.32)	48.03 (12.16)
HH earning member, mean (SD)	2.64 (1.19)	2.01 (0.89)
HH primary source of earning		
Agriculture (%)	56.94	8.33
Aquaculture* (%)	2.08	39.74
Wage labor (%)	20.14	27.56
Business (%)	6.25	7.69
Professional job (%)	6.94	8.97
Socioeconomic group		
Extreme poor (%)	63.19	73.72
Lower-middle-income (%)	27.08	18.59
Upper-middle-income (%)	6.25	5.77
Wealthy (%)	3.47	1.92

Note: HH = household; SD = standard deviation
* Aquaculture includes only collecting shrimp fry, shrimp, and other fish farming
US$ to BDT exchange rate (January–February 2023): 1 US$ = 106.13

3.4.2 Impact of climatic variabilities on water resources

Local stakeholders in *Krishnanagar* and *Mathureshpur Unions* identified climate change as the major cause of water-related stresses such as salinity intrusion into water bodies, waterlogging, changing rainfall patterns (e.g., inadequate and extensive rainfall), and increased temperatures, which has created a water crisis in relation to both drinking and agriculture uses. Household survey data obtained using a Likert scale captured the negative impacts on water sources and their availability caused by uneven climatic variability and extreme climatic events (Figure 3.2). Notably, the majority of respondents reported that climate variability in the region had extensively affected the availability and quality of surface water (78.47% in *Krishnanagar Union* and 68.59% in *Mathureshpur Union*) and groundwater (54.86% in *Krishnanagar Union* and 75% in *Mathureshpur Union*).

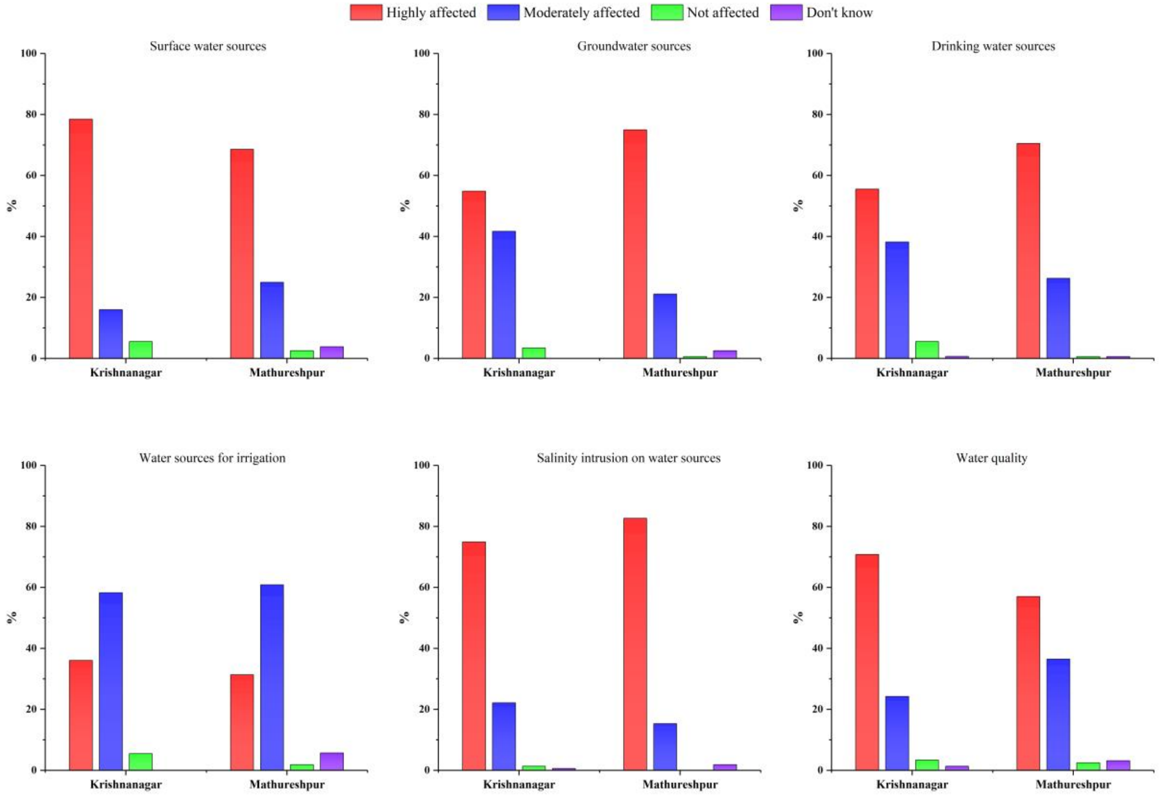


Figure 3.2 Impacts of climatic variability on water sources as reported by the respondents in the study area.
Source: Collected field data 2022.

The respondents also reported that salinity intrusion had significantly impacted the quality of surface water and groundwater sources (75% in *Krishnanagar Union* and 82.69% in *Mathureshpur Union*), resulting in unbearable suffering for people living near the coastal belt along the riverbank. Additionally, the local farmers noted that salinity levels typically increase from December to July, reaching excessive levels between March and May. The major climatic factors influencing salinity intrusion in the study area were inadequate rainfall, high temperatures, and rising sea levels. Furthermore, the participants observed that the expansion of shrimp farming into low-laying and arable lands in both study *Unions* had also contributed to increased salinity intrusion. The expansion of shrimp farming into these areas entails the redirection of saline water from coastal rivers to inland locations via sluice gates, which are predominantly controlled by large shrimp cultivators and local elites. Finally, the respondents identified water seepage from coastal rivers due to weak embankments and water overtopping from increased tidal-water levels as frequently occurring events that significantly influence salinity intrusion.

These stressors had an especially severe impact on drinking water availability, as over half of the respondents in both *Unions* reported that climate-based stressors had significantly restricted their access to potable water (55.56% in *Krishnanagar Union* and 70.51% in *Mathureshpur Union*). Similarly, the majority of respondents in *Krishnanagar Union* (70.83%) and *Mathureshpur Union* (57.05%) reported that climate-based stressors had negatively affected the quality of the drinkable water they were able to access. The participants further shared that drinking water scarcity reached extreme levels during the dry season, as the lack of precipitation resulted in lower groundwater levels and higher salinity.

More than half of the respondents from *Krishnanagar Union* (58.33%) and *Mathureshpur Union* (60.90%) reported that climate-based stressors had moderately impacted the availability of water for irrigation. This finding is notable, as the livelihoods of local people, especially in the agricultural sector, depend on the availability and quality of irrigation water. Lack of access to fresh water, extreme salinity intrusion into the groundwater, and insufficient rainfall often force farmers to use saline water, which results in reduced productivity and high economic losses.

3.4.3 Adoption of technology as an adaptation process in the coastal water sector

According to the *Union Parishad*, there are approximately 2,050 privately-owned tube wells, 377 low-lifting pumps, 1 community-based rainwater harvesting system, and 10 pond sand filters in the *Krishnanagar Union*. Conversely, *Mathureshpur Union* has around 1,052 privately-owned tube wells, 4 community-based rainwater harvesting systems, 16 pond sand filters, and 2 privately-owned deep submersible pumps. Table 2 shows the distribution of technologies used to obtain drinking, domestic, and agricultural water by socioeconomic group. As can be seen, most respondents in *Krishnanagar Union* depended on deep tube wells (DTW) for their drinking and domestic water supply, while reverse osmosis (RO) and rainwater harvesting (RWH) were more commonly used in *Mathureshpur Union*. Furthermore, the respondents from both *Unions* expressed a general preference for low-lifting pumps (LLP) as the best technology for ensuring an adequate supply of irrigation water (Table 3.2).

A Likert scale was employed to assess these technologies' effectiveness as adaptation strategies for alleviating climate-induced water stress (Figure 3.3). The data revealed that, in both *Unions*, groundwater-based technologies (e.g., RO, DTW, and deep submersible pumps (DSP)) were viewed as highly efficient adaptation techniques for dealing with climate-induced water scarcity, while shallow tube wells (STW) and pond sand filters (PSF) were viewed as less efficient, and, thus, were less favored.

3.4.3.1 Tube wells

Tube wells consist of a thin tube that is driven into the sub-surface to extract the groundwater from unconfined aquifers. Tube wells were introduced to Bangladesh during British colonization in the 1920s and were subsequently adopted, with support from governmental and international organizations, in the 1960s and early 1970s as part of the Green Revolution initiatives. By the early 1990s, approximately 95% of rural communities in the country depended on tube wells for their drinking water supply (Caldwell et al., 2003). Households that rely on STWs typically utilize the water for domestic purposes. However, in 1993, arsenic contamination was detected in tube-well water (Ahmad et al., 2018), which led to a significant decline in the use of hand-driven STWs for drinking water (the Department of Public Health Engineering (DPHE) defines STWs as wells with a boring depth of less than 76.2 m (DPHE, 2022) (Table 3.2). The perceived ineffectiveness of this technology can be seen in Figure 3.3. Indeed, the rising health risks associated with the use of STWs have become a major public concern and have highlighted the urgent need for alternative sources of clean drinking water.

Table 3.2 Distribution (%) of uses of technology for drinking, domestic, and irrigation water supply by socioeconomic group.

Socioeconomic group	**For drinking water supply**					**For domestic water supply**				**For irrigational water supply**			
	RWH	**STW**	**DTW**	**PSF**	**RO**	**RWH**	**STW**	**DTW**	**PSF**	**RWH**	**PSF**	**LLP**	**DSP**
Krishnanagar													
Extreme poor group	5.49	-	89.01	-	9.89	13.19	8.79	51.65	-	2.20	-	70.33	12.09
Low-middle-income group	5.13	-	71.79	-	25.64	23.08	12.82	43.59	-	-	-	74.36	20.51
Upper-middle-income group	-	-	88.89	-	11.11	22.22	22.22	44.44	-	-	-	66.67	33.33
Wealthy group	40.00	-	60.00	-	20.00	40.00	-	60.00	-	-	-	80.00	20.00
Total	**6.25**	**0.00**	**83.33**	**0.00**	**14.58**	**17.36**	**10.42**	**49.31**	**0.00**	**1.39**	**0.00**	**71.53**	**15.97**
Mathureshpur													
Extreme poor group	58.26	4.35	40.87	13.04	55.65	64.84	35.65	16.52	13.91	4.35	1.74	4.35	-
Low-middle-income group	48.28	3.45	34.48	13.79	65.52	43.59	44.83	3.45	6.90	6.90	-	13.79	3.45
Upper-middle-income group	44.44	-	-	-	77.78	33.33	11.11	-	-	-	-	11.11	-
Wealthy group	66.67	33.33	33.33	-	33.33	40.00	33.33	-	33.33	66.67	-	33.33	-
Total	**55.77**	**4.49**	**37.18**	**12.18**	**58.33**	**56.25**	**35.90**	**12.82**	**12.18**	**5.77**	**1.28**	**7.05**	**0.64**

Note: RWH = Rainwater harvesting; STW = Shallow tube well; DTW = Deep tube well; PSF = Pond sand filter; RO = Reverse osmosis plant; LLP = Low-lifting pump; DSP = Deep submersible pump

During the early 2000s, both the government and international institutions ardently promoted the adoption of DTWs (which have a boring depth greater than 76.2 m (DPHE, 2022)) as reliable and effective substitutes for STWs. By 2015, DTWs had surpassed STWs as the principal source of drinking water for 75% of the population living along Bangladesh's southwest coast (Akter, 2019). The principal advantage of a DTW is its capacity to provide safe drinking water without additional treatment or electricity (Kundu et al., 2016). This ability makes DTWs a highly effective option for addressing the climate-change-induced freshwater scarcity and has led to its widespread adoption (Figure 3.3) in both *Krishnanagar* and *Mathureshpur Unions* (Table 3.2). Households that had installed a DTW used the water for both drinking and domestic purposes. The participants cited the lack of an available high-grade aquifer and a shrinking groundwater table as the two major barriers to installing a DTW; this was particularly the case in *Mathureshpur Union*, where groundwater had been highly affected by salinity intrusion caused by rising sea levels and man-made factors.

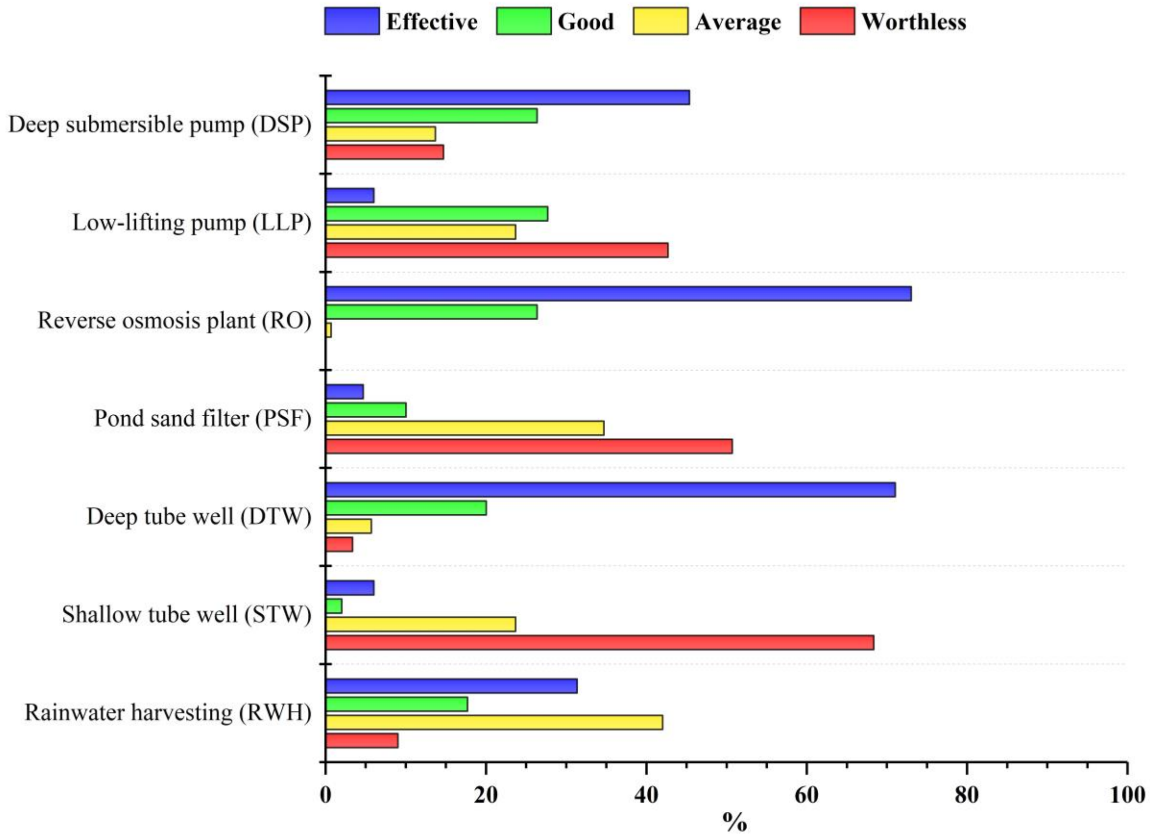


Figure 3.3 The relative effectiveness of various technology-based adaptations at reducing climate-induced water stress in the study area.
Source: Collected field data 2022.

3.4.3.2 Rainwater harvesting (RWH)

Rainwater harvesting (RWH) is an ancient, time-honored technique that involves the careful collection, preservation, and purification of rainwater for daily use (Hasan & Irfanullah, 2022). While the roots of RWH stretch back to Prehistoric times (3,200–1,100 BC), its current global popularity has been fostered by technological advancements such as the incorporation of roof catchments and water filtration facilities into RWH systems (Bashar et al., 2018; Hasan & Irfanullah, 2022; Mays et al., 2013). The relatively lower installation costs for RWH systems have made them an effective adaptation approach for the LMICs, where per capita water consumption is significantly lower compared to more developed countries (Musayev et al., 2018). RWH is an especially promising and sustainable water supply option for Bangladesh's coastal regions, as these areas are increasingly experiencing critical water shortages during the dry (i.e., non-monsoon) season due to erratic rainfall patterns caused by climate change. The survey results indicated that approximately 45% of the population in the study area had access to RWH for their water needs. Depending on the size of the reservoir, a typical RWH system can fulfill the water needs of a four-person family for four to six months.

Figure 3.4 Technologies being used for water supply: (A) Rainwater harvesting (RWH) (B) Low-lifting pump (LLP) (C) Deep submersible pump (DSP) attached with deep tube well (DTW) (D) Reverse osmosis plant (RO).

The use of RWH for drinking purposes was significantly limited, especially in the *Krishnanagar Union*, primarily due to potential health risks posed by contamination from bird excreta, plants, dust on the rooftop, and design flaws that do not permit the first foul rainwater to be bypassed in order to maintain microbial quality (Karim, 2010). In recent years, the emergence of other reliable technologies has reduced dependency on RWH for drinking water purposes in recent years; however, the data showed that most people in the *Mathureshpur Union* (where DTWs are rarely found) still relied on this method to meet their drinking water requirements (Table 3.2). Although RWH was rated as average in terms of effectiveness due to its maintenance requirements and limited usefulness during the dry season (Figure 3.3), stakeholders from both *Unions* nevertheless recommended it as a climate change adaptation technology, as it can be highly efficacious for meeting drinking, domestic, gardening, and homestead water demands during water-stressed periods.

3.4.3.3 Pond sand filter (PSF)

Bangladesh's rural population relies heavily on ponds as a primary source of water for their daily needs. Unfortunately, pond water is often contaminated with high levels of turbidity and bacteria, which can lead to significant health complications, including diarrhea, dysentery, and cholera. In response, the implementation of a low-cost PSF is a popular water treatment option in rural areas of Bangladesh. PSFs are small-scale filtration devices made of brick chips, stones, sand, and plastic pipes that are installed at the edge of a pond and manually operated by a hand-driven tube well (Alam et al., 2011; Yokota et al., 2001). This technology was introduced to Bangladesh's coastal regions in 1984 by the DPHE and the United Nations Children's Emergency Fund (UNICEF) to ensure the region's access to a safe water supply (Alam et al., 2011). On average a PSF costs around US$1,500 to install (Abedin et al., 2019), with a standard-sized PSF (8 meters in length, 2.7 meters wide and 1.8 meters tall) having the capacity to treat up to 1,000 liters per hour. This volume of production is capable of satisfying the water needs of around 100 households (Yokota et al., 2001).

Despite these advantages, the survey results revealed that residents in the *Krishnanagar* and *Mathureshpur Unions* generally relied on technologies other than PSF to meet their drinking, domestic, and irrigation water needs (Table 3.2). The participants viewed PSFs as being ineffective, instead preferring the use of more advanced options to attain a safe water supply (Figure 3.3). Furthermore, the respondents noted that high rates of infiltration and evaporation often led to ponds drying up, thus rendering PSFs unusable. Another obstacle to the use of this technology is the challenge of finding ponds that are not used for fish farming, bathing, washing clothing, and watering livestock. This challenge is even more pronounced in regions where water scarcity has become a crisis due to climate change. Additionally, PSFs are not suitable in areas with extremely high saline, potassium, and chloride levels. Despite their effectiveness in reducing coliform and general bacteria levels, PSFs are unable to eliminate pathogens from contaminated water, which may pose health concerns and decrease their appeal in the study area.

3.4.3.4 Reverse osmosis (RO)

RO is a membrane-based desalination technology that was invented in 1964 by Srinivasa Sourirajan (Orooji, 2022). In this technique, water is purified by using pressure to separate out sodium chloride, dissolved solids, and other impurities (Clever et al., 2000; Orooji, 2022; Shamsuzzoha et al., 2018). RO has become widely used for water purification applications throughout the world, as its effectiveness is comparable or superior to other desalination and water treatment methods (Jamaly et al., 2014). Over the last decade, many non-governmental organizations and private sector enterprises have invested in this technology via a locally owned fee-based business model in an effort to promote the construction of RO facilities along the coast of Bangladesh (Hoque et al., 2019; WV, 2021; Figure 3.4). These projects have demonstrated RO's ability to successfully alleviate the lack of potable water, which has motivated the steady growth of this technology's popularity within Bangladesh's coastal communities. As part of this initiative, wealthy residents in the study region have been encouraged to become "water entrepreneurs" by funding the construction of groundwater-based RO plants.

Among the various technologies, the participants from the *Krishnanagar* and *Mathureshpur Unions* rated RO as the most effective for dealing with climate-induced stresses on drinking water availability (Figure 3.3), with a total of 72.91% of households depending on RO plants to meet their drinking water demands. The cost to install an RO plant capable of producing 1000 liters per hour is approximately US$26,000, which includes all machinery and civil structure costs (WV, 2021). Drinking water produced by an RO plant costs US$0.005 per liter if it is picked up from the plant, and US$0.01 per liter if it is delivered. RO's efficacy in providing safe drinking water and improving quality of life by reducing water-borne diseases has led to its exponential adoption in many other parts of the world. Furthermore, RO plants provide employment opportunities for local individuals, particularly women, who often oversee their operation and maintenance. However, this technology is hampered by a number of limitations, including high energy consumption, the need for frequent chemical cleaning, and the need to replace membranes and other machinery to avoid membrane fouling and to obtain the optimum output (Jiang et al., 2017). In an effort to minimize membrane fouling and prolong the lifetime of the RO systems, most of the RO plants in the study region were strategically located in areas with lower salinity levels. As a result, the RO plants operated primarily using high-quality groundwater, thus bolstering the cost-effectiveness of the technology.

3.4.3.5 Low-lifting and deep submersible pumps

Water lifting devices have been employed to provide water since as early as 3,000 B.C. (Yannopoulos et al., 2015). The demand for and applications of water lifting methods in various industries has significantly increased alongside advances in these technologies. Until the 1970s, the people of Bangladesh relied entirely on canal water and rainfall to satisfy their agricultural water demand (Haque et al., 2017;

Shamsudduha et al., 2011). However, this practice underwent a noticeable transformation with the introduction of power-operated water lifting technologies. For example, the introduction of pumps between 1963-1966 ensured adequate water supply for *Boro* rice production during the dry season (December-April) (Shamsudduha et al., 2011; Shelley et al., 2016). Low-lifting pumps (LLPs), known locally as shallow pumps, and deep submersible pumps (DSPs) (Figure 3.4) were identified as the most commonly used water lifting technologies in the *Krishnanagar* and *Mathureshpur Unions*.

The main limitations to the use of DSPs include the availability of high-quality aquifers, reduced groundwater tables, and high installation costs. Furthermore, the availability of DSPs was limited in the study area. One farmer in *Krishnanagar Union* who owned a DSP outlined the costs of using this technology:

> *The average installation cost of an electricity-driven deep submersible pump with a capacity of 150 horsepower and a boring depth of more than 200 m is 500,000 Taka* [US $4,500]. *In addition, the maintenance cost of this pump is nearly 5,000 Taka* [US $47] *per year. The monthly electricity cost to operate this technology is 10,000 Taka* [US $95]. *This submersible pump can fulfill the water demand for irrigation of 1,320 decimal agricultural land.*

DSP technology is primarily used to meet irrigation demand during the four-month *Boro* rice growing season. DSPs are primarily owned by local elites and financially solvent stakeholders, who have become vendors for water supply for irrigation during the dry season. Water is supplied to farmers' lands via flexible rubber hose pipes connected to the DSP, which is located elsewhere—typically on the owner's land. The respondents noted that it costs approximately US$40 to have irrigation water supplied to 33 decimals of agricultural land for the entire four-month *Boro* rice growing season. Overall, 45.33% of respondents rated DSP as an effective technology due to its effectiveness in meeting the farmers' water demands during the dry season. In the study area, access to this technology created opportunities for farmers to expand their rice cultivation to the dry season, as they had been previously confined to cultivating *Aman* rice during the monsoon season (July-November) due to water scarcity and extreme salinity during the dry season.

Compared to DSPs, LLPs are cost-effective and easy-to-use. The average cost to install an LLP with a boring depth of less than 76.2 m is approximately US$1,000. The majority of LLPs in the study area were diesel driven. Although LLPs are a cost-effective option for satisfying irrigational water demand, this technology was rated as being a less effective adaptive strategy for mitigating climate-induced stress on water resources compared to DSPs (Figure 3.3). Farmers mostly used LLPs when they had no facilities or access to a DSP, or when they were unable to install a DSP due to the lack of a good groundwater aquifer and extreme salinity intrusion into the groundwater. In contrast, farmers in areas with comparatively lower salinity intrusion preferred to use LLPs to meet their irrigational water demand. This technology was also used to lift water from the river to the *gher*, which is a modified field with peripheral dikes for shrimp farming. In the *Krishnanagar Union*, local people's livelihoods mostly depended on agriculture; hence, the number of people using both LLPs and DSPs was quite sizeable compared to the *Mathureshpur Union* (Tables 3.1 and 3.2).

3.4.4 Dynamics of adopting technology-based adaptations

3.4.4.1 Adoption process

The dissemination of information and knowledge relating to technology-based adaptations significantly influences their adoption to mitigate climate-induced water scarcity. The roles played by various stakeholders and media in spreading knowledge and encouraging the adoption of technology in the study area are shown in Figure 3.5. In recent years, electronic media, such as television and radio, have emerged as significant mediums for disseminating information about technology-based adaptation across social groups. These media have also raised awareness among local communities regarding the risk to waterborne diseases and the need to adopt advanced technologies such as RO and DTW to ensure safe drinking water.

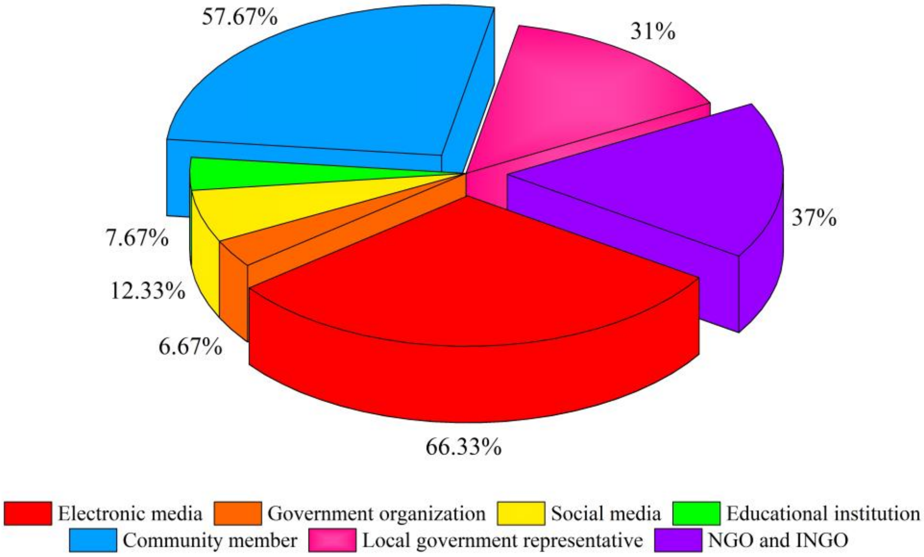


Figure 3.5 Distribution (%) of communication channels for spreading knowledge and information related to technology-based adaptations in the water sector.
Source: Collected field data 2022.

Community-based organizations and members from neighboring communities also played a critical role in educating the respondents about technology-based adaptation to water scarcity, as such local-level engagement can help to overcome barriers to behavioral change and values impeding the adoption of new technologies. A farmer in *Krishnanagar Union* who owned a DTW and DSP highlighted the importance of community engagement in facilitating technology adoption:

> *Prior to 2018, we cultivated rice only in the Aman season, where rainwater was the primary water source. Due to lack of water availability and extreme salinity, we could not cultivate rice in the Boro season. I learned from some farmers in our neighboring community who started producing rice in the Boro season on a limited scale by installing diesel-powered submersible pumps to withdraw groundwater for irrigation. Since then, I've been interested in harvesting rice on my arable land during the Boro season, but I was concerned that the location of my village is considerably closer to the coastal river area, where salinity intrusion poses the greatest difficulty. Initially, I assessed the possibility of having a good soil layer to extract water from a groundwater aquifer on my land by installing a hand-driven deep tube well. Then I installed the deep submersible pump with the help of a third-party contractor. These collective efforts worked very well.*

NGOs, INGOs, and local government representatives, including those from *Upazila* and *Union Parishad*, also served as essential communication channels by promoting technology-based adaptations in the water sector and organizing training programs at the community level. Furthermore, local governing bodies, particularly the DPHE, played a vital role in supporting community members who lacked financial means, but were interested in adopting adaptive technologies. Individuals seeking to adopt these technologies were only required to contribute service fees, which were substantially reduced, with the remaining expenses being partially subsidized. Similarly, NGOs and INGOs played a crucial role in the adoption of high-cost technology (e.g., RO) within the community through the implementation of two models: a hybrid subsidy model wherein they partially covered the implementation costs for interested individuals, and a locally-operated fee-based business model for operation and maintenance. These interventions have resulted in the rapid adoption of adaptive technologies at the community level, which has significantly alleviated climate-change-induced water crises.

3.4.4.2 Access to technology

Our field data revealed disparities between socioeconomic groups in the *Krishnanagar* and *Mathureshpur Unions* regarding access to technology and its benefits for mitigating climate-induced water stress (refer to Table 3.2). In the *Krishnanagar Union*, individuals had greater access to DTWs (compared to RWH and RO) for securing adequate water supply. Specifically, 45.14% of respondents from this *Union* had a DTW on their property, while 50.69% of respondents who did not have a DTW had access to one owned by someone else. Access to the RO is considerably limited owing to its less availability in this area. Notably, as the majority of people in *Krishnanagar Union* lived in poverty, they found it challenging to obtain drinking water from RO plants due to its relative unaffordability. For households without an RWH system, DTW, or easy access to an RO plant—but that did have access to someone else's DTW—the average round-trip distance to fetch drinking water was approximately 874 meters. In most of these households, the women were largely responsible for fetching potable water from distant sources to fulfill their household's drinking water demand.

Due to its fee-based business model, access to RO-produced drinking water was entirely dependent on whether a household could afford it. The majority of respondents in the study area relied on RO for its ability to reliably supply of safe water, as well as due to the limitations of RWH during the dry season. Households that cannot afford home delivery, it is the women from those households who are typically tasked with fetching water from the RO plant. For households that relied on RO but could not afford the delivery charge (and that did not have access to RWH or DTW), the average round-trip distance to fetch water was 1993.34 meters. As agricultural activity in this *Union* has become significantly limited due to salinity intrusion, the use LLPs and DSPs is considerably low. However, a handful of wealthy shrimp cultivators have access to LLPs and use them to carry saline water into their *ghers* for shrimp farming.

Locals in the *Krishnanagar Union* who owned or had access to a DTW preferred to use this technology to meet their domestic water demands. Aside from DTWs, the data indicated that people also still relied on pond water and rainwater collected through traditional means to satisfy their domestic and personal water demands. As most people in *Krishnanagar Union* depended on agriculture for their livelihood, a significantly larger proportion of respondents in this *Union* had access to LLPs and DSPs (89% compared to 17.07% in *Mathureshpur Union*), which they used to fulfill their agricultural water demands (Tables 3.1 and 3.2). In contrast, in *Mathureshpur Union*, where available water sources were significantly affected by salinity intrusion, RO and RHW were more commonly used than STWs and DTWs to procure potable water. Although *Mathureshpur Union* has four community-based RWH cisterns where locals can collect water, 72.44% of household survey respondents reported having a RWH system in their home, which significantly helped to fulfill their drinking and domestic water needs.

3.4.4.3 Disparities in resources distribution

The field investigation revealed wide disparities in the distribution of resources and benefits from modern technologies. In the study area, RO technology has become essential for everyday life due to its ability to efficiently provide safe water throughout the year. However, RO plants are expensive to construct, and NGOs and INGOs only provide financial support to financially secure individuals, thus resulting to a locally-owned business model. Although NGOs typically impose specific standards for RO plant operation, such as making water affordable and providing it free of charge to the disabled, these requirements are often not followed. As noted above, most residents in the study region lived in poverty and struggled to access drinking water from RO plants due to affordability issues.

Economically disadvantaged communities that purchase water from RO plants but cannot afford home delivery services disproportionately suffer from severe hardship, especially the women, as they are often the ones who must fetch water for their families. During a focus group discussion, a female farmer expressed concern about the suffering of community members who depend on RO for drinking water, particularly during the peak of the COVID-19 pandemic in 2020.

> *Although the installation of RO plants has significantly reduced the community's struggle with drinking water scarcity, it is still extremely difficult for poor individuals to collect water due to their limited financial resources. Nonetheless, they still manage to collect water from the RO plant because the acceptance and reliability of this technology in providing adequate drinking water supply are high. The situation worsened during the pandemic when the water supply from the RO plant, which serves the majority of the village, was halted for nearly six months as a precautionary measure to prevent the spread of the virus. During this time, some community members were forced to collect water from far-off sources, while others relied on pond water to meet their needs.*

Another major disparity observed in the study area was the uneven access to water resources for irrigation, particularly regarding the use of DSPs, as these pumps are predominantly owned by wealthier individuals and local elites, with limited support on the part of NGOs or governmental entities. When it comes to providing water for irrigation during the dry season, priority is given to wealthy farmers and the elite class who own more arable land. The lack of financial resources to install DSPs, the absence of high-quality groundwater aquifers, and the use of the pump's maximum capacity to supply water to wealthy farmers and local elites results in poor and marginalized farmers being deprived of access to these resources. Thus, these marginalized farmers suffer most from water scarcity for irrigation. Additionally, despite the government's extension of financial assistance to community members, most participants in the FGDs who owned one or more of the aforementioned technologies did not receive any financial support to install them. They explained that favoritism is prevalent in the local government and other institutions with regards to the allocation of such funds, which deprives poor and marginalized people of financial support that could be used to implement technology to alleviate climate-induced water stress.

3.4.4.4 Constraints and barriers

The expansion of advanced groundwater-based technology in the study area faces significant challenges due to salinity intrusion. The majority of STWs in the study area, as well as some DTWs, ROs, and DSPs, have failed or become less effective at providing an adequate water supply due to groundwater aquifer failure caused by extreme salinity. Despite the need for advanced technology (e.g., RO, DTWs, and DSPs) in these regions, installing and expanding such equipment near shrimp farming areas is almost impossible because the saline water used for shrimp farming infiltrates and significantly pollutes groundwater aquifers.

Although the impacts of climate change are not discriminatory, disadvantaged groups are disproportionately affected by unequal access to resources that could help them implement adaptive technologies, thus making it significantly more difficult for them to mitigate water stress. Financial barriers to acquiring these technologies in the water sector have limited the adaptation process, as most people in the study area live in poverty. Furthermore, as Bangladesh is an LMIC, limited budgets for climate finance and uneven distribution of resources create inequalities in society such that the wealthy and elite class obtain most of the benefits from technology-based adaptation approaches. Moreover, most respondents in the participatory research reported that development activities conducted by NGOs had substantially decreased, especially those involved with providing microfinance in *Kaliganj Upazila* after the emergence *Rohingya* refugee crisis in Bangladesh in 2017.

3.5 Discussion

Similar to other LMICs and areas of Bangladesh (Bashar et al., 2018; Calow et al., 2010; Hasan & Irfanullah, 2022; Rahman et al., 2017), STWs, DTWs, and RWH were the most commonly used adaptation technologies at the household level in the study area. Technology-based adaptations used at the community level included PSFs, RWH, DTWs, and RO (Rahman et al., 2017; Shamsuzzoha et al., 2018). The increased availability of LLPs and DSPs significantly helped to alleviate irrigation water crises during the dry season and expand agricultural activities in the study area. With regards to climate change adaptation, the outcomes of adopting and implementing such technologies conform with the findings of Bell et al. (2015).

Especially high levels of effectiveness of various technologies were found to be particularly high for RO, DTWs, and DSPs, which have been implemented in parts of the study area with comparatively low levels of salinity. These technological measures were adopted in consideration of the limitations and lesser availability of high-quality groundwater aquifers. It is important to note that the majority of these highly efficient technologies rely on groundwater as the primary source. This high dependency, along with the excessive extraction of groundwater, places immense pressure on the water table, which leads to its reduction and, ultimately, the lateral intrusion of saline water from the sea into coastal groundwater aquifers (Lam et al., 2022; Pethick & Orford, 2013). The integration of environmental factors and maximization of technological efficiency requires capacity building in community members, which can be achieved via community-focused approaches aimed at reducing dependency on groundwater-based technologies and encouraging the adoption of environmentally friendly alternatives, such as RWH (Figure 3.1).

A household's socioeconomic status plays a pivotal role in determining its vulnerability to crises or hazards. This is especially true of Bangladesh's coastal areas (Rahman et al., 2017). The high proportion of low-income groups and agriculture-based livelihoods in the study area makes it particularly vulnerable to climate-induced water crises. With regards to the adoption process, the ability of community members to afford adaptive technologies was the most crucial factor affecting whether they were adopted and installed. Additionally, stakeholder influence was also critical to the dissemination of information and diffusion of knowledge relating to technology-based adaptations and the distribution of resources and the benefits of adopting such technologies. Empirical studies (Abebe, 2014; Sovacool et al., 2015; Tan et al., 2015; Thomas & Twyman, 2005) have found that limited access to public goods and services, unequal distribution of wealth and benefits, and unequal participation in the decision-making process negatively impact rural communities' adaptive capacities with respect to reducing the effects of climate change. Furthermore, these conditions also reinforce and exacerbate pre-existing inequalities in society, particularly for marginalized groups, including women; the findings of our study reaffirm this relationship.

Studies in various LMICs in Africa and South Asia have found that the distribution of and access to resources is often unequal and subject to favoritism and power dynamics between local stakeholders (Nakawuka et al., 2018; Narain, 2014; Yohannes et al., 2017). For instance, in Gurgaon, India, the majority of adaptive facilities (e.g., DTWs) are owned by local elites, while favoritism and power dynamics regarding water distribution have forced the affected poor communities to use saline water for drinking and irrigation. The same factors and outcomes were observed in the study area of the present study (i.e., Bangladesh's coastal communities). In addition, the lack governmental monitoring over the use of these technologies also contributed to inequalities in access to resources and the distribution of benefits among the communities. Operational standards imposed by NGOs, such as ensuring affordable water and free access to the disabled from RO plant, are often not followed. These findings align with those of studies conducted in LMICs in Africa. For example, in East African countries—where DTWs, motorized pumps, and drip irrigation are the most common technology-based adaptive actions—ineffective monitoring by governing institutions has resulted in social discrimination (Nakawuka et al., 2018). Similarly, in Ethiopia, water distribution is exclusively controlled by community leaders known as "Abo Mai," which has resulted in inequitable resource distribution, as there is little oversight on the part of the appropriate governing bodies (Yohannes et al., 2017). In our study area, low budgets and ineffectiveness on the part of governing authorities also resulted in the poor monitoring of resource allocation and the distribution of water using such technologies, which in turn amplified inequity within Bangladesh's coastal communities.

As in the above-discussed technology-based adaptation studies, we found that the operational standards set by donors to maintain equity in distributing the benefits of advanced technologies (e.g., RO, DTWs, and DSPs) were not being followed. In most cases, advanced technologies were owned by elite and wealthy groups, who consequently enjoyed the lion's share of the benefits. Our findings revealed the prevalence of discrimination in access to governmental financial facilities—and thus, the ability to adopt such technologies—as such access is often determined based on favoritism. Additionally, affordability is a primary barrier to the use of these technologies to reduce water vulnerability, as attempts to scrape together the funds to acquire such technologies often create financial stress for poor and marginalized communities. The reduced availability of these technologies in more saline-affected areas further creates suffering and hardship for marginalized communities, as it is more difficult to obtain safe water using these technologies and women are often required to fetch clean water from distant sources. A large portion of the poor and marginalized households in the studied communities that lacked access to such technologies (due to either availability and affordability) still relied on pond water and traditional RWH methods using plastic or cloth, followed by filtration with Potassium Alum (known locally as *Fitkari*) and boiling.

Although groundwater-based technologies were highly preferred, RWH was rated by the participants as moderately effective and was widely recognized by stakeholders as the most sustainable technology for ensuring water security at the household level (Musayev et al., 2018). Unfortunately, most of the community-based RWH systems had become dysfunctional due to lack of maintenance. Thus, local leaders and community members must take responsibility for the maintenance of such community-based RWH technologies, as doing so will significantly reduce water stress for marginalized households that cannot afford water from RO plants. The governing authorities and NGOs also have a major responsibility to provide more training on climate change adaptation and the maintenance of such technologies to alleviate climate-induced water stress at the community and household level.

Nonetheless, pretreating the primary water used in RO systems and deploying RO plants in more saline-affected areas, particularly those adjacent to the coastal belt, would be able to ensure an adequate water supply and benefit thousands of poor and marginalized households. Recent studies have demonstrated that “coagulation,” which aids in the initial destabilization of suspended solids in the water, is an effective pretreatment process for RO systems (Harif et al., 2012; Jiang et al., 2017; Lee & Gagnon, 2016; Villacorte et al., 2015). For instance, Tabatabai et al. (2014) evaluated the efficacy of coagulation for removing organic matter from seawater, with findings indicating that it possesses immense potential for removing suspended solids and enhancing membrane longevity. While the cost to install RO systems with sophisticated facilities may high, such investments promise significant returns, as they can reduce membrane fouling and operational expenses and boost the availability of RO technology in saline-affected areas, thus alleviating climate-induced stress on drinking water accessibility.

3.6 Conclusion

This study examined the dynamics influencing the adoption and implementation of technology as an adaptation measure to alleviate climate-induced water crises in the coastal communities of Bangladesh. The findings of this work address a significant knowledge gap, as they provide valuable insights into the effectiveness of the studied technology-based adaptation measures and how they can be expanded among Bangladesh’s coastal communities. For instance, our findings showed that technology-based adaptation approaches significantly reduced climate-induced stress related to the availability of water drinking and irrigation purposes. Furthermore, community-based organizations, members from neighboring communities, and electronic media were all found to play a critical role in the diffusion and adoption of these technologies, as they served as communication channels for raising awareness about these adaptation options among community members. Notably, financial assistance from GOs, NGOs, and INGOs has made it easier to adopt such adaptation technologies to reduce water scarcity.

Given the inadequate availability of data and knowledge regarding the effects of technology adoption, it is necessary to develop effective systems for monitoring groundwater-based technologies, as such systems will be key in ensuring equitable access to water resources, especially by poor and marginalized community members. To alleviate climate-change-induced stress in the water sector, program and policy development should prioritize transparency and devoting a larger portion of the budget to climate-related initiatives aimed at promoting the adoption of appropriate adaptation technologies. The use of sustainable technologies such as RWH must increase at the household and community levels, as such methods will undoubtedly enhance access to fresh water and reduce reliance on groundwater-based methods. We suggest that incorporating pretreatment facilities into RO plants and deploying this technology in more saline-affected will significantly improve the wellbeing of community members and mitigate water vulnerability in the region. Moreover, equitable access to such technology across socioeconomic groups should be prioritized in order to ensure equity with respect to access to water.

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Chapter 4: Discussion and Conclusion

4.1 Introduction

In this Chapter, the implications of the results of the present study, the major findings of the empirical investigation, and the recommendations are systematically presented. In this discussion section, the position of the results in the existing literature is highlighted, especially comparing them with the findings of other comparable studies in various parts of the world.

The scholarly literature strongly endorses the need for a comprehensive analysis of individuals' perceptions of climate change and their strategies for adaptation. Such approach is crucial to the development of effective policies aimed at reducing the effects of climate change and the related risks to local livelihoods. This argument becomes especially pertinent in the context of low- and-middle income countries (LMICs) like Bangladesh, which stands as one of the most vulnerable nations in the world to climate change-related hazards, such as floods, cyclones, tidal surges, droughts, waterlogging, and salinity intrusion (Eckstein et al., 2021; Lázár et al., 2015). Agriculture is the cornerstone of Bangladesh's economy, contributing 14.23% of the country's GDP and employing over 40.60% of the total labor force (Bangladesh Bureau of Statistics [BBS], 2018). Having adequate water supply for agricultural activities as well as drinking and domestic usages has become the major concern for Bangladesh due to the long-term climate-induced effects on water resources (Abdullah et al., 2022; Lam et al., 2022; Pethick & Orford, 2013). The coastal region of Bangladesh is one of the prime hotspots for climate change-related hazards, where the lion's share of the population depends on agriculture for their livelihoods. Water scarcity for drinking and irrigation has become a major concern for that region (Abdullah et al., 2022; Lázár et al., 2015). The frequency of extreme climatic events in Bangladesh has increased by 7% per year, which significantly increases the vulnerability created by climate change (Mukherjee et al., 2019). It is anticipated that over 7.5 million households in Bangladesh from 2015 to 2020 experienced direct consequences resulting from various climate change-related hazards (BBS, 2021). Indeed, it is important to comprehend the people's perspectives on climate change and how locals deal with such adverse consequences over the years. Regrettably, despite the significance of this issue, limited research has been conducted on the specific topic in the context of Bangladesh.

Similar to the significance of understanding people's perceptions, examining the dynamics of the process of adopting technology-based adaptations is equally important, where environmentally sound engineered technology is highly recommended worldwide to reduce climate-induced stress on water resources (Intergovernmental Panel on Climate Change [IPCC], 2014). Although Bangladesh has achieved considerable improvement in maintaining water security by adopting various technology in the water sector (such as tube wells, rainwater harvesting [RWH], pond sand filters [PSFs], reverse osmosis [RO], low-lifting pumps [LLPs], and deep submersible pumps [DSPs]), these measures are not adequate to reduce the negative consequences posed by climate change on marginalized communities and stability of their society. The issue of unequal access to technology and inequities in resource distribution stands as a salient focal point of discussion within the discourse of climate change adaptation. These disparities have the potential to impede the adaptation process. We identified a lack of comprehensive documentation and analysis of these issues in the context of Bangladesh. Moreover, there is a lack of comprehensive data about the dynamics of the adoption process of such technology across all socio-economic categories. This dearth of information hampers the ability of policy-making institutions to effectively implement technology in the water sector, with the aim of mitigating climate-induced water stress.

Considering such research gaps, the study aimed to evaluate the elements contributing climate-induced stress on livelihoods and the drivers that encourage the implementation of adaptation strategies from a local standpoint. The study examines various aspects including the effectiveness and types of technology, the adoption process, accessibility of affordable and safe water services, and disparities in resource distribution. This study also makes a significant contribution to the policy domain by conducting a thorough analysis of the dynamics of technology-based adaptation measures for drinking, domestic, and agricultural water usages in coastal communities of Bangladesh.

4.2 Discussion

4.2.1 Perceived climate change-related hazards, and their adverse effects on livelihoods and water resources

Climate change-related hazards and their associated stress on the local livelihoods and water resources within the study area have a multifaceted impact. In our study, it has been statistically demonstrated that the participants from both *Unions* perceive climate-related concerns to be of substantial magnitude. Considerable changes in precipitation patterns in recent years, resulting in extreme rainfall and enormous runoff (Chowdhury & Ward, 2007; Shahid, 2011), are recognized as the major climatic reasons for increased flooding and waterlogging. Farmers from both *Unions* exhibited greater awareness of the consequences of climate change on their livelihoods, as crop production has been substantially damaged due to drastic rainfall changes. Their perceptions of the adverse effects of rising temperature on crop yield are consistent with research from China (Peng et al., 2009) and Punjab, Pakistan (Abbas & Mayo, 2021). Nonetheless, it is noteworthy that the local population does not have comprehensive awareness of the dire repercussions of increasing temperatures on the freshwater resources, such as increasing pH levels, waterborne pathogens, and decreasing dissolved oxygen (Delpla et al., 2009).

Salinity intrusion is the most pressing concern out of all climate-induced hazards in both study *Unions*. Inadequate rainfall and rising temperatures are recognized by the locals as the primary reasons for higher evaporation and freshwater depletion, which subsequently influence salinity intrusion (Akter et al., 2020). In addition, the rapid increase in sea levels along the coastal region facilitates the lateral movement of saline water from the sea into the groundwater, causing contamination and a reduction in the volume of fresh groundwater aquifers (Lam et al., 2022; Pethick & Orford, 2013). Local stakeholders also expressed concern about fragile embankments along coastal rivers, which permit the intrusion of saline water and restrict the availability of fresh water.

Shrimp farming is perceived as a pragmatic solution by the locals to deal with climate-induced yield-reducing effects and increasing salinity intrusion. The proclivity of the locals toward shrimp aquaculture led to a 16% expansion of the shrimp farming area between the years 1990 and 2016. As of 2016, 36% of the land area of *Kaliganj Upazila* has been occupied by shrimp farming (Morshed et al., 2020). The dynamics of shrimp farming in both *Unions* involve land conversion, controlled by landowners and elites who manage sluice gates and draw saline water into land for shrimp farming. Crop farmers expressed their deepest concern regarding the salinity intrusion in their farmland that could be triggered due to the unplanned expansion of shrimp production. The Morshed et al. (2020) study aligns with the concern expressed by the local farmers, revealing that shrimp farming has externalities on nearby rice fields, with a 1 m reduction in the distance between rice and shrimp farming land, leading to a 0.14% increase in soil salinity and reduced rice harvesting profits of US$0.31 and US$0.15 per hectare for *Aman* and *Boro* rice, respectively. As a result, the value of such rice-harvested land has significantly dropped, making it more affordable for shrimp cultivators to expand shrimp farming.

Shrimp aquaculture is now vulnerable to salinity intrusion, which is rapidly worsening. Substantial increases in viral infections, influenced by high salinity, have increased mortality rates for larval shrimp and other fish, resulting in enormous economic losses. This finding conforms to the studies on aquaculture in LMICs and other parts of the world, highlighted by the various pathogenic infections in shrimp and other fish farms, which are being significantly influenced by climate change (Ahmed & Diana, 2016; Flegel, 2012; Stentiford et al., 2012).

4.2.2 Locally practiced adaptation approaches

Local stakeholders' perceptions and experiences of the impacts of climate change-related hazards on agriculture and freshwater resources demonstrate an association with meteorological data, influencing their adaptive strategies. Coastal communities in Bangladesh continuously adapt to climate-induced stress and livelihood risks. An illustration of this adaptation is seen in local farmers' modification of the traditional rice production period in the *Aman* season to align with seasonal changes, to adapt to water scarcity and inadequate rainfall. Their experience and perceptions of climate change play a pivotal role in this context. Water scarcity and increasing salinity drive the adoption of advanced adaptation measures in both study *Unions*, including cultivating short-duration, saline-tolerant, high-yield crop varieties, aligning with the findings of Huq et al. (2004). Locals employ various adaptation strategies including the integrated farming of rice, shrimp, fish, and vegetables; homestead gardening of vegetables and fruits; crop diversification; and integrated pest management. The efficacy of these adaptation strategies in addressing the challenges presented by climate change has been well documented in the literature (Mondal et al., 2019).

The communities being studied have implemented adaptive measures in the water sector in response to their understanding of the negative effects of climatic stress on water supplies and how it affects people's lives. These strategic adaptations focus on strengthening resilience against climate-induced stress, improving the quality of drinking water, and promoting the diversification and preservation of water resources for both agricultural and drinking purposes at both household and community levels. Common approaches include locally-driven adaptation measures, such as excavating mini-ponds near arable land to meet agricultural water needs, and dredging canals to maintain sufficient water flow, which conforms with Anik and Khan (2012).

This study confirms the widespread use of shallow tube wells (STWs), deep tube wells (DTWs), and RWH as household-level adaptation technologies, which is consistent with findings from other LMICs and areas of Bangladesh (Bashar et al., 2018; Calow et al., 2010; Hasan & Irfanullah, 2022; Rahman et al., 2017). Meanwhile, technological adaptations implemented at the community level included the use of PSFs, RWH, DTWs, and RO. These technologically advanced adaptive techniques have greatly reduced the climate-induced stress concerning water availability for drinking purposes. Furthermore, the increased availability of LLPs and DSPs has been crucial in reducing water scarcity for irrigation, especially in the non-monsoon period. This technology-based adaptation measure has significantly assisted local farmers in expanding *Boro* rice production, particularly in salinity-prone areas (Bell et al., 2015). Indeed, these adaptive approaches have created additional opportunities for individuals dependent on agricultural-based day labor for subsistence, thereby marking a noteworthy enhancement in the standard of living compared to the past.

4.2.3 Driving factors and challenges in adopting adaptation measures

Government and non-governmental entities, private investments, increasing literacy rates, and the diffusing of information through electronic media played crucial roles in increasing knowledge among the local people, shaping their perceptions and beliefs. Community-based organizations and members from neighboring communities played a critical role in disseminating information and knowledge and educating community members in both study *Unions* about the advantages of adopting such technology-based adaptations. Additionally, different projects such as the Reducing Vulnerability to Climate Change (RVCC) in southwestern Bangladesh from 2005 to 2006 have notably improved knowledge, ensuring food security and boosting household income through community participation (Chowhan & Barman, 2005). Community members who adopted effective adaptation measures have become role models, turning challenges into opportunities. Notable examples include the cultivation of Indian jujube in highly saline-affected areas, resulting in distinctive-tasting fruit grown in salty soil, and integrated farming practices in less saline-affected areas. These actions significantly reduce livelihood risks and enhance financial stability, promoting sustainable agricultural practices. The tangible benefits of these strategies inspire locals, strengthening community capacity and sustaining engagement in climate change adaptation at both individual and community levels.

The vulnerability of a coastal community to climate-related hazards is significantly influenced by its socio-economic attributes (Rahman et al., 2017). In the study area, the prevalence of a substantial low-income population and an economy primarily reliant on agriculture render the region highly vulnerable to climate-induced stress. Such climatic stress and a lack of water availability substantially damaged crop production, particularly rice production in the *Boro* season. This finding conforms with the Lázár et al. (2015) study, which predicted a substantial decline in crop productivity in high-saline areas, including the southwest coastal region of Bangladesh, by 2050. The cumulative impact of climatic stress, less availability of fresh water and quality seeds, and increasing pest infestations leads to enduring financial setbacks in the agricultural sector—compelling farmers to either transition to alternative livelihoods or consider migration to different regions (Chen & Mueller, 2018).

In adopting technology as adaptation measures in the water sector, the effectiveness of RO, DTW, and DSP is particularly higher than other technologies, and mostly implemented in lower saline areas in both study *Unions*. The major drawback for adapting such technologies in larger scale is the lesser availability of high-quality groundwater aquifers. Notably, many of these highly efficient technologies rely heavily on groundwater as their primary source. This heavy reliance on, and excessive extraction of, groundwater imposes significant pressure on this resource, leading to a decline in groundwater levels and subsequently facilitating the intrusion of saline water from the sea into coastal groundwater aquifers (Lam et al., 2022; Pethick & Orford, 2013).

4.2.4 Disparities and inequitable distribution of resources exacerbate challenges for marginalized communities

Empirical evidence for adaptation research (Alston, 2013; Abebe, 2014; Deressa et al., 2009; Sovacool et al., 2015; Tan et al., 2015; Thomas & Twyman, 2005) illustrates that limited access to public goods and services, unequal wealth and benefit distribution, and limited participation in decision-making negatively impact rural communities' adaptive capacity, exacerbating pre-existing societal inequalities, particularly among marginalized groups such as women. In both study *Unions*, the ability to afford such measures is a crucial factor for community members having technology-based adaptations on their premises. Access to resources often exhibits disparities influenced by favoritism and power dynamics, as identified by local stakeholders. Local elites predominantly own such technological facilities like deep tube wells, employing favoritism and power dynamics in water distribution, thus compelling impoverished communities to use saline water for irrigation, which conforms with the findings of adaptation research in African and South Asian countries (Nakawuka et al., 2018; Narain, 2014; Yohannes et al., 2017). Moreover, discrimination has been observed in accessing financial facilities of the government to adopt such technologies, where favoritism is highly exercised. The absence of monitoring by governing authorities regarding technology use in the study area leads to resource and benefit distribution inequalities among communities, aligning with the study conducted in Ethiopia (Yohannes et al., 2017). Manpower shortages, budget constraints, and ineffective operation by the governing authority contribute to a deficient monitoring system for resource allocation and water distribution using such technology, which subsequently increases societal inequity in the study region.

Technology like RO predominantly reduces the drinking water scarcity in both study *Unions*, where non-governmental organizations (NGOs) introduced fee-based RO plants in the coastal area in 2015 (World Vision [WV], 2021). The operation standards set by donor instructions for ensuring equity in water distribution are not consistently followed. Affordability is a primary factor in accessing water from these technologies like RO, placing financial stress on poor and marginalized communities struggling with water scarcity for drinking. In more saline-affected areas, the limited availability of such technology compounds the challenges faced by marginalized communities—especially for women, who must fetch water from distant sources. A large portion of poor and marginalized communities still rely on pond water and traditional rainwater collection methods involving filtration with potassium alum (locally known as *Fitkari*) and boiling before consumption. The reduced availability of these technologies in more saline-affected areas further creates suffering and hardship for marginalized communities, as it is more difficult to obtain safe water using these technologies and women are often required to fetch clean water from distant sources.

While groundwater-based technology is highly favored, rainwater harvesting (RWH) is considered moderately effective, widely recognized as a sustainable means to ensure water security, and highly recommended by stakeholders in the study area (Kahinda et al., 2010; Musayev et al., 2018). However, most community-based RWH systems have become dysfunctional due to a lack of maintenance. Local leaders and community members need to take responsibility for maintaining these community-based RWH technologies, which can significantly alleviate water stress for marginalized individuals who cannot afford RO water. The governing authority and NGOs must play a pivotal role by providing training on climate change adaptation and technology maintenance to alleviate climate-induced water stress at both the community and individual levels.

4.3 Key findings of the Research

In light of the primary themes of my thesis, the following section provides a summary of the key findings that are in line with the two outlined objectives. Table 4.1 summarizes crucial discoveries that are relevant to the aims of the thesis. Following that, concise explanations aligned with key findings are provided.

Table 4.1 Synthesis of key findings aligned with study objectives.

	Objectives of the research	
	Objective 1	**Objective 2**
Major findings of the research	Examine the perceptions of farmers and shrimp cultivators about climate change-related hazards and its associated effects on livelihoods	Analyze the dynamics of technology-based adaptation measures in water use for drinking, domestic, and agricultural purposes in coastal communities in Bangladesh
The perception of climate change-related hazards significantly influences the formulation of strategies for local adaptation.	√	
The efficacy of adaptive measures implemented by local communities, shaped by their perceptions, demonstrates a varying nature of effectiveness.	√	
Substantial expertise and clear perceptions of climate change provide a foundation for transforming challenges into opportunities.	√	√
Embracing technological advancements in the water sector presents opportunities to enhance resilience and mitigate stressors induced by climate change.	√	√
Community-led technology-based adaption approaches create opportunities to overcome barriers and enhance resilience to climate-induced water crisis.		√
Disparities in accessing technology and resource distribution amplify hardships for marginalized communities.	√	√

- **The perception of climate change-related hazards significantly influences the formulation of strategies for local adaptation.**

Studies examining the impacts of climate change on people's livelihoods have highlighted the need to understand how communities perceive climate-related hazards. This understanding is crucial for developing effective and sustainable adaptation strategies (Dobbin et al., 2023). Researchers underscore the need to critically examine people's perceptions of climate change-related hazards and to understand the underlying factors driving climate change in order to develop and implement reasonable and efficient adaptation measures. If people do not perceive climate change-related hazards and the associated risks to their livelihood security as real, they are less likely to undertake adaptation actions (Howe et al., 2014; Markowitz & Shariff, 2012).

In the present study, a substantial majority of respondents perceived the prevalence of these climatic hazards, emphasizing the associated adverse impacts on local livelihoods and water resources, which conforms to the existing literature and the hydro-meteorological data. The local communities' adoption of adaptation measures in both crop production and water resource management had been strongly influenced by their perceptions. Higher exposure to climate change-related phenomena and associated consequences had shaped the locals' perceptions, influencing their continuous response to climate-induced stresses, shocks, and livelihood risks. Illustratively, local farmers responded to freshwater scarcity for crop production by shifting the conventional rice production period. The formulation of this strategy had been notably influenced by farmers' perceptions of climate change.

Furthermore, perceiving the adverse climate-induced effects on crop production and freshwater availability prompted a willingness to implement advanced adaptation measures to reduce climatic risks to livelihoods. These measures include the adoption of fast-maturing, salinity-resistant, and higher-yielding crop varieties, as well as traditional knowledge-based and technology-based adaptations for water supply. Together, these strategies had played a pivotal role in alleviating the impact of climate-induced stress on livelihoods.

- **The efficacy of adaptive measures implemented by local communities, shaped by their perceptions, demonstrates varying nature of effectiveness.**

Adaptation research in LMICs and different global regions has found a positive association between individual experience and perceptions, which encourages individuals to adopt adaptation measures (Hansen et al., 2004; Jha et al., 2018; Shah et al., 2023; Silvestri et al., 2012). However, divergent findings exist in the literature, with some studies presenting inconclusive results regarding the impact of human perception on the adoption of adaptation strategies. Moreover, the effectiveness of adaptive actions undertaken by communities tends to vary (Albright & Crow, 2019; Shao et al., 2017; Wachinger et al., 2013).

The present study investigated locals' perceptions and demonstrated that shrimp farming was an expedient solution to the reduced yields in crop production and increased stresses caused by salinity intrusion. Such perceptions had played a pivotal role in shaping the dynamics of shrimp farming, motivating locals to transform their arable land into *gher* (reconstructed farmland with dikes around the perimeter for shrimp farming) to deal with climate-induced livelihood risks, aligning with the findings of Morshed et al. (2020). It is noteworthy that these adaptive actions primarily benefit local elites and large shrimp cultivators. Conversely, concerns expressed by the crop farmers conform with the findings of Morshed et al.'s study, as shrimp farming influences increasing salinity and creates adverse external effects on neighboring rice cultivation land. Shrimp farming close to the arable land significantly damages rice harvesting, and increased salinity intrusion causes the price of neighboring rice-growing land to decline, thus facilitating easier acquisition and expansion for shrimp cultivators (Morshed et al., 2020). Locals also perceived the unplanned growth of shrimp farming by modifying tributaries and canals to be the major reason for increased waterlogging.

- **Substantial expertise and clear perceptions of climate change provide a foundation for transforming challenges into opportunities.**

Personal experience is identified as a major driving force in climate change perception (Markowitz & Shariff, 2012; Pageaux, 2016). These experiences are typically acquired through the individual's senses and encompass their knowledge and observations of changes in climate (Howe et al., 2014; Shi et al., 2015). Possessing such experiences and clear perceptions of climate change and its associated consequences significantly influences individuals' decision-making, a strategy notably effective within the local context for mitigating climate-induced livelihood risks (Hansen et al., 2004; Jha et al., 2018; Shah et al., 2023).

The findings of the present study revealed that some experienced community members have become exemplars through their adoption of effective adaptation measures, which have transformed adversities into opportunities. Noteworthy instances of this phenomenon encompass the cultivation of Indian jujube in regions significantly impacted by salinity, resulting in the fruit acquiring a distinctive taste due to cultivation in saline soil. Integrated farming practices have found acceptance in areas less affected by salinity. The visible benefits of these adaptation strategies have inspired locals, strengthened community capacity, and motivated climate change adaptation at both the individual and community levels.

- **Embracing technological advancements in the water sector presents opportunities to enhance resilience and mitigate stressors induced by climate change.**

Technology-driven adaptation within the water sector has the potential to substantially enhance the quality of life by building resilience to extreme climate hazards, reducing drinking water pollution, and encouraging the diversification and conservation of water resources. In recent decades, there has been considerable progress made worldwide in implementing different adaptation technologies for water usages. Aligned with other LMICs and areas of Bangladesh (Bashar et al., 2018; Calow et al., 2010; Hasan & Irfanullah, 2022; Rahman et al., 2017), the present study identified that shallow tube wells (STWs), deep tube wells (DTWs), and rainwater harvesting (RWH) were the most commonly used adaptation technologies at the household level. Simultaneously, technology-based adaptations used at the community level included pond sand filters (PSFs), RWH, DTWs, and reverse osmosis (RO). These technology-based adaptation approaches had significantly reduced climate-induced stress concerning the availability of water drinking. Furthermore, the increased availability of low-lifting pumps (LLPs) and deep submersible pumps (DSPs) had played a crucial role in reducing water shortages for irrigation during the non-monsoon season. This technology-based adaptive measure had notably benefited local farmers to expand *Boro* rice production, particularly in salinity-prone areas. Indeed, such adaptation approaches have generated more opportunities for individuals who depend on agricultural-based day labor for their subsistence, marking a notable improvement in standard of living compared to the past.

- **Community-led technology-based adaption approaches create opportunities to overcome barriers and enhance resilience to climate-induced water crisis.**

The study revealed that the dissemination of information and knowledge regarding technology-based adaptations had significantly shaped the locals' adaptation approach to mitigate climate-induced water scarcity. Community-based organizations and members from neighboring communities had played a critical role in educating locals about technology-based adaptation to water scarcity. This local-level engagement had proved to enhance adaptive capacity by overcoming barriers to behavioral change and values that were impeding the adoption of new technologies. Financial assistance from diverse entities had also emerged as a crucial facilitator in the adoption of these technologies.

Additionally, NGOs and international non-governmental organizations (INGOs) played a vital role in facilitating the adoption of high-cost technologies (e.g., RO) within the community. They employed two distinct models: a hybrid subsidy model, wherein they partially covered the implementation costs for interested individuals, and a locally-operated fee-based business model for operation and maintenance. These actions greatly accelerated the widespread use of adaptable technology within communities, significantly improving the water crises caused by climate change. Notably, such adaptive measures engendered employment opportunities for economically disadvantaged people, who are often involved in the operation and maintenance of these plants.

- **Disparities in accessing technology and resource distribution amplify hardships for marginalized communities.**

Inequities in accessing technology and resource distribution remain major concerns, as these social justice dimensions can impede the adaptation process. Disparities in resource distribution across socio-economic groups not only limit adaptive capacity, but can also result in disproportionate hardship for marginalized people, thus further exacerbating pre-existing social inequalities (Abebe, 2014; Tan et al., 2015). The present study illustrated that affordability is the leading factor in determining who has access to these technologies. Financial barriers to acquiring these technologies in the water sector have limited the adaptation process, as most people in the study area live in poverty. The local elite predominantly possess such technology, while favoritism and power dynamics regarding water distribution have forced the affected poor communities to use saline water for drinking and irrigation. A large portion of the poor and marginalized households in the studied communities that lacked access to such technologies (due to either availability and affordability) still relied on pond water and traditional rainwater collecting and water filtration methods. The reduced availability of these technologies in more saline-affected areas further creates suffering and hardship for marginalized communities, as it is more difficult to obtain safe water and women are often required to fetch clean water from distant sources. In addition, NGOs typically impose specific standards for RO plant operation, such as making water affordable and providing it free of charge to the disabled, but these requirements are often not followed. The lack of governmental monitoring over the use of these technologies also contributed to inequalities in access to resources and the distribution of benefits among the communities.

4.4 Major Contribution of the Research

The study addresses the existing research gaps regarding people's perceptions of climate-induced stress in coastal Bangladesh. It contributes to the current body of knowledge by presenting new findings that highlight the crucial influence of personal experiences on individuals' perceptions of climate-induced stress. From an interdisciplinary perspective, this study offers valuable insights on the effects of climate-related risks on local livelihoods and the implementation of adaptation strategies to alleviate these adverse consequences. In addition, long-term use of environmentally friendly technology is highly prioritized as an adaptation measure, where unequal access to technology and inequities in resource distribution stand as major arguments within the discourse of climate change adaptation. Given the lack of comprehensive documentation on this matter within the context of coastal Bangladesh, the study offers novel findings on the adoption process of such technology-based adaptations among the different socio-economic groups by examining various aspects, including the effectiveness and types of technology, the adoption process, accessibility of affordable and safe water services, and disparities in resource distribution.

4.5 Major Barriers and Challenges on Technology-based Adaptation

In the coastal communities of Bangladesh, groundwater-based technologies such as Reverse Osmosis (RO), Deep Tubewells (DTW), and Deep Submersible Pumps (DSP) are widely embraced to address the water needs for drinking and irrigation. However, their adoption is constrained by the limited availability of groundwater aquifers with acceptable salinity levels. The RO technology, despite being favored, faces several drawbacks, including substantial energy consumption, frequent chemical cleaning requirements, and the necessity for membrane and machinery replacement to prevent fouling and ensure optimal performance. Consequently, RO plants primarily operate using high-quality groundwater, enhancing their cost-effectiveness. On the other hand, the use of Rainwater Harvesting (RWH) for drinking purposes is limited due to health-related issues stemming from the possibility of contamination by bird excreta, plants, and rooftop dust. Despite being deemed moderately effective due to maintenance demands and reduced utility during dry periods, RWH remains a viable option for meeting drinking, household, gardening, and homestead water needs during periods of water scarcity. The limited financial resources pose a significant barrier for coastal communities when it comes to adopting technology-based adaptation measures.

4.6 Policy Implications and Recommendations

The results of this research have the following key policy implications for achieving the desired outcome from adaptation measures:

- The results of the study strongly suggest that effective climate change adaptation policy can be achieved by emphasizing on interventions of integrating local knowledge and perception, such as critically understanding people’s perceptions and level of knowledge on climate change, locally developed strategies to deal with climate-induced stress on livelihoods, and their behavior for adopting technology as adaptation measures.
- In the policy formation stage, an effective scheme needs to be developed to enhance awareness about on how climate-induced stress and human activities impact livelihoods and water resources, by engaging all effective mediums including community-based organizations, community members, members form government and non-government organization, and electronic media.
- In order to alleviate the consequences of climate change-related hazards (e.g., waterlogging), locally preferred measures such as construction of more sluice gates with effective monitoring systems, prohibition of unauthorized growth of agriculture and shrimp aquaculture on water bodies, excavating of canals, and dredging the riverbed are recommended.
- The coastal embankment program of the government, which aims to restrain salinity intrusion and floods, is perceived to have failed to serve the expected outcome (Masud et al., 2018). This

embankment program needs to be redesigned with advanced engineering solutions, with an emphasis on protecting coastal land and groundwater aquifers from the lateral intrusion of saline water from the Bay of Bengal. Enough drainage facilities in the embankment program need to be highly prioritized, to drain excessive runoff and protect the inland coastal area from floods.

- In order to increase the crop productivity, government and private entities need to ensure adequate supply of high-quality climate-smart seeds and promote it among the communities for cultivation. In addition, integrated framing with a combination of different varieties of crop and fish needs to be promoted in less saline-affected areas. Farmers also need to be encouraged to use more organic fertilizers instead of chemical fertilizers, by providing enough supply and educating them through training and subsidy facilities.
- Further research should be conducted on crop diversification in the context of climate stress conditions, and more diversified crop production should be promoted in coastal regions to reduce climate-induced stress on livelihoods. More inclusive strategies incorporating local farmers' views should be formulated.
- Groundwater-dependent technologies like RO, DTW, and DSP prove highly effective in ensuring an adequate water supply for drinking and irrigation. However, excessive groundwater extraction intensifies pressure, leading to a decline in the groundwater table and facilitating saline water intrusion into coastal aquifers (Lam et al., 2022; Pethick & Orford, 2013). To address this, there is a need for capacity building through community-focused strategies and the promotion of sustainable technologies, such as RWH, to reduce dependency on a single water source.
- The primary determinant for the adoption of technological facilities within communities is affordability of the members. To ensure equitable access to technology-based water services, governing authorities must establish operational standards, giving priority to impoverished and marginalized communities. Transparent monitoring mechanisms should be implemented to enforce these standards effectively. Installing water meters and other monitoring instruments, guided by advanced engineering principles, is essential. Additionally, a publicly accessible database incorporating parameters such as the number and location of technologies, quantity of extracted and supplied water, and the functional status of these technologies is recommended. This systematic approach aims to alleviate the administrative burden on governing authorities while ensuring fair technology access across all socio-economic groups and maximizing the benefits of adaptation measures.
- RO has typically been in areas of lower salinity, due to low availability of fresh groundwater, which is typically used in the process, and also because of reduced maintenance costs. Ensuring an adequate drinking water supply can be achieved by strategically placing RO plants in more saline-

affected areas and by improving the pre-treatment of the initial water used in RO systems. This approach will significantly reduce reliance on a singular water source (e.g., high-quality groundwater aquifers) and be particularly beneficial for numerous marginalized households. While the initial installation costs of sophisticated RO systems may be higher, the investment is anticipated to yield significant returns by reducing membrane fouling and operational expenses. This, in turn, enhances the widespread availability of RO technology in saline-affected areas, thereby addressing climate-induced challenges related to drinking water accessibility.

- It is of utmost importance to promote transparency in the allocation of funds by governing bodies for the adoption and implementation of technology-based adaptation measures to mitigate resource distribution inequalities. In addition, augmenting the climate budget, providing supplementary subsidies, including tax-reduced prices on these technologies, and providing complimentary electricity for its operation will facilitate the widespread adoption of these adaptation measures and substantially reduce the climate-induced risks to livelihoods and water resources.

4.7 Limitations of the Study

The study has following limitations:

- The study focused on two specific *Unions* of *Kaliganj Upazila* in the *Satkhira* district. While the study reveals climate change-related impacts on local livelihoods and the dynamics surrounding the adoption and implementation of technology-based adaptation in coastal regions of Bangladesh, it is important to note that the entire spectrum of such influences may not be fully captured. It is advisable to use caution before making any generalizations based on the outcomes of this thesis study.
- The availability of climatic data at both the national and specific location levels from the governing instruments is not always publicly accessible. Consequently, conducting a comprehensive analysis comparing the evidence collected from the fieldwork with the national data for the study area was challenging.

4.8 Future Research

This study specifically targeted two *Unions* within the *Kaliganj Upazila* of the *Satkhira* district, recognized as one of the most vulnerable coastal areas in Bangladesh due to climate change-related hazards. It established a robust foundation by revealing the significance of understanding the local perceptions of climate-induced stress and adaptive strategies practiced within the community. It also makes a significant contribution to enhancing our knowledge of the intricate dynamics associated with the adoption and implementation of technology, particularly in the realm of adaptation measures for water use. It is crucial to recognize that the issues associated with climate change might exhibit variations in different geographical places. In order to achieve optimum outcomes in the implementation of adaptive measures, more research is indispensable. It is essential to conduct a thorough investigation in every *Upazila* within each coastal district to obtain a holistic perspective on people's perspectives on climate-induced hazards. Such research is suggested to prioritize the locals' preferences and limitations surrounding the adoption and implementation of technology-based adaptations.

Moreover, it is vital to identify and address policy gaps in this context. A subsequent phase of research needs to prioritize revising policies to facilitate the effective adoption and implementation of technology. The emphasis should be on prioritizing accessibility for economically disadvantaged and marginalized communities to reduce disparities in the allocation of resources and mitigate vulnerability to climate change impacts. The implementation of a comprehensive strategy would enhance the community's capacity to effectively address the multifaceted challenges posed by climate change in the coastal region of Bangladesh.

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Appendix 1: Certificate of completion of TCPS 2: CORE 2022

PANEL ON
RESEARCH ETHICS
Navigating the ethics of human research

TCPS 2: CORE 2022

Certificate of Completion

This document certifies that

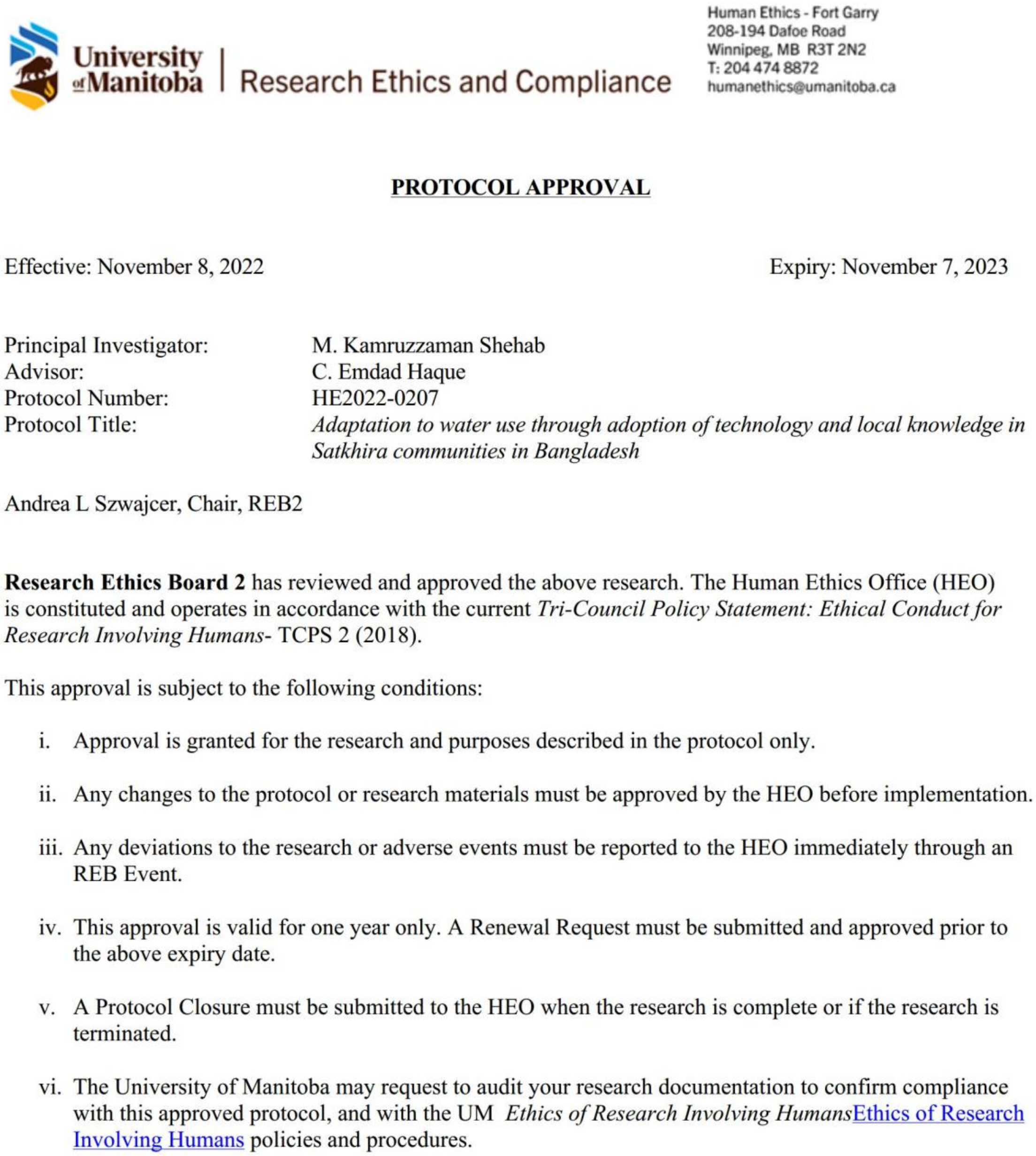
M. Kamruzzaman Shehab

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 # 0000819049

7 May, 2022

Appendix 2: Ethics approval form the University of Manitoba



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PROTOCOL APPROVAL

Effective: November 8, 2022 Expiry: November 7, 2023

Principal Investigator:	M. Kamruzzaman Shehab
Advisor:	C. Emdad Haque
Protocol Number:	HE2022-0207
Protocol Title:	*Adaptation to water use through adoption of technology and local knowledge in Satkhira communities in 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 3: Interview guide for Key Informant Interviews (KII)

- **Guided questionnaire for KII for local-level stakeholders**

Code: Date:

Location:

1. What kind of local knowledge is available in relation to the drinking, domestic, and agricultural water use?
2. What kind of technologies are being adopted for drinking, domestic, and agricultural water use?
3. Do you think such adaptation technologies are effective for alleviating the climate change impact on water resources (e.g. rising sea-level, waterlogging, and salinity intrusion)? If yes, how? Elaborate.
4. Does adoption of technological adaptation influence your income and assets positively or negatively? If yes, how? Elaborate.
5. How technology-based adaptation have been introduced in your community? How have you adopted such adaptation approaches for drinking, domestic, and agricultural water use? Elaborate.
6. Who are the key decision makers in adoption of technology-based adaptation? Whose voice is heard to implement such adaptation approaches? Elaborate.
7. How do NGOs and government agencies engage local-level stakeholders for adopting technology-based adaptation? What is the role of media in adopting such climate change adaptation technologies? Elaborate.
8. What are the major constrains and barriers in adopting technology-based adaptation in your community?
9. Do you have any access to adaptation technologies? If yes/not, why and how? Elaborate.
10. Do you think such adaptation technologies for drinking, domestic, and agricultural water use and their benefits are distributed fairly among the communities? If not, who gets what? Why and how? Elaborate.
11. Does women get equal opportunities to access adaptation technologies?
12. Does women get equal benefits from technological adaptation in your community?
13. Do you think adopting these adaptation technologies in the water sector affect the poor communities, particularly women? If yes/no, why and how? Elaborate.

➢ Guided questionnaire for KII for NGOs practitioners and GOs representatives

Code: Date:

Location:

1. What kind of technologies are being adopted for drinking, domestic, and agricultural water use?
2. Do you think such adaptation technologies are effective for alleviating the climate change impact on water resources (e.g. rising sea-level, waterlogging, and salinity intrusion)? If yes, how? Elaborate.
3. Does adoption of technological adaptation influence income and assets, positively or negatively? If yes/no, how? Elaborate.
4. How technology-based adaptation have been introduced in the community? Elaborate.
5. Who are the key decision makers in adoption of technology-based adaptation? Whose voice is heard to implement such adaptation approaches? Elaborate.
6. How do NGOs and government agencies engage local-level stakeholders for adopting technology-based adaptation?
7. What is the role of media in adopting such climate change adaptation technologies?
8. What are the major constrains and barriers in adopting technology-based adaptation in your community?
9. Do you think such adaptation technologies for drinking, domestic, and agricultural water use and their benefits are fairly distributed among the communities? If not, who gets what? Why and how? Elaborate.
10. Dose women get equal opportunities to access adaptation technologies?
11. Does women get equal benefits from technological adaptation in your community?
12. Do you think adopting these adaptation technologies in the water sector influence affect the poor communities, particularly women? If yes/no, why and how? Elaborate.

Appendix 4: Interview guide for Focus Group Discussions (FGD)

- **Guided major discussion issues for Focus Group Discussions**

Code: Date:

Location:

1. Please tell us about some examples of technology-based adaptation for drinking, domestic, and agricultural water use.
2. What was the extent of effectiveness of adopting such adaptation measures in alleviating climate change impact on water resources?
3. What were the process of adoption of technology-based adaptation for drinking, domestic, and agricultural water use?
4. What and how technological adaptation impacted (positively and negatively) on income and assets?
5. What were the role of actors such as community, gender, government, NGO, and media in adopting of technology-based adaptation for drinking, domestic, and agricultural water use?
6. What were the major constrains and barrier for adopting of technology-based adaptation for agricultural and domestic water use?
7. Has the access to the adopted adaption been fair, and how their benefits were distributed?

Appendix 5: Interview guide for Household Survey

Identification Information

Date of interview: ☐☐☐☐☐☐☐☐ (DD MM YYYY)

Questionnaire number: ☐☐☐

SL.	**Question**	**Coding**	**Answer**
1	Name of respondent		
2	Age of respondent	In years	
3	Sex of respondent	1 = Male 2 = Female 3 = Others	
4	Occupation	1= Agricultural crop production/farming, 2 = Agriculture wage labor, 3 = Non farming day labor, 4 = Housewife/Home maker, 5 = Livestock and poultry rearing, 6 = Fishing, 7 = Crab collection, 8 = Fish farming, 9 = Shrimp culture, 10 = Handicraft (swing, hand loom, cottage etc.), 11 = Transport worker (Rickshaw/Van/Cart/), 12 = Boatman, 13 = Business, 14 = Service, 15 = Looking for employment, 16 = Student, 17 = Others (specify here)	
5	What is the main source of the household income?	1 = Agriculture 2 = Fishing 3 = Shrimp/crab production 4 = Day labor (agricultural work) 5 = Day labor (non-agricultural work) 6 = Transport worker (Rickshaw/Van/Cart) 7 = Business 8 = Job 9 = Handicraft (swing, handloom, etc.) 10 = Depend on the household members' earnings who have migrated to different places 11 = Others (specify here)	
6	What is your monthly average household income	In Taka	
7	What is the main source of water for drinking?	1 = Supply water by pipeline 2 = Tube well 3 = Pond/river 4 = Well 5 = Waterfall/string 6 = Rainwater storage 7 = Bottled water 8 = Water supply from market-based organization 9 = Reverse osmosis (RO)	

		10 = Others (specify here)	
8	What are the sources for irrigational water supply? (Multiple options)	1 = Deep tube well 2 = Shallow tube well 3 = Rainwater 4 = Pond 5 = River 6 = Irrigation canals 7 = Well 8 = Spring 9 = Supply water by pipeline 10 = Water reservoir 11 = Low-Lifting pumps 12 = Deep Submersible Pumps 13 = Others (please specify)	
9	What are the types of technologies being used for drinking water supply? (Multiple options)	1 = Rainwater harvesting 2 = Deep tube well 3 = Shallow tube well 4 = Deep tube well 5 = Artificial aquifer tube well 6 = Pond sand filter 7 = Reverse osmosis (RO) 8 = Solar disinfection 9 = Managed aquifer recharge 10 = Household drinking water treatment 11 = Water purifier 12 = Others (specify here)	
10	What are the types of technologies being used for domestic water supply? (Multiple options)	1 = Rainwater harvesting 2 = Deep tube well 3 = Shallow tube well 4 = Deep tube well 5 = Artificial aquifer tube well 6 = Pond sand filter 7 = Reverse osmosis (RO) 8 = Solar disinfection 9 = Managed aquifer recharge 10 = Household drinking water treatment 11 = Others (specify here)	
11	What are the types of technologies being used for agricultural water supply? (Multiple options)	1 = Rainwater harvesting 2 = Deep tube well 3 = Shallow tube well 4 = Deep tube well 5 = Artificial aquifer tube well 6 = Pond sand filter 7 = Reverse osmosis (RO) 8 = Solar disinfection 9 = Managed aquifer recharge 10 = Low-Lifting pumps 11 = Deep Submersible Pumps 12 = Others (specify here)	

12	What are the other technologies being used in agricultural production for reducing climate change impact? (Multiple options)	1 = Cultivating salinity/drought tolerant crop varieties 2 = Using smartphone for receiving SMS, Interactive Voice Response (IVR), and Call Centre services on agrometeorology and an early warning. 3 = Using sandbar cropping technology growing pumpkins 4 = Building embankment 5 = Floating gardens 6 = Intergraded farming 6 = Others (specify here)	
13	Do you own any of this adaptation technology?	1 = Yes 2 = No	
14	Do you have access to others' owned adaptation technology for agricultural and domestic water use?	1 = Yes 2 = No	
15	Who has played a major role to implement such adaptation technology for agricultural and domestic water use in your community? (Multiple options)	1 = Community leader 2 = Community members 3 = Local representative 4 = School/college/university teacher 5 = Government officials 6 = NGO officials 7 = Friends/family 8 = Others (specify here)	
16	Do you think adaptation technology for agricultural and domestic water use and its benefits are distributed among the communities?	1 = Yes 2 = No	
17	Who is primarily responsible in your household to collect water for drinking and other (cooking and sanitary) purposes?	1 = Male 2 = Women 3 = Both	
18	Who is primarily responsible for collecting water for agricultural purposes?	1 = Male 2 = Women 3 = Both	

Appendix 6: Consent for data collection

- Consent form for KII

Natural Resources Institute
220 Sinnott Building
Winnipeg, Manitoba
Canada R3T 2M6
T (204) 474-8373
F (204) 261-0038
E nriinfo@umanitoba.ca

Consent Form for Key Informant Interview (KII)

Research Title: Adaptation to water use through adoption of technology and local knowledge in *Satkhira* communities in Bangladesh

Principal Investigator: M. Kamruzzaman Shehab, MNRM student, Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba, Canada, R3T 2M6. [redacted], email: [redacted].

Research Supervisor: Dr. C. Emdad Haque, Professor, Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba, Canada. [redacted], email: [redacted].

Sponsor: This research project is being funded by the International Development Research Centre (IDRC), Ottawa, Canada. The title of the IDRC project is "Scaling climate change adaptation knowledge and technologies for empowering women, and to enhance social equity and disaster resilience in Bangladesh" (project ID: 108960).

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Purpose of the research

This research is to examine the climate change adaptation measures in domestic and agricultural water use through technology and local knowledge, and how such technological adaptation approaches affect access to resources, income, asset, and gender disparities in your community (that is, the *Satkhira* communities in Bangladesh). The research is being guided by the following specific objectives:

I. Examine the state and role of technology and local knowledge in adaptation to water use due to climate change;
II. Examine the dynamics of adoption of adaption technologies and local knowledge in concern of water use;
III. Examine the impact of technological adaptation on access to resources, income, asset, and gender disparities.

Selection of participants

For achieving the goal of the research, I will be conducting Key Informant Interviews with different community members to understand the research problem and collect in-depth data. Participants will be considered eligible for the interview if they are 18+ years old, live in the climate change affected area in the project site, and have familiarity or experienced climate change adaption measures for domestic/agriculture water use and willing to be audio recorded. Additionally, participants need to be one or more of the following communities: local representative of community-based organizations, *Upazila* Parishad chairman, *Upazila* Parishad members, NGOs practitioners, government officer. Your experience with technology and local knowledge-based adaptation have been playing an important role in alleviating climate change impact and building community resilience at the community and household level. You can share your valuable thoughts and ideas based on your experience with technology and local knowledge-based adaptation measures and its effect on society. You are being requested to participate in this study to share your knowledge.

Study procedures

- I will ask a set of questions (10 questions in total) in regard to the research topic and if you would like to review the questions, I can provide the whole set of questions for your review.
- The interview will be designed as a one-hour session, and it will arrange at your convenience time and location.
- For conducting the interview, I (the principal investigator) will facilitate the session.
- During the interview session, I will not ask for any identifying information such as name, address, and number of NID (National Identity Card). Your information will be anonymous. I also request you not to mention any identifying information of others during or after the interview session.
- You have the option to skip or refuse any questions that you do not feel comfortable answering during the survey. If that happens, I'll leave these questions unanswered and go on to the interview's next question.

Data gathering, storage, and destruction

For collecting the data, if you provide your consent, an audio voice recorder will be used to record the interview, and I will take notes on important issues of the discussion in my notebook. If any participant does not want to be audio recorded, will be considered ineligible for the research. Please feel free to inform me if you have any objections.

The audio recorder will be password protected and it will be kept with handwritten note in a locked filing cabinet, which will be under my surveillance. After completing interview session, I will transfer the audio recording file to my UM OneDrive through the University of Manitoba student account from the recorder. After all files have been transferred, I will delete the recording files from the audio recorder. I will transcribe the audio recording manually for maintaining data accuracy. I will not use any software for data transcription. After the interview session, I will convert the handwritten notes into an electronic version by typing them into a word document. The paper-based version of the written note for each interview will be shredded by a paper shredder, and the electronic version will be kept in my UM OneDrive. To ensure the accuracy of the data, I will keep the audio recordings and handwritten notes till December 2024 for subsequent cross-checking with the written data.

For preparing Participant ID, participants' contact information will be collected and stored separately in my UM OneDrive. This data will also be used for sending the nontechnical summary of the findings of the research to the participant. The preliminary results of the research will be prepared by approximately April 2023. A (2-3 page) summary of the findings of the results will be sent to their address by May 2023.

In January 2025, I will delete all transcribed data, audio recording files, electronic copies of handwritten notes, and Participant ID from my UM OneDrive. I will also shred the consent forms and destroy them properly.

Nature of participation and compensation

Your participation in this research will be voluntary. There will be no financial compensation or remuneration will be given for this participation in this research.

Privacy & Confidentiality

As the study's chief investigator, I will scrupulously uphold confidentiality and privacy at all stages of the research work. I won't keep track of anything that could be used to identify you specifically. Your provided information will be anonymous. A coding number will be used to eliminate any directly identifiable information. Indirect identifying information, such as organization name and address will also be coded and preserved in my UM OneDrive through the University of Manitoba student account. Additionally, coded information will be used to link the raw data with the data given participant. It will help to recheck and clarify the information if any confusion arises during the data analysis process. Please note that only I and my research supervisor will have the access to all information including any directly or indirectly identifiable information.

Reporting Results

Data will be used for preparing the thesis, summary, and publication in journals and conferences. A descriptive and analytical mode will be followed to present the results of the research. If direct quotation from participants is needed to present valuable information regarding the research problem, I will use a general descriptor to maintain privacy and confidentiality. For instance, one of NGOs practitioners mentioned that "Salinity intrusion is extreme in this locality....farmers harvest only one crop during the rainy season in a year".

Withdrawal

Participants can decline their participation in this research at any time. Any participant can discontinue and withdraw verbally in the middle of the interview and leave the session. In that case, participant needs to inform me verbally and can withdraw from the research. I will remove all relevant information from Participant ID list, destroy the paper-based handwritten note by a paper shredder, and delete the recording the file from the audio recorder. If any participant wants to withdraw after completing the data collection through interview are requested to contact me immediately by phone or email. I will remove all relevant information from Participant ID list, destroy the paper-based handwritten note by a paper shredder, delete the recording the file both from the audio recorder and my UM OneDrive, and delete all transcribed data.

The deadline for the withdrawal from the research will be February 2023. The data analysis process will start in March 2023, so it is impossible to erase and destroy data after the data analysis process has started.

Risk and benefits

There are minimal risks for participation in this research. During the interview session, if you feel any emotional distress and find the discussion is very stressful to you, please tell me immediately, and I will discontinue the interview session.

The participants will get only one direct benefit of participating in this research, which will be that they would be able to understand the overall need and nature of the adaptation measures in domestic and agricultural water use through technology and local knowledge, and how such adaptation approaches help to alleviate climate change impacts on water resources. However, the major indirect benefit of your participation in this research is that you will be a part of knowledge generation and policy recommendations.

Dissemination

Comprehensive analysis and findings of this research will be disseminated in academic conferences and peer-reviewed journals. The final thesis paper will also be available on the MSpace of the University of Manitoba (https://mspace.lib.umanitoba.ca), where university faculty members and students can read the scholarly work. A hard copy of this thesis will also be made available in your *Union* Parishad, and the summary of the findings of this research will be disseminated among the participants who wish to receive it.

Feedback

In the last ten minutes of the interview session, I will quickly restate the summarized key facts you have shared with me based on the interview and you will be requested to verify my interpretation is accurate and share your feedback.

A non-technical summary of findings (2-3 pages) will be provided to the participants by May 2023. Please give a choice of mechanisms how you would like to receive the summary of findings:

☐ Sent to e-mail address: ____

☐ Sent to the following address: ____

☐ Not interested to receive the summary of findings

Consent

I am requesting you to indicate the following items that you agree with these.

☐ Yes ☐ No	I agree that the researcher can use the audio voice recorder for this interview session.
☐ Yes ☐ No	I agree that I will not disclose any names, address, and indirectly identifying information of any other community members in the interview session.
☐ Yes ☐ No	I agree that the PI has read out the full consent form, and I give my verbal consent.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their

legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the Research Ethics Board at the University of Manitoba, Fort Garry campus. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Officer at 204-474-7122 or HumanEthics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Name of the participant: ____

Participant’s signature: ______________________________________ Date: _________________

Researcher’s signature: ______________________________________ Date: _________________

Appendix 7: Consent form for FGD

Natural Resources Institute
220 Sinnott Building
Winnipeg, Manitoba
Canada R3T 2M6
T (204) 474-8373
F (204) 261-0038
E nriinfo@umanitoba.ca

Consent Form for Focus Group Discussion (FGD)

Research Title: Adaptation to water use through adoption of technology and local knowledge in *Satkhira* communities in Bangladesh

Principal Investigator: M. Kamruzzaman Shehab, MNRM student, Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba, Canada, R3T 2M6. [redacted]; [redacted], email: [redacted].

Research Supervisor: Dr. C. Emdad Haque, Professor, Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba, Canada. [redacted], email: [redacted].

Sponsor: This research project is being funded by the International Development Research Centre (IDRC), Ottawa, Canada. The title of the IDRC project is "Scaling climate change adaptation knowledge and technologies for empowering women, and to enhance social equity and disaster resilience in Bangladesh" (project ID: 108960).

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Purpose of the research

This research is to examine the climate change adaptation measures in domestic and agricultural water use through technology and local knowledge, and how such technological adaptation approaches affect access to resources, income, asset, and gender disparities in your community (that is, the *Satkhira* communities in Bangladesh). The research is being guided by the following specific objectives:

IV. Examine the state and role of technology and local knowledge in adaptation to water use due to climate change;
V. Examine the dynamics of adoption of adaption technologies and local knowledge in concern of water use;
VI. Examine the impact of technological adaptation on access to resources, income, asset, and gender disparities.

Selection of participants

For achieving the goal of the research, I will be conduct focus group discussions with different community members to understand the research problem and collect in-depth data. Participants will be considered eligible for the focus group discussion if they are 18+ years old, live in the climate change affected area in the project site, and have familiarity or experienced climate change adaption measures for domestic/agriculture water use. Additionally, participants need to be one or more of the following communities: farmer, fisherperson, day labor, female, a local water user group, and willing to be audio recorded. Your experience with technology and local knowledge-based adaptation have been playing an important role in alleviating climate change impact and building community resilience at the community and household level. You can share your valuable thoughts and ideas based on your experience with technology and local knowledge-based adaptation measures in the discussion session. You are being requested to participate in this study to share your knowledge.

Study procedures

- Each FGD will be performed with a group of participants consists of 8 to 12 people, who have experiences with technology and local knowledge-based adaptation measures in agricultural and domestic water use. The FGD will help to understand community member's ideas, experiences, and opinions regarding the specific research problem.
- For conducting the FGDs, I (the principal investigator) will facilitate this group discussion, and the discussion will be guided through the key discussion topics of the research.
- The discussion will be designed as a one-hour session, and it will arrange at your convenience time and location.
- During the discussion, I will not ask for any identifying information such as name, address, and number of NID (National Identity Card). Your information will be anonymous. I also request you not to mention any identifying information of other participants that you may know during the discussion session. However, if someone calls other participants by name or by other identifying information, I will remove such information from the transcripts.
- All participants will be requested to respect privacy and maintain the confidentiality of other members. Besides, each participant will be asked to give their consent for not disclosing any information about this group discussion for maintaining privacy and confidentiality (described in the following box of the consent).

Data gathering, storage, and destruction

For collecting the data, if you provide your consent, an audio voice recorder will be used to record the interview, and I will take notes on important issues of the discussion in my notebook. If any participant does not want to be audio recorded, will be considered ineligible for the research. Please feel free to inform me if you have any objections.

The audio recorder will be password protected and it will be kept with handwritten note in a locked filing cabinet, which will be under my surveillance. After completing focus group discussion sessions, I will transfer the audio recording file to my UM OneDrive through the University of Manitoba student account from the recorder. After all files have been transferred, I will delete the recording files from the audio recorder. I will transcribe the audio recording manually for maintaining data accuracy. I will not use any software for data transcription. After the focus group session, I will convert the handwritten notes into an electronic version by typing them into a word document. The paper-based version of the written note for each FGD will be shredded by a paper shredder, and the electronic version will be kept in my UM OneDrive. To ensure the accuracy of the data, I will keep the audio recordings and handwritten notes till December 2024 for subsequent cross-checking with the written data.

For preparing Participant ID, participants' contact information will be collected and stored separately in my UM OneDrive. This data will also be used for sending the nontechnical summary of the findings of the research to the participant. The preliminary results of the research will be prepared by approximately April 2023. A (2-3 page) summary of the findings of the results will be sent to their address by May 2023.

In January 2025, I will delete all transcribed data, audio recording files, electronic copies of handwritten notes, and Participant ID from my UM OneDrive. I will also shred the consent forms and destroy them properly.

Nature of participation and compensation

Your participation in this research will be voluntary. There will be no financial compensation or remuneration will be given for this participation in this research.

Privacy & Confidentiality

Confidentiality can not be guaranteed as the participants in the focus group discussion might know each other as they will be from the same community. They may address each other by directly identifying information such as name, or they might reveal other indirectly identifying information such as organization name and address, or they may share what is said during the focus group discussion. Considering this situation, one specific condition is added in the consent section (please see the table below) where every participant will give his/her consent that he/she will maintain the privacy and confidentiality of all information addressed by the participants during focus group discussions and will not disclose any information about this discussion. Moreover, I will avoid such directly identifying information during the data transcription, and indirect identifying information will be coded to protect privacy and confidentiality.

As the study's chief investigator, I will scrupulously uphold confidentiality and privacy at all stages of the research work. I won't keep track of anything that could be used to identify you specifically. Your provided information will be anonymous. A coding number will be used to eliminate any directly identifiable information. Indirect identifying information, such as organization name and address will also be coded and preserved in my UM OneDrive through the University of Manitoba student account. Additionally, coded information will be used to link the raw data given by the participant. It will help to recheck and clarify the information if any confusion arises during the data analysis process. Please note that only I and my research supervisor will have the access to all information including any directly or indirectly identifiable information.

Reporting Results

Data will be used for preparing the thesis, summary, and publication in journals and conferences. A descriptive and analytical mode will be followed to present the results of the research. If direct quotation from participants is needed to present valuable information regarding the research problem, I will use a general descriptor to maintain privacy and confidentiality. For instance, a farmer said that "Salinity intrusion is extreme in our locality....we harvest only one crop during the rainy season in a year".

Withdrawal

Participants can withdraw their participation from this research at any time. Any participant can discontinue and withdraw verbally in the middle of a group discussion and leave the session. In that case, participants need to inform me verbally and can withdraw from the research. If any participant wants to withdraw after completing the data collection through focus group discussion are requested to contact me immediately by phone or email. In a focus group discussion, sometimes the direction of the discussion depends on any participant's comment. It is extremely challenging to retract the discussion and analyze the data if any participant wants to withdraw and remove his or her conversation from the audio recording. Hence, if any individual in a focus group discussion wants to withdraw from the research, the withdrawing participant will not be quoted.

The deadline for the withdrawal from the research will be February 2023. The data analysis process will start in March 2023, so it is impossible to erase and destroy data after the data analysis process has started.

Risk and benefits

There are minimal risks for participation in this research. During the group discussion, if you feel any emotional distress and find the discussion is very stressful to you, please tell me immediately, and I will discontinue the discussion session.

The participants will get only one direct benefit of participating in this research, which will be that they would be able to understand the overall need and nature of the adaptation measures in domestic and agricultural water use through technology and local knowledge, and how such adaptation approaches help to alleviate climate change impacts on water resources. However, the major indirect benefit of your participation in this research is that you will be a part of knowledge generation and policy recommendations..

Dissemination

Comprehensive analysis and findings of this research will be disseminated in academic conferences and peer-reviewed journals. The final thesis paper will be available on the MSpace of the University of Manitoba (https://mspace.lib.umanitoba.ca), where the public can read the scholarly work. A hard copy of this thesis will also be made available in your *Union* Parishad, and the summary of the findings of this research will be disseminated among the participants who wish to receive it.

Feedback

In the last ten minutes of the discussion session, I will quickly restate the summarized key facts you have shared with me based on the focus group discussion and you will be requested to verify my interpretation is accurate and share your feedback.

A non-technical summary of findings (2-3 pages) will be provided to the participants by May 2023. Please give a choice of mechanisms how you would like to receive the summary of findings:

☐ Sent to e-mail address: ____

☐ Sent to the following address: ____

☐ Not interested to receive the summary of findings

<u>Consent</u>

I am requesting you to indicate the following items that you agree with these.

☐ Yes ☐ No	I agree that the researcher can use the audio voice recorder for this focus group discussion.
☐ Yes ☐ No	I declare that I will maintain the confidentiality and privacy of all information that addressed by the participants of focus group discussions. I will not disclose any information about this discussion.
☐ Yes ☐ No	I agree that the PI has read out the full consent form, and I give my verbal consent.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the Research Ethics Board at the University of Manitoba, Fort Garry campus. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Officer at 204-474-7122 or HumanEthics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Name of the participant: ____

Participant's signature: ______________________________________ Date: _________________

Researcher's signature: ______________________________________ Date: _________________

Appendix 8: Consent form for household survey

University of Manitoba | Clayton H. Riddell Faculty of Environment, Earth, and Resources

Natural Resources Institute
220 Sinnott Building
Winnipeg, Manitoba
Canada R3T 2M6
T (204) 474-8373
F (204) 261-0038
E nriinfo@umanitoba.ca

Consent Form for Household Survey

Research Title: Adaptation to water use through adoption of technology and local knowledge in *Satkhira* communities in Bangladesh

Principal Investigator: M. Kamruzzaman Shehab, MNRM student, Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba, Canada, R3T 2M6. [redacted]; [redacted], email: [redacted].

Research Supervisor: Dr. C. Emdad Haque, Professor, Natural Resources Institute, University of Manitoba, Winnipeg, Manitoba, Canada. [redacted], email: [redacted].

Sponsor: This research project is being funded by the International Development Research Centre (IDRC), Ottawa, Canada. The title of the IDRC project is "Scaling climate change adaptation knowledge and technologies for empowering women, and to enhance social equity and disaster resilience in Bangladesh" (project ID: 108960).

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Purpose of the research

This research is to examine the climate change adaptation measures in domestic and agricultural water use through technology and local knowledge, and how such technological adaptation approaches affect access to resources, income, asset, and gender disparities in your community (that is, the *Satkhira* communities in Bangladesh). The research is being guided by the following specific objectives:

VII. Examine the state and role of technology and local knowledge in adaptation to water use due to climate change;
VIII. Examine the dynamics of adoption of adaption technologies and local knowledge in concern of water use;
IX. Examine the impact of technological adaptation on access to resources, income, asset, and gender disparities.

Selection of participants

For achieving the goal of the research, I will be conducting 300 Household Survey. Participants will be considered eligible for the household survey if they are 18+ years old, live in the climate change affected area in the project site, and have familiarity or experienced climate change adaption measures for domestic/agriculture water use. Additionally, participants need to be the head of the household and have experience with any major climatic hazard (e.g. cyclone Sidr in 2007 or cyclone Aila in 2009).

Study procedures

- I will ask a set of questions which focus on your demographic characteristics, employment, household earning, assets, and expenditure, information on climate change and its impact on water sector, information on water supply, adaptation technology and its impact on social equity and gender disparities. Your wide range of experience regarding the above-mentioned topics will help the study to provide a comprehensive analysis.
- You will be asked 18 questions in total in the survey session. The survey session will take a 30-minute session, and it will be arranged at your convenience time and location.
- For conducting the survey, I (the principal investigator) will facilitate the session.
- You have the option to skip or refuse any questions that you do not feel comfortable answering during the survey. If that happens, I'll leave these questions unanswered and go on to the survey's next question.

Data gathering, storage, and destruction

The data will be collected through the survey questionnaire (hardcopy). After completing the data collection procedure, I will input the data from hard copies into electronic copies. These electronic data will be coded, made anonymous, and kept in my UM OneDrive using a University of Manitoba account till December 2024. These anonymous data will be used for further data analysis. The tentative date to complete the procedure is March 2023. All paper-based data will be kept in a lockable file cabinet that I will monitor until this procedure is finished. In April 2023, I will use a paper shredder to destroy all survey data that was collected on paper.

For preparing Participant ID, participants' contact information will be collected and stored separately in my UM OneDrive. This data will also be used for sending the nontechnical summary of the findings of the research to the participant. The preliminary results of the research will be prepared by approximately April 2023. A (2-3 page) summary of the findings of the results will be sent to their address by May 2023. In January 2025, I will delete all survey data and Participant ID from my UM OneDrive. I will also shred the consent forms and destroy them properly.

Nature of participation and compensation

Your participation in this research will be voluntary. There will be no financial compensation or remuneration will be given for this participation in this research.

Privacy & Confidentiality

As the study's chief investigator, I will scrupulously uphold confidentiality and privacy at all stages of the research work. I won't keep track of anything that could be used to identify you specifically. Your provided information will be anonymous. All direct or indirect identifying information, such as organization name and address will also be coded and preserved in my UM OneDrive through the University of Manitoba student account. Additionally, coded information will be used to link the raw data with the data given participant. It will help to recheck and clarify the information if any confusion arises during the data analysis process. Please note that only I and my research supervisor will have the access to all information including any directly or indirectly identifiable information.

Reporting Results:

Data will be used for preparing the thesis, summary, and publication in journals and conferences. A descriptive and analytical mode will be followed to present the results of the research. I will use a general descriptor to maintain privacy and confidentiality. For instance, 50% respondents' livelihood depend on crop farming, and they use groundwater to meet the irrigational water demand.

Withdrawal

Participants can withdraw their participation from this research at any time. Any participant can discontinue and withdraw verbally in the middle of the survey and leave the session. In that case, participants need to inform me verbally and can withdraw from the research. I will remove all relevant information from Participant ID list and destroy the paper-based survey data by a paper shredder. If any participant wants to withdraw after completing the data collection through survey are requested to contact me immediately by phone or email and I will remove all relevant information from Participant ID list, and destroy the paper-based survey data by a paper shredder, and delete the electronic coded from my UM OneDrive.

The deadline for the withdrawal from the research will be February 2023. The data analysis process will start in March 2023, so it is impossible to erase and destroy data after the data analysis process has started.

Risk and benefits

There are minimal risks for participation in this research. During the survey, if you feel any emotional distress and find the discussion is very stressful to you, please tell me immediately, and I will discontinue the survey session.

The participants will get only one direct benefit of participating in this research, which will be that they would be able to understand the overall need and nature of the adaptation measures in domestic and agricultural water use through technology and local knowledge, and how such adaptation approaches help to alleviate climate change impacts on water resources. However, the major indirect benefit of your participation in this research is that you will be a part of knowledge generation and policy recommendations.

Dissemination

Comprehensive analysis and findings of this research will be disseminated in academic conferences and peer-reviewed journals. The final thesis paper will also be available on the MSpace of the University of Manitoba (https://mspace.lib.umanitoba.ca), where university faculty members and students can read the scholarly work. A hard copy of this thesis will also be made available in your *Union* Parishad, and the summary of the findings of this research will be disseminated among the participants who wish to receive it.

A non-technical summary of findings (2-3 pages) will be provided to the participants by May 2023. Please give a choice of mechanisms how you would like to receive the summary of findings:

☐ Sent to e-mail address: ____________________

☐ Sent to the following address: ____________________

☐ Not interested to receive the summary of findings

Consent

I am requesting you to indicate the following items that you agree with these.

☐ Yes ☐ No	I agree that I will not disclose any names, address, and indirectly identifying information of any other community members during and after the survey session.
☐ Yes ☐ No	I agree that the PI has read out the full consent form, and I give my verbal consent.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the Research Ethics Board at the University of Manitoba, Fort Garry campus. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Officer at 204-474-7122 or HumanEthics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Name of the participant: ____________________

Participant's signature: ____________________ Date: __________

Researcher's signature: ____________________ Date: __________