Evaluating the Water Crisis and Management Strategies in Climate-Sensitive Coastal Areas of Bangladesh: A Focus on Household, Agricultural, and Aquaculture Water Risks

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Abstract

The study assesses the water crisis and its management in the climate-vulnerable coastal areas of Bangladesh, focusing on household, agriculture, and aquaculture water risks. Coastal areas like Assasuni (Satkhira) and Moheshkhali (Cox's Bazar) face severe water insecurity due to salinity intrusion, seasonal variability, and inadequate infrastructure. Household water risks are linked to contamination, high costs, and the disproportionate burden on women for water collection. Rainwater harvesting, pond water, purchased water, and tubewells serve as primary sources, but their availability and quality fluctuate with the seasons, especially during cyclones and floods. In agriculture, dependence on climate-sensitive water sources leaves crop production and livestock vulnerable to salinity intrusion, erratic rainfall, and weak irrigation systems. Similarly, aquaculture in both regions faces challenges from saltwater intrusion, poor water control, and infrastructure damage, with limited institutional support for adaptation.

The study identifies key water management issues, including fragmented governance, poor infrastructure maintenance, and limited access to climate-resilient technologies. Coping strategies, such as water rationing and the use of salt-tolerant species, are insufficient to address the scale of the water risks. The findings emphasize the need for integrated water resource management, better infrastructure, improved governance, and community-based solutions. Gender-sensitive interventions and strengthening institutional capacities are crucial to ensure long-term water security and resilience for the affected coastal communities.

Keywords

Water Crisis, Water Insecurity, Household, Agriculture, Aquaculture, Water Management, Climate-Sensitive, Coastal Areas

1. Introduction

Access to safe drinking water is a fundamental human right that asserts that every individual should have access to clean water, both now and in the future [1]. However, the reality for many rural populations, especially in developing countries, is that unsafe and unimproved water sources such as surface water and unprotected wells remain widespread. In Bangladesh, where 73% of the population resides in rural areas, tube wells have traditionally served as the primary source of drinking water for these communities [2]. However, the situation is markedly different in the coastal regions of the country. In this area, the scarcity of fresh water is compounded by the absence of suitable fresh water aquifers at reasonable depths and the high salinity and turbidity of surface water [3].

Climate change is exacerbating the water crisis in Bangladesh, with rising sea levels and melting glaciers influencing both the availability and quality of water for agriculture and drinking. Sea level rise increases the intrusion of saltwater into coastal freshwater aquifers, while changing precipitation patterns and extreme weather events, such as cyclones and floods, further disrupt water resources and increase contamination. As a result, coastal residents are increasingly dependent on surface water and groundwater sources that are vulnerable to pollution and salinity, which poses a serious threat to both human health and agricultural productivity [4,5].

In particular, the salinity of drinking water is a growing concern in coastal areas, affecting the health of approximately 25 million people in the lower Ganges-Brahmaputra-Meghna (GBM) delta. Alongside the physical impacts of increased salinity, the risk of waterborne diseases, such as diarrhea and cholera, is also rising due to the contamination of water sources during floods, waterlogging, and other extreme events. This situation is further aggravated by inadequate infrastructure, limited access to safe drinking water sources, and insufficient management of water resources in rural and coastal regions [6,7].

The challenges of maintaining and improving water supply infrastructure are particularly acute in coastal Bangladesh, where the interaction of natural risks (e.g., salinity, flooding) and socioeconomic factors (e.g., inadequate governance and technical capacity) creates a complex scenario for water management. While infrastructure such as tube wells, pond-sand filters, and rainwater harvesting systems provides some relief, these solutions often fall short in addressing the increasing demand and contamination risks. Moreover, local governments and NGOs, despite their efforts, face significant obstacles in managing water resources sustainably in these regions [8,9].

The study seeks to assess the water crisis and its management in climate-vulnerable coastal areas of Bangladesh, focusing on the risks to household, agriculture, and aquaculture water security. By examining the existing water management infrastructure, the impacts of climate change on water resources, and the socio-economic challenges faced by coastal populations, this research aims to contribute to the development of more resilient and sustainable water management practices for the affected communities.

1.1 Objective of the Study

The key objective of this study is to assess the water crisis and its management in climate-vulnerable coastal areas of Bangladesh, especially in different sectors, such as the household, agriculture, and aquaculture sectors. The specific objectives are given below:

1.Assess the current water risks and management conditions at the household level in climate-vulnerable coastal regions.

2.Analyze the water risks and management conditions in agriculture within the climate-risk-prone coastal zones.

3.Examine the water risks and management conditions in aquaculture in the climate-vulnerable coastal areas.

1.2 Study Locations and their Justification

The selection of Assasuni in Satkhira and Moheshkhali in Cox's Bazar as the study locations for assessing water risks and management in climate-vulnerable coastal areas of Bangladesh is based on several key factors related to the unique environmental, socio-economic, and climatic challenges faced by these regions.

1. Climate Vulnerability: Both Assasuni and Moheshkhali are located in the coastal zones of Bangladesh, which are highly susceptible to the impacts of climate change. Rising sea levels, increased frequency of cyclones, and extreme weather events, such as floods and droughts, are prominent concerns in these regions. These climatic factors lead to saltwater intrusion into freshwater sources, affecting water availability and quality. As such, these locations serve as prime examples of areas most at risk from climate-induced water crises.

2. Salinity Intrusion: One of the major challenges faced by these coastal communities is the intrusion of saline water into freshwater sources, including groundwater aquifers, ponds, and rivers. The salinity of drinking water in these areas has reached alarming levels, which directly impacts the health and well-being of the populations. Assasuni and Moheshkhali are both situated in areas where salinity intrusion is a critical issue, affecting agricultural productivity, aquaculture, and access to safe drinking water.

3. Agricultural and Aquaculture Importance: These regions are heavily dependent on agriculture and aquaculture as primary sources of livelihood. Assasuni and Moheshkhali have large agricultural sectors, including rice cultivation, livestock farming, and fishery activities. However, the increasing salinity of water resources, erratic rainfall, and lack of proper irrigation infrastructure have led to severe water-related challenges in these sectors. Aquaculture, particularly shrimp farming in Moheshkhali, faces significant threats from water quality degradation due to saltwater intrusion and contamination during storms and floods. These sectors are vital for local economies, and studying water risks in these contexts is crucial for understanding the broader implications of water management in climate-vulnerable areas.

4. Socio-economic Characteristics: The populations of Assasuni and Moheshkhali are predominantly rural, with a high dependence on subsistence farming and small-scale aquaculture. Both regions have limited access to formal water management infrastructure, which increases their vulnerability to seasonal and disaster-related water shortages. Furthermore, women in these areas are disproportionately affected by the water crisis, as they bear the responsibility for water collection, often walking long distances to fetch water from unreliable and contaminated sources. Examining the gendered aspects of water access in these regions adds a critical dimension to understanding water risks and their social implications.

5. Representation of Diverse Coastal Challenges: Assasuni and Moheshkhali represent different types of coastal environments within Bangladesh. Assasuni is a low-lying area with river and canal networks that are prone to saline intrusion, while Moheshkhali is an island region where limited freshwater aquifers and high exposure to tidal surges further complicate water access. These distinct environmental settings allow for a more comprehensive analysis of the diverse water management challenges faced by coastal communities.

6. Existing Research Gaps: Despite the recognition of water security challenges in Bangladesh's coastal regions, there is a lack of in-depth studies focusing on the intersection of climate vulnerability, water risks, and community-level water management in areas like Assasuni and Moheshkhali. This study aims to fill these gaps by examining water risks across multiple sectors—household, agriculture, and aquaculture—offering valuable insights for policy makers and local authorities working to improve water resource management in similar coastal settings.

1.3 Limitations of the Study

1.Participants were dispersed across a wide area, requiring significant travel time for data collection.

2.Arranging participants for FGDs was time-consuming.

3.Adverse weather conditions, including frequent rain and poorly constructed roads, hindered data collection efforts.

1.4 Ethical Consideration

Selected study participants were fully informed about the purpose of the study, and permission was taken for discussions and interviews. Consents were taken from all participants before conducting the survey or interview. All possible safety measures were taken during the survey, FGDs, and KII, especially considering gender sensitivity. Security of personal and sensitive data at all stages of the study was kept confidential to maintain research ethics and respect the community perspective.

2. Methodological Process

2.1 Methodology

This study employed a mixed-method strategy, combining both qualitative and quantitative data. The primary qualitative data were collected through Key Informant Interviews (KIIs), Focus Group Discussions (FGDs), In-Depth Interviews (IDIs), and the quantitative data (surveys)were collected using Kobo Toolbox. Secondary data was gathered through an extensive literature review.

2.2 Quantitative Study Design

The sample is required to estimate a proportion with an approximate 95% confidence level and 3.69% margin of error. We will use W.G. Cochran's widely used formula to estimate the sample size.

Sample Size: $$n_0 = \frac{Z_{\alpha/2}^{2} \times p(1-p)}{e^2} = \frac{1.96^2 \times 0.5(1-0.5)}{(0.0369)^2} = 704 \quad (1)$$

Where,

n_0 =Sample size	704
$Z_{95\%} = Z_{\alpha/2}$ value for 95% confidence interval	1.96
p =The proportion of the population	0.5
e =The degree of precision (Margin of error: 3.69%)	0.0369

Considering 10% non-respondent participants, the total collected survey data was 783. The sample distribution is given below in a table format:

Table 1. Quantitative Study Participants distribution

Locations	Survey Participants (in numbers)		Survey Participants (in %)	
	Female	Male	Female	Male
Assasuni	145	203	47%	53%
Moheshkhali	206	229	42%	58%

2.3 Qualitative Study Design

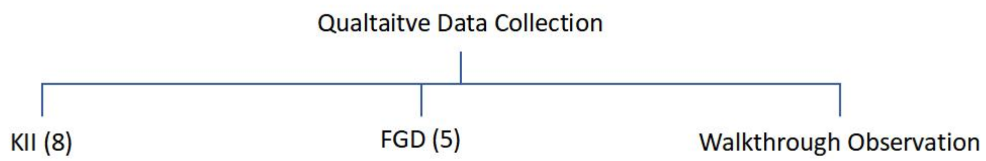


Figure 1. Summary of Qualitative Date Collection

The Key Informant Interview (KII) participants included local leaders, some agricultural sector specialists, and others, while the Focus Group Discussion (FGD) participants were mostly arming community people, especially marginalized female farmers and their spouses. Note that, in the FGD, separate male and female groups were interviewed to reduce bias and ensure freedom of speech. A walkthrough observation was conducted in both areas to gather insights on the existing water sources and their condition.

3. Analysis of Socio-Economic Situation

Socio-Demographic Situation Analysis

Table 2. Socio-Demographic Situation Analysis

Variables	Groups	Moheshkhali	Assasuni
Age	20-29	3%	4%
	30-39	18%	19%
	40-49	34%	31%
	50-59	24%	24%
	60-69	17%	16%
	70-79	4%	4%
	80-89	1%	1%
Marital Status	Single	2%	1%
	Married	98%	97%
	Widowed	0%	1%
Total No. of Household Members	1-5	85%	86%
	6-11	15%	14%
Total No. of Earning Members	No earning member	1%	1%
	1	75%	78%
	2	21%	20%
	3	2%	1%
Educational Qualification	No Education	3%	4%
	Can sign	12%	11%
	1st Grade	0%	0%
	2nd Grade	1%	3%
	3rd Grade	3%	5%
	4th Grade	1%	4%
	5th Grade	8%	12%
	6th Grade	4%	7%
	7th Grade	4%	5%
	8th Grade	13%	12%
	9th Grade	20%	14%
	SSC/Submission	21%	13%
	HSC/Alim	8%	6%
	Diploma/Technical Education	0%	0%
	BA/BSc/BCom/Fazil	2%	3%
	MA/MCom/MSc/Kamil	1%	1%
Own House	Yes	97%	93%
	No	3%	7%

3.1 Economic Condition Analysis

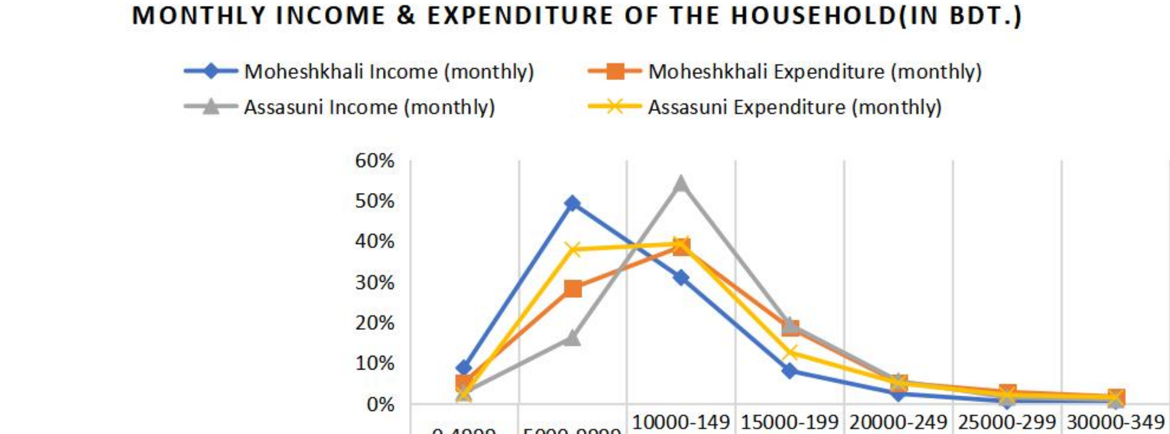
3.1.1 Main Occupation

Table 3. Main Occupation of the Survey Participants

Location & Occupation	Farmer	Fish/shrimp Farming	Agricultural Day Labor	Fishing in community/public waterbodies	Fishmongers	Grand Total
Moheshkhali	73%	16%	10%	0%	1%	100%
Assasuni	68%	20%	8%	2%	3%	100%
Grand Total	71%	18%	9%	1%	2%	100%

3.1.2 Income Condition & Expenditure Condition

The figure2 depicts the income and expenditure patterns of households in Moheshkhali and Assasuni. In both areas, the highest income and expenditure percentages are found in the BDT.5,000-9,999 bracket. In Moheshkhali, 49% of households fall within this range, with 28% of their expenditure allocated to it. In contrast, Assasuni has 16% of households earning in this range, but a notably higher 38% of expenditure in this category.



	0-4999	5000-9999	10000-14999	15000-19999	20000-24999	25000-29999	30000-34999
Moheshkhali Income (monthly)	9%	49%	31%	8%	2%	0%	0%
Moheshkhali Expenditure (monthly)	5%	28%	39%	19%	5%	3%	2%
Assasuni Income (monthly)	3%	16%	54%	19%	5%	1%	1%
Assasuni Expenditure (monthly)	2%	38%	39%	13%	5%	2%	1%

Figure 2. Income Vs Expenditure

As the income increases, the percentage of households earning in higher income brackets (BDT.10,000-14,999 and above) decreases, with both income and expenditure showing a sharp decline. However, in Moheshkhali, there is a notable disparity where expenditure consistently exceeds income in the lower income categories. In Assasuni, the gap between income and expenditure is smaller but still visible. For households in the highest income brackets (above BDT.20,000), both income and expenditure percentages drop to very low levels, with Moheshkhali showing slightly higher expenditure compared to Assasuni. In short, households in both regions generally experience a higher expenditure proportion compared to income in the lower-income categories, with the gap narrowing as income increases.

The quantitative data highlights that the workforce in Moheshkhali has a long tenure in their current occupations, with a significant portion of individuals having worked in the same role for 18-23 years or 30-35 years. A smaller proportion of workers have shorter or longer durations in their occupation. In Assasuni, a similar trend is found, with most individuals having worked for 12-17 years or 18-23 years. Overall, a large percentage of the population has stable employment, with fewer workers in the 0-5 and 42-47-year ranges. Regarding changes in the source of income over the past decade, the data show that there has been minimal change across all regions. In Moheshkhali, only 3% reported a change in their income source, while in Assasuni, the figure was even lower at 2%. This indicates that most households have maintained the same source of income and occupation over the past 10 years.When it comes to household expenditure, groceries emerge as the dominant spending category in all regions, with 80-96% of income spent on groceries, followed by smaller portions for healthcare and education. In Moheshkhali, 13% is allocated to healthcare and 7% to education, while in Assasuni, only 2% of income is spent on education and healthcare each. This shows that for most households, spending on necessities, especially groceries, takes up the largest portion of income, with very little allocated for education or healthcare.

4. Key Findings as per Objectives

4.1 Assess the Current Water Risks and Management Condition at the Household Level in Climate-Vulnerable Coastal Regions

In the climate-vulnerable coastal regions of Moheshkhali and Assasuni, household water risks are closely linked to environmental degradation, seasonal changes, and socioeconomic challenges. Salinity intrusion is the most widespread threat, caused by sea-level rise, tidal surges, and decreased upstream freshwater flows. The graph below illustrates the drinking water source of the household in different seasons:

According to the figure 3, during the monsoon season, rainwater use is relatively higher in Satkhira Assasuni (29% females, 29% males) compared to Moheshkhali (14% females, 12% males), reflecting greater reliance on direct rainfall collection in Assasuni. Supply/pipe/tap water is marginal in both locations (4 -6%), while purchased jar water is notable in Moheshkhali (38% for both sexes) compared to around 24 -26% in Assasuni. Pond water contributes modestly in both areas (10 -17%), but tubewell use is more common in Moheshkhali (39% females, 33% males) than in Assasuni (33% females, 38% males).

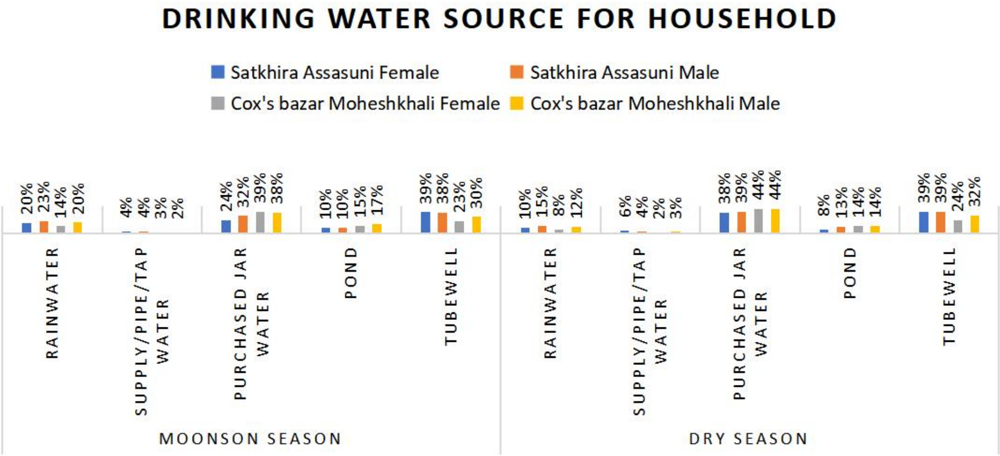


Figure 3. Season wise drinking water soure

During the dry season, water use drops significantly in both areas, especially in Moheshkhali (10 -12%) compared to Assasuni (19 -20%). Dependence on purchased jar water slightly increases, remaining higher in Moheshkhali (38 -42%) than in Assasuni (34 -38%). Pond water uses decreases in both areas during this time, while tubewell use stays a major source in both, with a slight rise in Moheshkhali (39% females, 32% males) and stable or slightly lower use in Assasuni (33% females, 29% males). Overall, the data highlights seasonal changes, with rainwater harvesting more common in Assasuni during the monsoon. Meanwhile, Moheshkhali continues to rely more on purchased jar water and tubewells all year, likely due to differences in water salinity, infrastructure, and household coping strategies.

As per FGD findings, in both areas, shallow tubewells, traditionally the main source of drinking water, are now often abandoned due to high salinity and sometimes arsenic contamination. This has compelled households to use alternative sources such as rainwater harvesting, pond water, bottled water, or piped water where infrastructure is available. However, these options have limitations: rainwater harvesting is seasonal and needs large storage, which many households cannot afford; pond water is often contaminated with bacteria, especially during the dry post-monsoon period; and purchasing water is costly for poorer families.

In Moheshkhali, the island's geographical isolation exacerbates water insecurity. Many communities have limited freshwater aquifers, and transport costs for safe water increase the price significantly. During the dry season, stored rainwater is depleted quickly, forcing households, especially women and children, to walk long distances or spend money on water delivery. In Assasuni, salinity intrusion from adjacent rivers and canals is compounded by cyclone-induced embankment breaches, which flood freshwater ponds with saline water. Here, even pond sand filters (PSFs) and shallow tubewells become ineffective without regular maintenance and protection from saline intrusion. The poor maintenance of community-based water infrastructure, often due to unclear ownership and lack of technical capacity, further undermines reliability. The figure 4 below highlights the source of drinking water during a flood or cyclone:

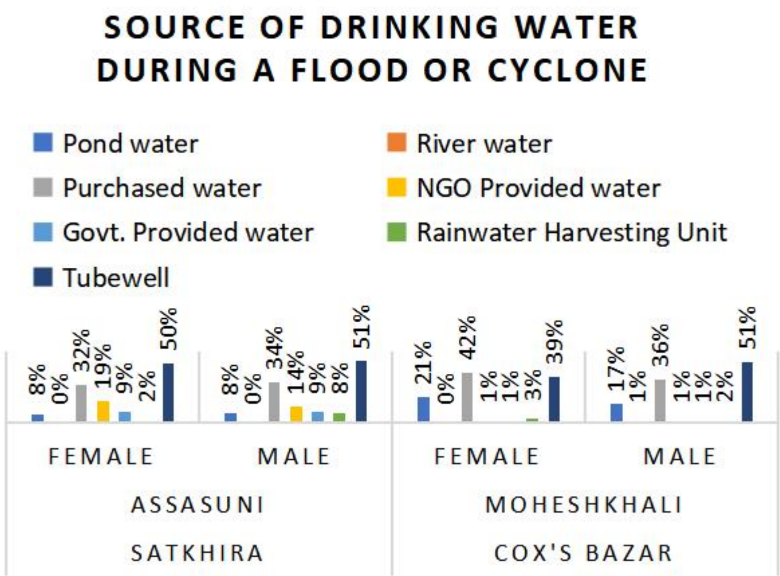


Figure 4. Source of drinking water during a flood or cyclone

During floods or cyclones, households in Satkhira (Assasuni) and Cox's Bazar (Moheshkhali) rely on a combination of traditional, purchased, and institutional water sources. In Satkhira, tubewells are the most common source, followed by purchased water and NGO-provided water, especially for females. In Cox's Bazar, purchased water dominates, with tubewells and pond water being significant sources. Water purification is generally low in both areas; in Assasuni, 95% of households do not purify water, while in Moheshkhali, 83% consume untreated water, though 17% purify theirs. The figure 5 below shows the household's purification strategy for drinking water before consumption:

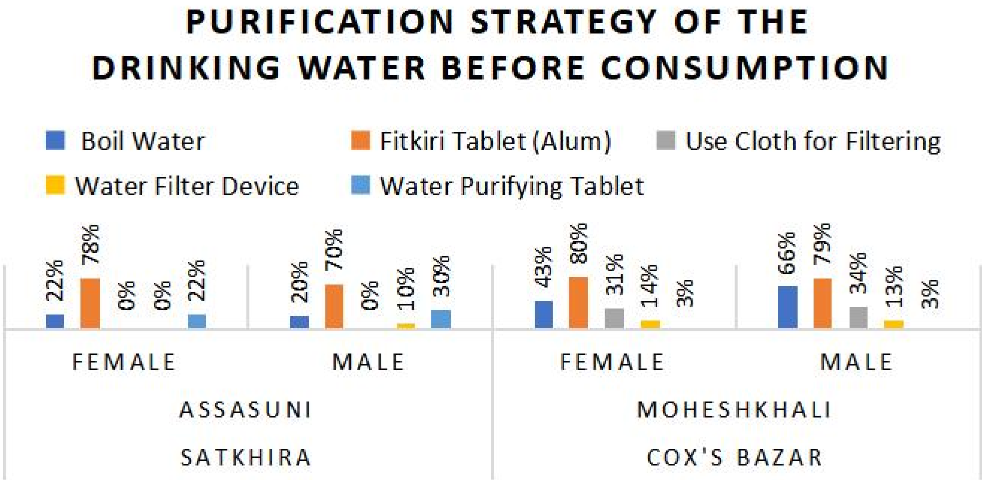


Figure 5. household's purification strategy for drinking water

The data indicates notable differences in household drinking water purification strategies between Assasuni (Satkhira) and Moheshkhali (Cox's Bazar). In Assasuni, the dominant method among females is boiling water (78%), followed by using cloth for filtering (22%), with no reported use of alum, filter devices, or water-purifying tablets. Among males in Assasuni, boiling is even more prevalent (70%), with small proportions using cloth filtration (20%), water filter devices (10%), or alum (2%), but no use of purifying tablets. In contrast, Moheshkhali households show a more varied approach. Among females, boiling (43%) is the leading method, followed by cloth filtration (36%), alum (13%), and minor use of filter devices (3%) and purifying tablets (3%). For males in Moheshkhali, boiling is most common (65%), followed by cloth filtration (33%) and minimal use of alum (3%), with no reported use of filter devices or purifying tablets. Overall, boiling water is the primary purification strategy across both regions, but Moheshkhali shows greater diversity in methods, whereas Assasuni relies more heavily on boiling and cloth filtration, with very limited adoption of modern filtration or chemical treatment options. The figure 6 below illustrates households' monthly expenses for purifying water for drinking:

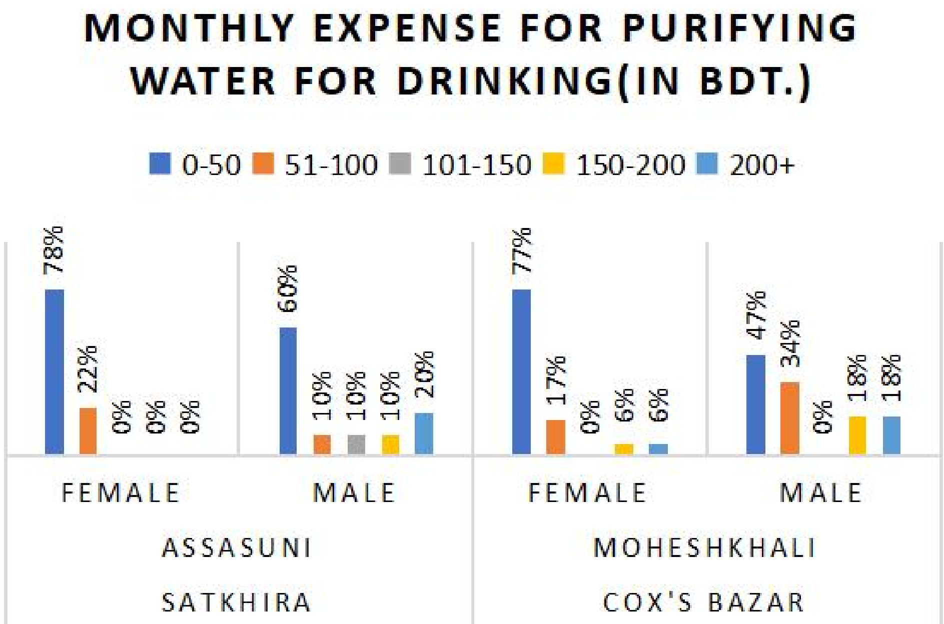


Figure 6. Households' monthly expenses for purifying water for drinking

In Assasuni, 78% of female respondents and 60% of male respondents fall into this lowest spending bracket, with females spending almost exclusively in the BDT. (0 -50) and BDT. (51 -100) ranges, while males show more variation:

20% spend over BDT. 200, and smaller proportions spend between BDT. (101 -200). In Moheshkhali, 77% of female respondents spend BDT. (0 -50), with small proportions in higher categories, whereas male respondents report more substantial expenditures—only 47% spend 0 -50 BDT, while 34% spend BDT. (51 -100), and 18% each spend BDT. (150 -200) and over 200 BDT. Overall, the findings indicate that women-headed responses in both areas cluster at minimal spending levels, while male-headed responses, particularly in Moheshkhali, reflect greater variation and higher spending on water purification.

The qualitative data indicate that water quality monitoring at the household level is rare, and most families rely on taste as an indicator, which fails to detect microbial or arsenic contamination. This results in significant health impacts, including hypertension, skin diseases, diarrheal illnesses, and in severe cases, kidney problems. The burden of water collection falls disproportionately on women and girls, reducing time for education and income-generating activities. The figure 7 below illustrates the survey participants' responses regarding the water collection responsibility structure in the household:

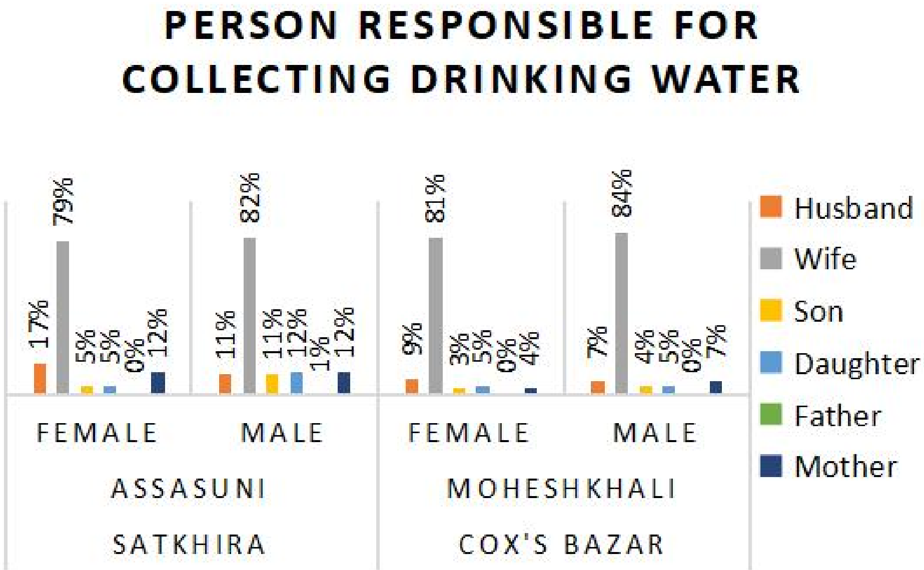


Figure 7. Key person for water collection

The data shows that in both Assasuni (Satkhira) and Moheshkhali (Cox's Bazar), the primary responsibility for collecting household drinking water falls predominantly on the wife, followed by the husband. In Assasuni, 79% of female respondents and 82% of male respondents reported the wife as the main water collector, while 17% of females and 11% of males identified the husband in this role. In Moheshkhali, 81% of female respondents and 84% of male respondents reported the wife as the main collector, with husbands accounting for 9% and 7% respectively. Other family members, such as sons and daughters, play a smaller role (ranging from 3 -12%), while fathers are seldom responsible, and mothers are involved in a small proportion of cases (4 -12%). Overall, the findings highlight a strong gendered division of labor in which women, particularly wives, bear the overwhelming responsibility for drinking water collection in both regions.

The key findings on challenges in drinking water collection reveal several critical issues faced by household members in Satkhira (Assasuni) and Cox's Bazar (Moheshkhali). Water costs are perceived as high by around 17-31% of people, with slightly higher concern among males. Long queues for water collection are common, affecting 70-90% of females and 82-100% of males across both areas. Additionally, water sources are not consistently available, impacting 10-24% of users, with males generally reporting higher unavailability. Sexual harassment during water collection is notably reported by all females in Assasuni (100%) and 80% in Moheshkhali, while males also agree that women face sexual harassment, ranging from 82-100%. Poor water quality is a significant concern in Moheshkhali, particularly among females (40%), whereas it is negligible or absent in Assasuni. Overall, these challenges highlight gender-specific vulnerabilities, especially regarding harassment and queue times, alongside ongoing issues of cost, availability, and water quality.

Qualitative data highlight that NGO and government interventions, such as PSFs, reverse osmosis plants, and small-scale piped water schemes, provide partial relief. However, coverage remains uneven, and systems often fail due to poor operation and maintenance. Quantitative data reveal that only a small portion of households have received support from government or non-governmental organizations for safe water for drinking and other uses. In Assasuni, just 18% of households reported receiving such support, with 12% of females and 22% of males indicating assistance. Similarly, in Moheshkhali, 17% of households benefited from aid, including 15% of females and 20% of males. This indicates that, despite the need, most households in both areas have yet to receive external assistance related to safe water access. The figure 8 below shows the types of support households receive from GO/NGO regarding safe water for drinking and other purposes.

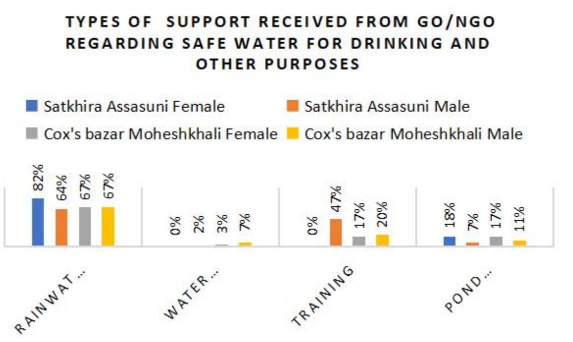


Figure 8. types of support receive from GO/NGO regarding safe water for drinking and other purposes by household

As per survey data, Households receiving support from government and NGOs for safe drinking water in Satkhira (Assasuni) and Cox's Bazar (Moheshkhali) primarily benefit from Rainwater Harvesting Units, which constitute the largest form of assistance. Other types of support are less common: Water Purifying Tablets were provided minimally, while training on safe water practices was provided to household members across the two regions. Pond Sand Filters (PSF) were distributed to a smaller portion of households, slightly higher among females in Assasuni. KII findings highlight that coping strategies are largely reactive: households ration safe water for drinking and use saline water for cooking, washing, and bathing, which still carries health risks.

The qualitative findings highlight that household water management in Moheshkhali and Assasuni is characterized by high dependence on climate-sensitive sources, inadequate storage and treatment infrastructure, high economic and time burdens, and limited adaptive capacity. Without integrated and sustained interventions, combining infrastructure investment, maintenance systems, affordable pricing models, and salinity control measures, these communities will remain trapped in a cycle of seasonal water insecurity and are likely to worsen with ongoing climate change. The table below illustrates qualitative findings regarding the water risks and management conditions at the household level:

Table 4. Qualitative findings regarding the water risks and management conditions at the household level

Aspect	Moheshkhali	Assasuni
Geographical & Environmental Context	Island areas with limited freshwater aquifers are highly exposed to tidal surges and saline intrusion from the surrounding sea, and there are transport challenges for importing water.	Mainland coastal sub-district; low-lying area with river and canal networks prone to saline intrusion; embankment breaches during cyclones cause saltwater flooding.
Main Water Risks	Persistent high salinity in shallow aquifers; seasonal freshwater shortage; high transportation cost for water supply; occasional cyclone damage to rainwater tanks and PSFs.	Severe salinity intrusion from rivers/canals; frequent pond contamination after floods; cyclone-induced embankment failure; pond drying in dry season.
Key Limitations of Sources	Rainwater storage is often insufficient for dry months; bottled water is expensive; ponds are prone to contamination; and piped systems have limited coverage.	PSFs require regular maintenance and protection from saline intrusion; shallow tubewells are saline most of the year, and rainwater tanks are inadequate in size.
Water Quality Concerns	Salinity; microbial contamination in pond water; no regular testing; reliance on taste to judge safety.	Salinity; arsenic in some tubewells; microbial contamination; lack of household-level treatment.
Health Impacts	Hypertension, skin diseases, gastrointestinal issues; risk increases in dry season.	Hypertension, diarrheal diseases, skin conditions, and kidney-related issues.
Coping Strategies	Prioritize safe water for drinking only; use saline water for cooking/bathing; buy water during shortages; rely on NGO-installed storage tanks and PSFs.	Use rainwater during monsoon; switch to pond water in dry season; purchase water during shortages; share PSFs between households; use saline water for non-drinking purposes.
Institutional/NGO Interventions	NGO-installed rainwater tanks, community PSFs, small desalination plants, and limited but growing piped water systems.	NGO/government-supported PSFs, embankment repair projects, small piped schemes, rainwater harvesting promotion.
Key Challenges in Management	Limited land for large rainwater tanks; cost of purchased water; maintenance of systems; transportation barriers for imported water.	Frequent cyclone damage to embankments; lack of community-based maintenance for PSFs; salinity penetration after floods; insufficient rainwater storage capacity.

4.2 Analyze the Water Risks and Management Conditions in Agriculture within the Climate-risk-prone Coastal Zones

Qualitative findings indicate that, in the targeted study areas, agricultural water risks are primarily driven by saltwater intrusion, irregular rainfall, and extreme hydrological events. In Assasuni, sea-level rise and higher tidal amplitudes push saline water and brackish groundwater further inland, reducing the available freshwater for irrigation and increasing soil salinity, especially during dry seasons. Groundwater is becoming more brackish and depleted, forcing farmers to depend on contaminated sources or salt-tolerant crops, which disrupts traditional planting schedules and lowers yields. Surface irrigation from rivers and canals is helpful in some seasons, but canal networks are often clogged with silt, poorly drained, or breached by floods and cyclones, which lowers their reliability. Flood-drought cycles worsen moisture stress and soil salinity, along with degraded soil structure, diminishing productivity. The figure 9 below illustrates the source of irrigation water in the targeted locations:

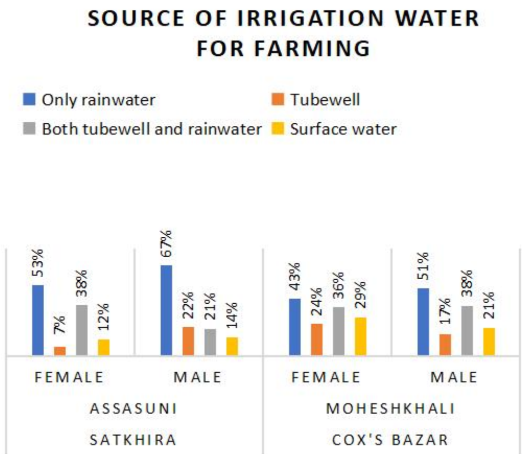


Figure 9. Source of irrigation water

In Satkhira (Assasuni), irrigation is heavily dependent on rainwater, reflecting high vulnerability to rainfall variability and seasonal water scarcity. Tubewell use is limited, particularly for females (7%), indicating constrained access to groundwater-based irrigation, which may be due to salinity intrusion, high installation/operation costs, or social and ownership barriers. A significant proportion of both female (38%) and male (21%) farmers use both rainwater and tubewell water, suggesting some diversification of sources but still with strong dependence on rainfall. Surface water use remains low due to the limited availability of freshwater ponds or canals during key cropping periods.

In Cox's Bazar (Moheshkhali), irrigation sources are more varied: while rainwater is still dominant, and greater reliance on both tubewell and rainwater, indicating a more diversified strategy. Surface water plays a larger role here than in Assasuni, particularly among females (29%), possibly due to greater availability of ponds or canal systems, though quality may be affected by salinity and contamination. In summary, both areas remain highly rain-dependent, making agriculture vulnerable to delayed monsoons, erratic rainfall, and droughts, but Moheshkhali shows comparatively better source diversification, while Assasuni's limited groundwater access increases exposure to climate-induced water stress.

In the agriculture sector, livestock are also important for the agrarian families. Due to climate change, livestock face parallel risks in the targeted locations, especially floodwater contamination leads to waterborne diseases, saline or stagnant water affects animal health and milk/meat productivity, and shortages after cyclones force farmers to compete with household needs for limited potable water. The figure 10 below shows the livestock water consumption (per day) situation in the targeted locations:

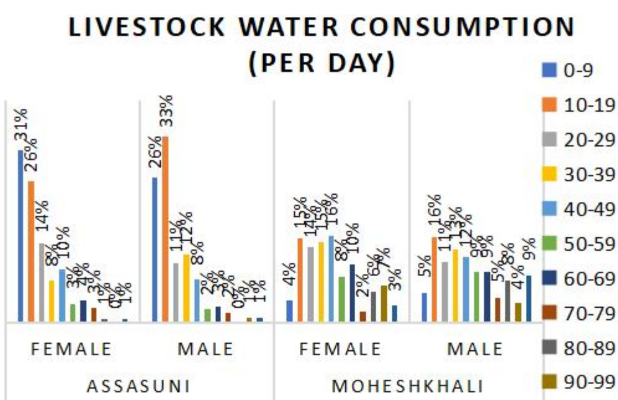


Figure 10. Per day Water Consumption of livestock

The data shows clear differences in daily livestock water consumption patterns between Assasuni (Satkhira) and Moheshkhali (Cox's Bazar), reflecting variations in livestock type, herd size, and water availability. In Assasuni, the majority of livestock consume relatively small amounts of water per day, with 28 -30% of households reporting 0 -9 liters and 10 -19 liters, and consumption above 50 liters being rare. This suggests smaller herd sizes, limited high-water-demand livestock (e.g., dairy cattle), or constraints in freshwater availability during climate events. In contrast, Moheshkhali displays a more even spread across medium to high consumption categories, with notable shares in 30 -39 liters (14%), 40 -49 liters (14%), and even 100 -109 liters (6%), pointing to larger livestock units or greater water-intensive activities.

The study participants said that in Assassuni, drinking saline water causes cows to diarrhea. As a result, people have to buy fresh water along with fodder for their livestock, which is costly. This can be a heavy burden for poor households. Temperature changes can also make poultry and livestock sick and even lead to their death. Additionally, excessive heat and rain affect cows' health and can cause strokes in chickens. Usually, women are mainly responsible for livestock rearing, and for widowed women, single mothers, and religious minorities, it is often their main source of income. So, when they feel unable to provide freshwater for their livestock, they are forced to sell them. Because of this, the livestock numbers in Assassuni drop significantly compared to Moheshkhali.

Qualitative findings identified that water management is limited by restricted and insecure irrigation access (often linked to inconsistent electricity supply and pumps), weak drainage and flood-control infrastructure, and fragmented governance that hampers integrated water resources management. Early-warning systems and community embankments offer some protection, but adaptation remains inconsistent and often superficial without scalable extension support, affordable stress-tolerant varieties, and dependable water storage solutions.

Moheshkhali, a barrier island in Cox's Bazar, faces a particularly fragile freshwater lens and heavy dependence on ponds and rainfall. The freshwater supply is narrow and highly susceptible to saltwater intrusion from storm surges and sea-level rise, with ponds and shallow groundwater turning brackish during dry spells and post-storm periods. Qualitative findings highlight that the water management is hampered by weak drainage, limited pumping capacity, and irregular electricity, which constrains irrigation timing and the operation of flood-control structures. The island's isolation and exposure to cyclones exacerbate encroachment of saltwater into irrigated areas and hinder timely post-disaster recovery of farming systems. In addition, Moheshkhali's agriculture often coexists with shrimp farming, which relies on brackish water and can compete for water resources and land use, further complicating water allocation.

FGD participants mentioned that the farmers have started using some salt-tolerant crops, brackish-water irrigation in select systems, and pond-based water harvesting. These practices are unevenly adopted due to cost, access to technology, and capacity gaps in extension services. FGD participants also identified that the water risks on Moheshkhali are characterized by a thin freshwater reserve, salinity pressure, and infrastructural and institutional gaps in drainage, storage, and Integrated water resource management (IWRM), which collectively reduce the resilience of the agricultural sector. The table below provides a snapshot of the qualitative findings regarding water risks and management conditions in the agriculture sector:

Table 5. Qualitative findings regarding water risks and management conditions in the agriculture sector

Location & Sector	Key Water Risks	Current Management Practices	Gaps/Limitations
Satkhira (Assasuni)-Crops	Salinity intrusion in groundwater and surface water; flooding/waterlogging; freshwater scarcity post-cyclone	Use of tubewell water for irrigation; some NGO water support; limited rainwater harvesting	Shallow aquifers becoming saline; small rainwater harvesting coverage; weak drainage systems
Satkhira (Assasuni)-Livestock	Contaminated water during floods, dehydration, and disease spread	Use of tubewell and pond water; temporary NGO water supply	Tubewells flood-contaminated; lack of protected livestock water storage
Cox's Bazar (Moheshkhali)-Crops	Pond and purchased water supply vulnerable to contamination and shortages; salinity intrusion; cyclone damage to water infrastructure	Irrigation from ponds and purchased freshwater; small private rainwater storage	Limited institutional support; dependence on private markets; ponds often brackish
Cox's Bazar (Moheshkhali)-Livestock	Loss of freshwater during cyclones; pond contamination; limited fodder water	Use of ponds and purchased water	High cost of purchased water; poor water quality control

In short, water risk management in these areas needs to focus on enhancing diversification of irrigation sources, improving water storage and drainage infrastructure, expanding affordable and accessible technologies, and strengthening institutional coordination. Effective management is critical to sustaining agricultural productivity, protecting livestock health, and safeguarding rural livelihoods against the increasing threats posed by climate variability and extreme weather events.

4.3 Examine the Water Risks and Management Conditions in Aquaculture in the Climate-Vulnerable Coastal Areas

In climate-vulnerable coastal areas, aquaculture faces significant water-related risks that challenge both production and sustainability. A recent study found that aquaculture, shrimp, open-water fish collection, and infrastructure are all vulnerable to disasters in coastal Bangladesh [10]. These risks are shaped by differing environmental and socio-economic contexts.

These risks are shaped by differing environmental and socio-economic contexts.

Qualitative findings highlight that, in Assasuni, Satkhira, aquaculture is heavily impacted by saltwater intrusion and fluctuating freshwater availability due to sea-level rise and altered hydrological patterns. The increasing salinity of groundwater and surface water limits options for freshwater aquaculture and forces reliance on brackish or saline water species. However, extreme events such as floods and cyclones often damage embankments and water control structures that regulate salinity in aquaculture ponds, leading to uncontrolled saltwater inflows or pond contamination. This disrupts breeding cycles and lowers productivity. Water management in Assasuni's aquaculture is further constrained by inadequate drainage systems, limited pumping capacity, and fragmented governance that restrict coordinated management of water resources across agricultural and aquaculture sectors. Although some farmers have adopted salt-tolerant species or hybrid systems, access to technology and institutional support remains weak. Additionally, contamination from floodwaters can introduce pathogens, impact fish health and increase disease risk.

In contrast, Moheshkhali in Cox's Bazar is characterized by extensive shrimp farming that inherently relies on brackish water, making aquaculture a dominant and economically important activity. However, this dependence on saline water heightens vulnerability to storm surges, cyclone-induced flooding, and salinity fluctuations, which can damage pond infrastructure and disrupt water exchange regimes critical for maintaining pond health. The freshwater lens beneath the island is thin and fragile, often turning brackish during dry spells or post-cyclone periods, complicating freshwater needs for aquaculture operations such as hatcheries or mixed farming. Water management challenges here include weak drainage systems, unreliable electricity supply affecting pump operation, and competition for limited freshwater resources between aquaculture, agriculture, and domestic use. Institutional support is limited, and reliance on private markets for water adds to operational costs. However, Moheshkhali farmers have shown some adaptive capacity by incorporating pond-based water harvesting and selective use of brackish water irrigation, although these practices are unevenly adopted due to cost and capacity barriers. The figure 11 below shows the types of fish cultivated in the targeted locations:

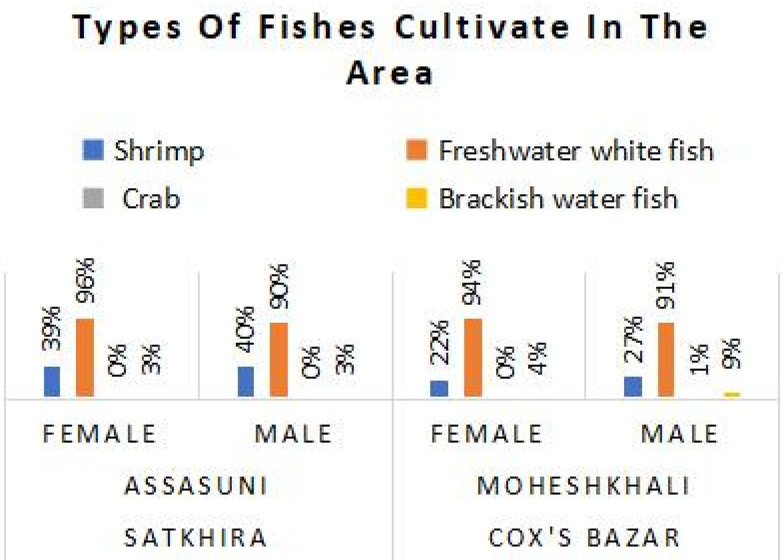


Figure 11. types of fish cultivated in the targeted locations

The figure 11 illustrates the types of fish cultivated by male and female farmers in two climate-vulnerable coastal locations: Assasuni in Satkhira and Moheshkhali in Cox's Bazar. In Assasuni, shrimp cultivation is dominant, especially among females (39%) and males (40%), while crab and freshwater white fish farming are minimal (0-3%). Brackish water fish cultivation is almost nonexistent in this area. In contrast, Moheshkhali shows a more diverse aquaculture profile. Female farmers primarily cultivate freshwater white fish (22%), with some shrimp (7%) and a small share of brackish water fish (4%). Male farmers in Moheshkhali lean heavily towards brackish water fish cultivation (91%), with minimal shrimp (1%) and freshwater white fish (9%). Crab cultivation remains negligible in both locations and genders. Overall, the data highlights that Assasuni's aquaculture is largely shrimp-focused, while Moheshkhali's farmers exhibit greater diversity, particularly among males who specialize in brackish water fish, reflecting adaptation to the different water salinity and resource conditions in these coastal areas. Local aquaculture specialist explained that when sweet and saltwater mix, it affects the different fish habitats, and since the water enclosures are not connected to rivers, there is no way for the water to drain out.

During FGD, female participants mentioned that due to high salinity in soil and water, high profitability in gher farming, many agri farmers converted their agri land into gher for fish farming. The figure below illustrates the quantitative finding that shows participants' perception regarding converting croplands into gher:

The figure 12 illustrates the reasons for converting cropland into gher (fish ponds) among male and female farmers. The primary reason across all groups is that "gher is more profitable,". In Satkhira, both male and female farmers think that "gher is more profitable" and "other crops do not grow because of salinity," indicating salinity as a major challenge there. The reason "other crops do not grow because of salinity" is notably high among females and males in Moheshkhali. This data highlights profitability as the main driver for conversion, but also emphasizes environmental challenges like salinity and saltwater intrusion impacting crop viability in these areas.

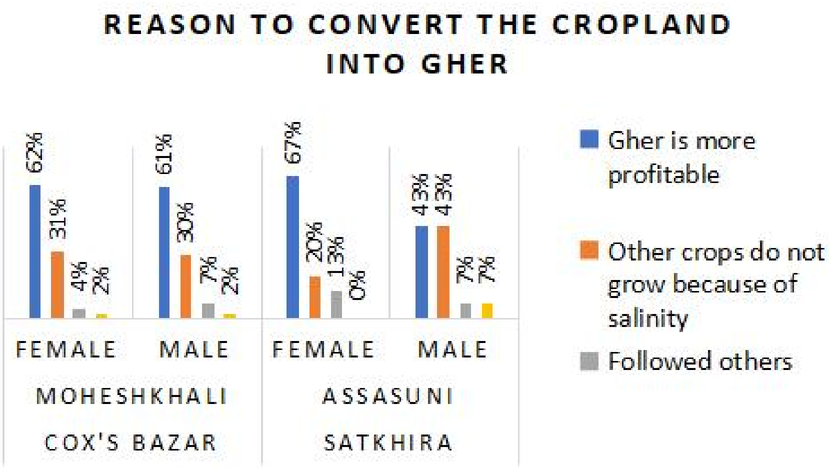


Figure 12. Reasons to convert cropland into gher

In summary, while both locations face salinity intrusion and infrastructure vulnerabilities, Assasuni's aquaculture is more constrained by the increasing salinization of traditionally freshwater systems and insufficient water control mechanisms. Moheshkhali's aquaculture, although more adapted to saline conditions, struggles with maintaining water quality and freshwater access critical for diversified aquaculture practices. Both areas suffer from weak integrated water resource management, fragmented governance, and limited extension services, which hinder effective, large-scale adaptation. Strengthening water infrastructure, improving institutional coordination, and expanding access to climate-resilient aquaculture technologies are essential to enhance water risk management and sustain aquaculture livelihoods in these climate-exposed coastal zones.

5. Conclusion

The study reveals that climate-vulnerable coastal regions such as Assasuni (Satkhira) and Moheshkhali (Cox's Bazar) face persistent and interlinked water risks across household, agriculture, and aquaculture sectors, with salinity intrusion emerging as the most pervasive threat. At the household level, water insecurity is shaped by seasonal variability, contamination risks, inadequate storage and purification practices, high costs, and the disproportionate burden on women for water collection, often in unsafe and time-consuming conditions. While rainwater harvesting, pond water, purchased water, and tubewells serve as key sources, their availability and quality are inconsistent, particularly in the dry season and during extreme events such as cyclones and floods. Limited institutional coverage, poor maintenance of infrastructure, and reactive coping strategies further constrain resilience. In agriculture, dependence on climate-sensitive water sources, predominantly rainwater leaves crop production and livestock management vulnerable to rainfall variability, saline water intrusion, and infrastructural gaps in drainage, storage, and irrigation systems. Moheshkhali exhibits somewhat greater source diversification than Assasuni, but both areas face high exposure to delayed monsoons, droughts, and storm surges. Livestock water scarcity not only affects productivity but also burdens households economically, particularly women-headed households. In aquaculture, Assasuni's freshwater-based systems are increasingly constrained by salinity intrusion and poor water control, while Moheshkhali's brackish-water systems, though better adapted, struggle with water quality maintenance, freshwater access for hatcheries, and infrastructure damage from extreme weather. The widespread conversion of cropland to aquaculture reflects both economic opportunity and the erosion of agricultural viability under salinity pressure.

Qualitative findings and walkthrough observation identified that across all sectors, water management is undermined by fragmented governance, inadequate infrastructure maintenance, and limited access to climate-resilient technologies. Existing coping mechanisms, such as selective water rationing, use of saline water for non-drinking purposes, and adoption of salt-tolerant species, are insufficient to address the scale and complexity of the risks. Without integrated water resource management, robust salinity control, equitable institutional support, and affordable, community-based solutions, these coastal communities will remain locked in a cycle of seasonal water stress, reduced productivity, and heightened vulnerability to climate change. Strengthening infrastructure, diversifying water sources, improving governance, and prioritizing gender-sensitive interventions are critical for safeguarding livelihoods and ensuring long-term water security in these regions.

Conflict of Interest Statement

The authors declare that there are no personal, financial, or professional conflicts of interest that could have influenced the design, data collection, analysis, interpretation, or reporting of the findings presented in this study on water risks and management conditions in the climate-vulnerable coastal regions of Moheshkhali and Assasuni of Bangladesh. The study was conducted with the sole purpose of generating unbiased, evidence-based insights for improving water security in the household, agricultural, and aquaculture sectors. All data and interpretations are presented independently, without influence from any governmental, non-governmental, or private sector entity that could benefit from the study outcomes.

Data Access Statement

The quantitative and qualitative data supporting the findings of this study on household, agricultural, and aquaculture water risks and management conditions in the climate-vulnerable coastal regions of Moheshkhali (Cox's Bazar) and Assasuni (Satkhira) were collected through structured household surveys, focus group discussions (FGDs), and key informant interviews (KIIs) conducted during the study period. The datasets include disaggregated gender-based statistics, seasonal comparisons of water sources, water purification practices, expenditure patterns, livestock and irrigation water usage, aquaculture species profiles, and perceived challenges in water access and management.

Due to the sensitive nature of the information, which contains personal and location-specific household data, the complete datasets are not publicly available to protect participant confidentiality. However, anonymized and aggregated data relevant to the study's objectives may be made available from the corresponding author upon reasonable request, subject to approval and compliance with ethical guidelines and data-sharing agreements.

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