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Salinity intrusion and disaster resilience in coastal agriculture: Impacts and adaptation strategies in Bangladesh

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ABSTRACT

Background: Salinity intrusion is a major environmental challenge in the coastal region of Bangladesh, threatening agricultural production, fisheries, livestock, and rural livelihoods. This study aimed to assess the causes and impacts of salinity intrusion on crop production, fisheries, and livestock, and to identify local adaptation strategies adopted by farmers in Baradal Union of Assasuni Upazila, Satkhira District. **Methods**: Primary data were collected through household surveys of 150 respondents and five key informant interviews (KIIs), complemented by secondary information from published literature and official reports. A purposive sampling technique was used, and the findings were analysed descriptively. **Findings:** The results revealed that the Kholpetua River is a major source of salinity intrusion, with more than 75% of respondents identifying it as the primary driver of increasing salinity in soil, surface water, and groundwater. Riverbank erosion and tidal flooding further exacerbate salinity levels, particularly during the dry season. Salinity has significantly reduced soil fertility, limited crop diversification, and adversely affected rice, vegetable, livestock, and freshwater fish production. Native freshwater fish species have declined substantially, while sheep and goat populations have decreased due to freshwater scarcity, fodder shortages, and disease prevalence. Farmers have adopted several adaptation measures, including salt-tolerant crop varieties, rainwater harvesting, crop calendar adjustment, raised-bed cultivation, and soil amendments. However, inadequate institutional support, limited technical knowledge, financial constraints, and governance-related barriers continue to hinder effective adaptation. **Conclusion**: Strengthening freshwater management, riverbank protection, climate-resilient agricultural practices, and farmer training programs is essential for enhancing resilience to salinity intrusion in coastal Bangladesh. **Novelty/Originality of this article:** This study provides a location-specific empirical assessment of the agricultural and livelihood impacts of salinity intrusion in Baradal Union and documents locally practiced adaptation strategies and barriers. The findings provide evidence to support locally appropriate adaptation planning and policy development in salinity-prone coastal areas.

KEYWORDS: adaptation; agriculture; coastal Bangladesh; livestock and fisheries; salinity intrusion.

1. Introduction

Salinity intrusion is one of the major environmental challenges affecting coastal regions worldwide, particularly in low-lying deltaic areas. The severity of salinity

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intrusion is expected to increase progressively due to climate change-induced factors such as sea-level rise, reduced upstream freshwater discharge, and the increasing frequency and intensity of cyclones and storm surges (Saito, 2001; Dasgupta et al., 2014; De Souza et al., 2015; Nicholls et al., 2016; Akter et al., 2019). In many Asian delta regions, including the Ganges Delta and the Mekong River Delta, rising sea levels and declining river flows are threatening agricultural productivity, especially rice cultivation (Wassmann et al., 2004; Haque, 2006; Phan et al., 2020). Bangladesh is highly vulnerable to salinity intrusion because of its geographical location, low elevation, and frequent exposure to cyclones and storm surges. Approximately 20% of the country's land area is coastal, and about 53% of this region is affected by varying degrees of salinity. The extent of salinity-affected land in Bangladesh has increased significantly over the decades, from 0.833 million hectares in 1973 to 1.020 million hectares in 2000, reaching 1.056 million hectares in 2009. Climate change is expected to further increase groundwater and river salinity in the southwestern coastal areas by 2050, affecting nearly 2.9 million people through shortages of safe drinking water and irrigation facilities. Storm surges associated with tropical cyclones are one of the principal drivers of salinity intrusion in coastal Bangladesh. These surges occur due to disturbances in sea level caused by intense cyclonic activity and atmospheric pressure changes (Alam et al., 2017; Kim et al., 2019; Ashrafuzzaman et al., 2022). Recurrent cyclones and tidal flooding introduce saline water into agricultural lands and freshwater ecosystems, causing severe environmental degradation and threatening food security. As a result, agricultural productivity in the coastal region has declined substantially, contributing to a negative nutritional balance and increased livelihood vulnerability (Mahmuduzzaman, 2014; Sharifuzzaman & Islam, 2024). Salinity intrusion has significant adverse effects on crop production, fisheries, livestock, and homestead vegetation. Coastal climatic hazards such as sea-level rise, saline water inundation, waterlogging, and cyclones reduce soil fertility and agricultural output. Increased salinity also affects livestock production, as higher temperatures and saline conditions reduce feed intake and productivity. Livestock species generally perform best within a temperature range of 10-30°C; however, temperatures above 30°C can reduce feed intake by 3-5% for every 1°C increase (Negacz et al., 2021). In addition, studies in Satkhira district have reported a yearly reduction of vegetation coverage by approximately 1.87% due to salinity-related stress on homestead forests. The expansion of shrimp farming in coastal Bangladesh has further intensified salinity intrusion. To cultivate saline-water shrimp, saline water is intentionally introduced into agricultural lands within polders, which has caused significant environmental, ecological, social, and economic problems (Rahman & Ahsan, 2001; Dutta & Iftekhar, 2004; Khan et al., 2006; Hoque et al., 2013; Ahmed & Diana, 2015a, 2015b). Shrimp farming currently occupies approximately 138,600 hectares of coastal land in the districts of Satkhira, Khulna, and Bagerhat. Consequently, the production of indigenous freshwater fish species such as rui, katla, boal, koi, shing, taki, and tengra has declined significantly because of increased salinity levels (Negacz et al., 2021).

From a disaster risk reduction perspective, salinity intrusion is considered a slow-onset climate-induced coastal hazard that interacts with exposure and vulnerability to influence agricultural production and rural livelihoods. Climate change, sea-level rise, cyclones, storm surges, reduced upstream freshwater flow, and anthropogenic activities jointly increase salinity in soil and water resources, thereby reducing agricultural productivity and increasing livelihood vulnerability. Farmers respond through a range of adaptation measures, including technological, agronomic, and livelihood-based strategies, which contribute to enhancing resilience. Guided by this conceptual framework, the present study examines the causes of salinity intrusion, its impacts on agriculture, fisheries, and livestock, and the adaptation strategies adopted by farming households in one of the most salinity-affected coastal areas of Bangladesh.

The southwestern coastal region of Bangladesh, particularly Assasuni Upazila of Satkhira District, experiences frequent tropical cyclones and associated storm surges originating from the Bay of Bengal (Dasgupta et al., 2010; Ashrafuzzaman et al., 2022).

Agriculture, which is the primary livelihood of local communities, has been severely affected by salinity intrusion. Increasing soil and water salinity negatively affect soil quality, irrigation systems, crop yield, fish production, livestock rearing, and the overall livelihoods of farming communities. Many farmers are unable to maintain agricultural production due to increasing salinity, lack of technical knowledge, inadequate infrastructure, and socio-political constraints. Reduced agricultural productivity has increased economic vulnerability, forcing many women to engage in outdoor labor, which also affects children's education and family wellbeing. Although local communities have adopted various adaptation strategies to cope with salinity intrusion, the effectiveness and sustainability of these practices require further assessment. Both indigenous and modern adaptation techniques are being practiced; however, limited research has comprehensively examined their effectiveness in mitigating the adverse impacts of salinity intrusion in Assasuni Upazila. Numerous studies have investigated the impacts of salinity intrusion on agriculture, water resources, and livelihoods in coastal Bangladesh, most have focused on individual sectors or broader regional assessments. Limited research has examined the integrated effects of salinity intrusion on crop production, livestock, fisheries, and farmers' adaptation strategies at the local level from a disaster risk and climate adaptation perspective. Moreover, evidence on the barriers that constrain effective adaptation in highly vulnerable coastal communities remains insufficient. This study addresses these gaps by providing a location-specific assessment of the causes and impacts of salinity intrusion and evaluating existing adaptation practices and institutional constraints in Baradal Union of Assasuni Upazila. Therefore, this study aims to assess the causes and impacts of salinity intrusion on agriculture, livestock, and fisheries, as well as to identify existing adaptation strategies adopted by farmers and local communities. The findings contribute to disaster risk reduction and climate adaptation planning by providing empirical evidence to support locally appropriate adaptation strategies and policy interventions in salinity-prone coastal regions.

By addressing these knowledge gaps, this study provides location-specific evidence on the causes, impacts, adaptation practices, and barriers associated with salinity intrusion. The findings will support disaster risk reduction, climate change adaptation planning, and evidence-based policy development for sustainable agricultural and livelihood management to enhance community resilience against future climate-induced disasters in coastal Bangladesh. Therefore, the specific objectives of this study are: 1. to identify the causes of salinity intrusion; 2. to assess the impacts of salinity intrusion on crop production, livestock, and fish production; and 3. to identify farmers' adaptation strategies to mitigate the adverse effects of salinity intrusion.

2. Methods

2.1 Study area

The study was conducted in Baradal Union of Assasuni Upazila, located in the Satkhira District in the southwestern coastal region of Bangladesh (Fig. 1). Baradal Union is characterized by unique geographical and socio-economic features and is highly vulnerable to salinity intrusion and other climate-induced hazards. The union covers an area of approximately 36.018 km^2 and is geographically located at 22°33′ N latitude and 89°10′5.16″ E longitude. Baradal Union is bordered by Shyamnagar Upazila to the south, Debhata and Satkhira Sadar Upazilas to the north, Koyra Upazila to the east, and Kaliganj Upazila to the west. The area is surrounded by several rivers and tidal channels, which significantly influence salinity levels, agricultural practices, and fish cultivation. Due to increasing salinity intrusion, the local community has developed various adaptation practices to cope with environmental and livelihood challenges. The economy of the area largely depends on agriculture, fisheries, and livestock rearing. However, these sectors are increasingly threatened by soil and water salinity. The union also has basic infrastructure facilities, including educational institutions, healthcare services, and road communication networks (BBS, 2011).

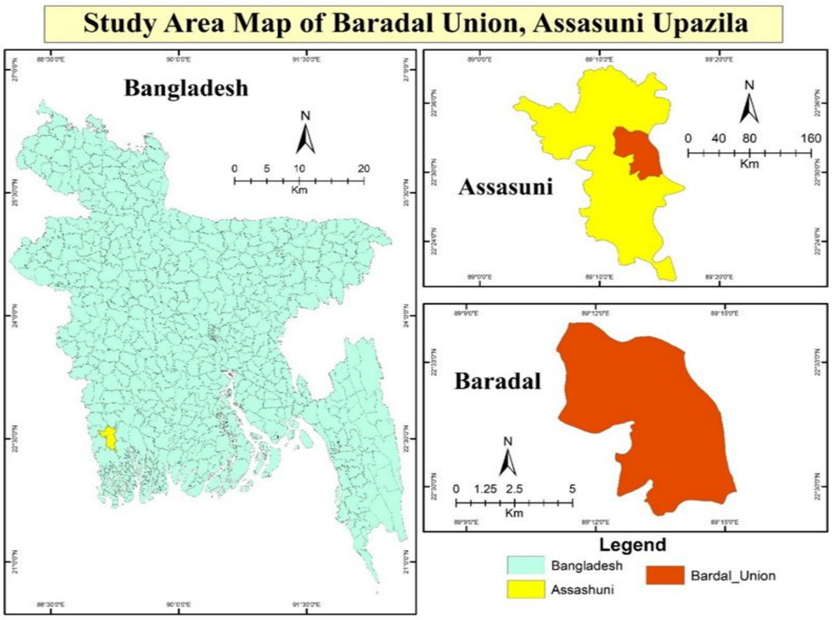

Fig. 1. Study area map of Baradal union at Assasuni upazila, Bangladesh

2.2 Criteria for the site selection

Assasuni Upazila consists of 11 unions, among which Baradal Union was purposively selected as the study area due to its high vulnerability to salinity intrusion and other climate-related disasters. A large proportion of the population in this union lives below the poverty line and depends primarily on climate-sensitive livelihoods such as agriculture and fisheries. Salinity intrusion has become one of the most severe environmental problems affecting agricultural production, freshwater availability, fish culture, and overall livelihoods in the area. According to the Bangladesh Bureau of Statistics (BBS, 2011), the total number of households in Baradal Union is approximately 5,850. The study area was selected to provide a location-specific assessment of the causes and impacts of salinity intrusion, as well as the adaptation strategies adopted by local farmers and communities.

2.3 Sampling design and sample size determination

The sample size for this study was determined using Cochran's (1963) sample size formula. The total number of households in Baradal Union was 5,850. A confidence level of 95%, a margin of error of 10%, and a standard deviation (p) of 0.5 were considered for the calculation. Total household, N =5,850; Confidence level= 95%; Margin of error, e= 10%; 95% level of significance, Z= 1.96; Estimated proportion of success, Standard deviation, P= 0.5; Estimated proportion of failure, q= (1-p) = 0.5

$$\text{Sample size, } n_o = \frac{(\chi^2 * p * q)}{e^2}$$
$$= \frac{1.96^2 * 0.5 * 0.5}{0.1^2}$$
$$= 96$$
$$\text{Adjusted, } n = \frac{n_o}{1 + \left[\frac{n_{o-1}}{N}\right]}$$
$$= \frac{96}{1 + \left[\frac{96-1}{5850}\right]}$$
$$= 94 \qquad \text{(Eq. 1)}$$

Although the calculated sample size was 94, the study conducted 150 household surveys to improve the reliability and validity of the findings. Cochran's (1963) formula was used to estimate the minimum sample size required for the study population. However, because the study specifically focused on farming households with direct experience of salinity intrusion, respondents were selected using purposive sampling rather than probability sampling. Thus, the sample size calculation was used only as a guide to ensure adequate sample coverage, while respondent selection was based on predefined eligibility criteria relevant to the research objectives. Eligible respondents were required to (i) reside permanently in Baradal Union, (ii) be directly involved in farming, livestock rearing, or aquaculture, (iii) have experienced the impacts of salinity intrusion, and (iv) be willing to participate voluntarily in the survey. Households were selected to capture respondents with practical knowledge of local agricultural practices and adaptation measures.

2.4 Methods of data collection

The structured questionnaire was developed based on the study objectives and an extensive review of relevant literature on salinity intrusion, agricultural adaptation, and coastal livelihoods. It consisted of both closed-ended and a limited number of open-ended questions covering household characteristics, causes and impacts of salinity intrusion, adaptation practices, institutional support, and perceived barriers to adaptation. Before the main survey, the questionnaire was pilot-tested with ten farming households outside the final sample to assess question clarity, wording, and logical flow. Based on respondents' feedback and expert suggestions from academic supervisors, minor modifications were made to improve content validity and readability before conducting the final survey.

Primary data were collected through face-to-face interviews using a structured questionnaire. A total of 150 respondents from separate households were surveyed by the researcher. Before conducting the interviews, the researcher established rapport with the respondents and clearly explained the objectives and purpose of the study using the local language to ensure better understanding and effective communication. Respondents were encouraged to provide accurate and honest responses without hesitation. Whenever respondents faced difficulties in understanding any question, necessary clarification was provided immediately. The researcher received valuable cooperation from the respondents and local community members throughout the data collection process. A total of five Key Informant Interviews (KIIs) were conducted with local experts, agricultural officers, community leaders, and experienced farmers to obtain in-depth information regarding the causes and impacts of salinity intrusion and the adaptation strategies practiced in the study area. The KIIs complemented the household survey by providing expert opinions, local experiences, and detailed contextual information related to agricultural practices, fisheries, livestock management, and climate adaptation in Baradal Union.

Secondary data were collected from various published and unpublished sources to develop the conceptual and analytical framework of the study. Relevant information was gathered from books, academic journals, research articles, reports, government publications, and reliable websites. The collected secondary data included information on the environmental context, salinity conditions, agricultural practices, crop patterns, socio-economic characteristics, and previous research findings related to salinity intrusion and climate change impacts in coastal Bangladesh.

2.5 Data analysis

Quantitative data were analysed using descriptive statistics, including frequencies, percentages, tables, and charts in Microsoft Excel 2010. ArcGIS was used to prepare the study area map. Qualitative information obtained from key informant interviews, field observations, and open-ended survey responses was analysed using thematic descriptive analysis to complement the quantitative findings. The study employed descriptive analyses to characterize respondents' perceptions, experiences, and adaptation practices and did not attempt to establish statistical causal relationships between variables.

2.6 Limitations of the study

This study was limited to Baradal Union of Assasuni Upazila; therefore, the findings may not fully represent all coastal areas of Bangladesh affected by salinity intrusion. In addition, the study primarily relied on selected farmers and households, which may limit the generalizability of the results. Several challenges were encountered during the field survey. Some respondents initially expected financial or material assistance from the researcher. When they understood that the research was conducted solely for academic purposes, a few respondents became less interested in providing information. Despite these limitations and challenges, the researcher conducted the study sincerely and systematically to ensure the reliability and validity of the findings. The predominance of male respondents reflects local agricultural decision-making patterns; however, it may have limited the representation of women's perspectives on salinity adaptation.

2.7 Ethical considerations

Ethical standards were strictly maintained throughout the research process. Prior to data collection, informed verbal consent was obtained from all respondents. Participants were informed about the objectives and purpose of the study and were assured that their identities and personal information would remain confidential and anonymous. Participation in the study was entirely voluntary, and respondents had the right to withdraw at any stage of the interview process. The researcher also ensured respect for local cultural values, social norms, and respondents' dignity throughout the fieldwork and data collection activities.

3. Results and Discussion

3.1 Population and socio-demographic characteristics

The study was conducted in Baradal Union of Assasuni Upazila under Satkhira District, Bangladesh. A total of 150 respondents participated in the survey. Among them, 90% were male and 10% were female respondents. The age distribution of the respondents indicates that 34% were between 20 and 40 years of age, 22.67% were between 40 and 50 years, while 43.33% were above 50 years old (Table 1). The findings suggest that a significant proportion of the respondents were elderly farmers with long-term experience in agriculture and exposure to salinity-related problems.

Educational attainment among the respondents was relatively low. Here 30% of the respondents had no formal education, 28.67% completed primary education, 17.33% completed secondary education, 15.33% completed higher secondary education, and only 8.67% had graduate-level or higher education. The high rate of illiteracy and low educational attainment may limit farmers' access to modern agricultural knowledge, climate information, and adaptation technologies. Agriculture was identified as the primary occupation of the respondents, accounting for 44.67% of the total respondents. In addition, 29.33% worked as laborers, 20% were involved in business activities, and 6% depended on fisheries for their livelihoods (Table 1). Other supplementary income-generating activities in the study area included poultry farming, livestock rearing, tailoring, and small-scale trading. The dominance of agriculture-based livelihoods indicates the high dependency of local communities on natural resources and climate-sensitive economic activities.

The housing condition of the respondents reflects their socio-economic vulnerability. Among the surveyed households, 34% lived in kutcha houses, 48.67% lived in semi-pucca tin-shed houses, and only 17.33% lived in pucca houses. The predominance of kutcha and semi-pucca housing structures indicates limited economic capacity and higher vulnerability to climate-induced hazards such as cyclones, flooding, and salinity intrusion. Regarding household size, 23.75% of households had fewer than four members, whereas 76.25% had four or more family members. However, the number of economically active household members was relatively low. About 58.75% of households had only one earning member, 35% had two earning members, and only 6.25% had three economically active members (Table 1). Larger household sizes combined with limited income earners increase economic pressure and reduce the adaptive capacity of households to cope with environmental stresses. The study findings indicate that the majority of the local population is highly dependent on agriculture for their livelihoods. At the same time, low literacy rates, large household sizes, limited income sources, and inadequate housing conditions contribute significantly to the socio-economic vulnerability of the community to salinity intrusion and other climate-related hazards.

Table 1. Population and socio-demographic characteristics of the respondents

Variables	No of Respondents	Percentage
Gender		
Male	135	90%
Female	15	10%
Age		
20 - 40 years	51	34%
40 – 50 years	34	22.67%
Above 50 years	65	43.33%
Main Occupation		
Labour	44	29.33%
Business	30	20%
Farming	67	44.47%
Fisheries	9	6%
Education level		
No formal education	45	30%
Primary	43	28.67%
Secondary	26	17.33%
Higher secondary	23	15.33%
Graduate or above	13	8.67%
House structure		
Kutcha	51	34%
Pucca	26	17.33%
Semi-pucca tin shed	73	48.67%

3.2 Causes of salinity intrusion

3.2.1 River-induced groundwater salinization

The study findings reveal that groundwater salinity is one of the major environmental problems in Baradal Union. Approximately 98% of the respondents reported that groundwater is unsuitable for drinking, irrigation, and household use due to excessive salinity. According to the respondents, the Kholpetua River is the principal source of salinity intrusion, as it carries saline water throughout the year. The river significantly contributes to the salinization of adjacent groundwater through continuous interaction between river water and shallow aquifers. Respondents indicated that groundwater within approximately 3 km of the river is highly saline and unsuitable for regular use. More than 50% of the respondents also stated that groundwater quality has gradually deteriorated over time due to increasing salinity intrusion. The increasing salinity of groundwater has created severe challenges for domestic water supply, irrigation, and agricultural productivity in the study area. The findings suggest that river-induced groundwater salinization is becoming an increasingly serious environmental and livelihood concern for coastal communities.

3.2.2 Seasonal severity and trends of salinity intrusion

The severity of salinity intrusion varies seasonally in the study area. The dry season, particularly from February to May, was identified as the most critical period for soil salinization, whereas the wet season was comparatively less affected due to increased rainfall and freshwater availability. The respondents identified major cyclonic events such as Cyclone Sidr in 2007, Cyclone Aila in 2009, and several cyclones occurring between 2019 and 2024 as significant contributors to increased salinity intrusion in the area. These disasters introduced large volumes of saline water into agricultural lands, ponds, and surrounding ecosystems, causing long-term environmental degradation. Most respondents reported that soil salinity has increased noticeably over the last five years. More than 50% of agricultural land in the study area is currently affected by salinity to varying degrees. Farmers reported that land utilization is mainly possible during the wet season when Aman rice is cultivated. During the remaining months of the year, a large portion of agricultural land remains fallow due to high salinity levels and lack of freshwater for irrigation. The findings indicate that seasonal variation, combined with repeated cyclonic events and saline water intrusion, has significantly reduced agricultural productivity and land-use efficiency in the study area.

3.2.3 Major drivers of salinity intrusion

The study identified several major factors currently responsible for salinity intrusion in Baradal Union, including riverbank erosion, tidal flooding, poor drainage systems, and storm surges. Among these factors, riverbank erosion was identified as the most significant driver, reported by 56.25% of the respondents (Fig. 2). Riverbank erosion occurs mainly due to changing river morphology, siltation, flooding, and strong water currents. The erosion process damages riverbanks and alters river channels, allowing saline water to spread into adjacent agricultural lands and water bodies. Consequently, both soil and water salinity increase, reducing land suitability for crop cultivation and negatively affecting agricultural productivity. Tidal flooding was identified as the second major cause of salinity intrusion, reported by 20% of the respondents. During high tides, especially in the wet season, saline river water enters low-lying agricultural fields and surrounding areas. When saline water remains stagnant for extended periods, salt accumulates in the soil, reducing soil fertility and adversely affecting seed germination, plant growth, and crop yields.

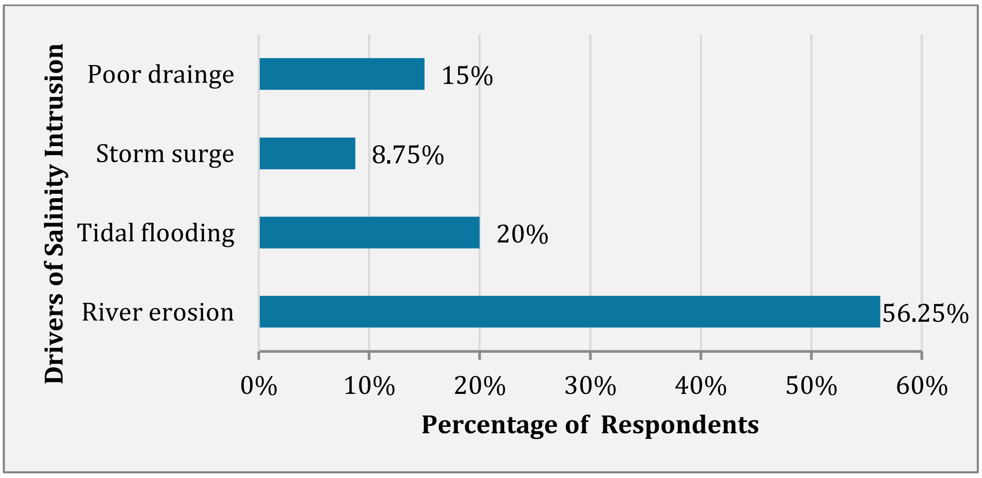

Fig. 2. Major factors contributing to salinity intrusion in the study area

Poor drainage conditions were reported by 15% of the respondents as another important factor contributing to salinity intrusion. Silted canals, blocked waterways, and inadequate drainage infrastructure prevent the proper removal of saline water from agricultural lands. As a result, saline water becomes stagnant in crop fields, increasing long-term soil salinity. Storm surges were reported by 8.75% of the respondents. During cyclones and extreme weather events, saline seawater is pushed inland through rivers and coastal embankments. This sudden intrusion of saline water severely damages agricultural lands, freshwater ponds, vegetation, and local infrastructure. Overall, the combined effects of riverbank erosion, tidal flooding, poor drainage, and storm surges are accelerating salinity intrusion in Baradal Union. These processes are creating significant environmental and socio-economic challenges for agriculture, fisheries, livestock production, and local livelihoods.

3.2.4 Hazard calendar

The hazard calendar illustrates the seasonal occurrence and interrelationship of major environmental hazards in the study area (Fig. 3). The findings indicate that salinity intrusion is strongly associated with several climate-induced hazards and environmental processes throughout the year.

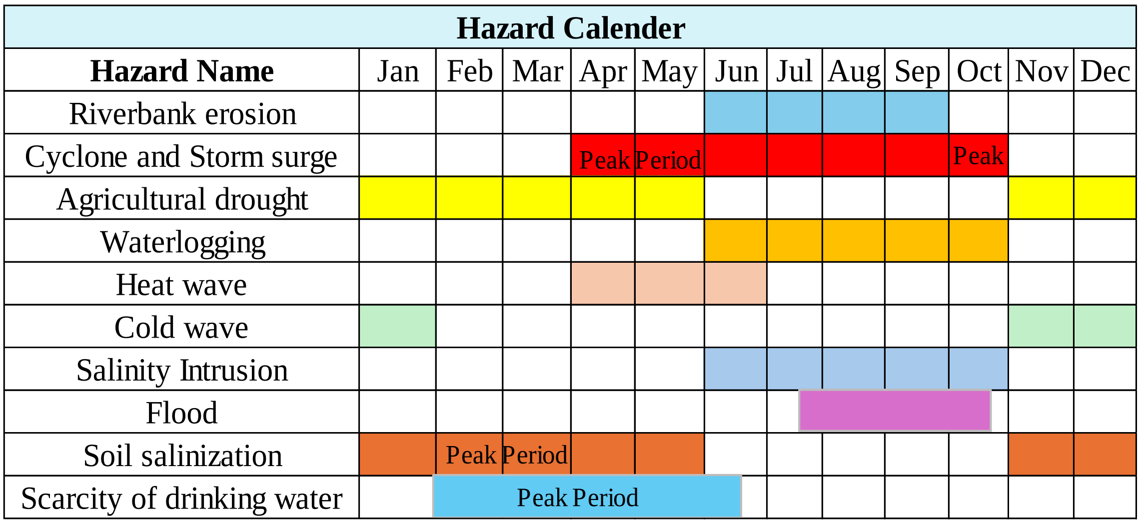

Fig. 3. Seasonal hazard calendar of the study area

Salinity intrusion becomes most severe during the dry season, particularly from February to May, when freshwater flow decreases significantly and soil salinity increases due to high evaporation and reduced rainfall. During this period, agricultural lands experience acute moisture stress and reduced soil productivity. The study area is also highly vulnerable to cyclones and storm surges, which are most frequent and intense from April to October. These extreme events accelerate salinity intrusion by inundating agricultural lands, ponds, and surrounding environments with saline water. As a result, long-term soil degradation and freshwater contamination occur in many parts of the region. Riverbank erosion and waterlogging are particularly prominent during the monsoon season, especially from June to October. These hazards further aggravate salinity intrusion by facilitating the movement, stagnation, and accumulation of saline water in agricultural fields and nearby water bodies. Poor drainage systems and prolonged waterlogging increase soil salinity and reduce the suitability of land for crop cultivation. In addition, scarcity of safe drinking water becomes severe during the dry season, particularly between February and May, due to declining freshwater availability and increased salinity in both surface and groundwater sources. This creates significant challenges for domestic water use and public health in the local community. Overall, the hazard calendar demonstrates that salinity intrusion is not an isolated environmental issue; rather, it is closely interconnected with cyclones, storm surges, riverbank erosion, waterlogging, and seasonal freshwater scarcity. These combined hazards intensify environmental vulnerability and negatively affect agriculture, livelihoods, and human wellbeing in Baradal Union.

3.3 Impacts of salinity intrusion on crop production, livestock, and fish production

The findings of the study indicate that salinity intrusion has significant adverse impacts on agriculture, livestock, fisheries, and overall rural livelihoods in Baradal Union. Increasing soil salinity has reduced soil fertility, degraded soil health, and decreased agricultural productivity. Salinity intrusion has also created severe shortages of fresh drinking water and fodder, increased the prevalence of livestock diseases, and reduced livestock ownership and income generation opportunities. In the fisheries sector, increased salinity has negatively affected native freshwater fish species and reduced overall fish biodiversity. Many freshwater fish species are gradually disappearing due to changes in water salinity and habitat conditions. These combined impacts have increased the socio-economic vulnerability of farming households in the study area.

3.3.1 Impacts of salinity intrusion on crop production

The study reveals that the majority of farmers (75.61%) cultivate their own agricultural land, while 21.95% cultivate leased land and only 2.44% practice sharecropping. This finding indicates that most farmers have ownership control over their land, which may encourage them to adopt long-term adaptation strategies to cope with salinity intrusion and other environmental challenges. However, more than 50% of agricultural land in the study area is affected by salinity, making year-round cultivation difficult. As a result, farmers mainly utilize their land during the wet season for Aman rice cultivation, while a substantial portion of land remains fallow during the dry season due to excessive soil salinity and lack of freshwater for irrigation. The increasing extent of fallow land reflects declining agricultural productivity and reduced land-use efficiency caused by salinity intrusion. This situation has negatively affected household income, food security, and livelihood sustainability in the study area. The study found that 53.66% of farmers operate small- to medium-sized farms ranging from 2 to 5 bighas. Approximately 24.39% of farmers own less than 2 bighas of land, while only a small proportion of farmers possess larger farms exceeding 6 bighas (Fig. 4). These findings indicate that agriculture in the study area is predominantly characterized by smallholder farming systems.

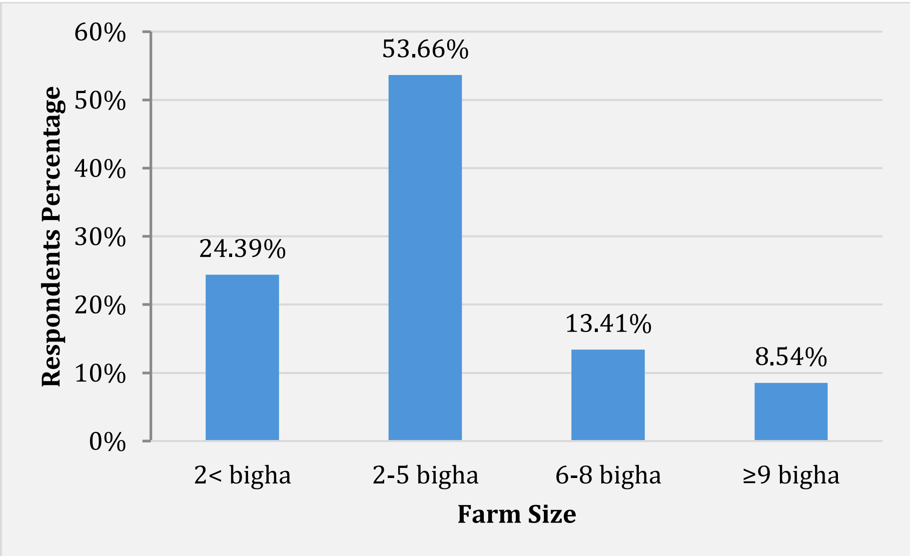

Fig. 4. Farm size distribution among the respondents in the study area

Salinity intrusion has significantly reduced the effective use of agricultural land. Many farmers are reluctant to cultivate large areas because high soil and water salinity increase the risks of crop failure, low agricultural yield, and financial losses. In addition, frequent climate-induced hazards such as tidal flooding, waterlogging, riverbank erosion, and storm surges have made agricultural activities increasingly uncertain and risky. Consequently, farmers often prefer to cultivate only limited and manageable portions of their land. The study also found that the majority of farmers (68.29%) depend primarily on rainfed agriculture, while 29.27% use canal water for irrigation and only 2.44% rely on groundwater sources. This finding suggests that farmers are highly dependent on rainfall and surface water because groundwater is largely unsuitable for irrigation due to excessive salinity. Limited access to freshwater irrigation restricts dry-season cultivation and increases farmers' vulnerability to salinity-induced crop losses. The dependence on rainfed agriculture also makes local farming systems highly sensitive to seasonal rainfall variability and climate change impacts.

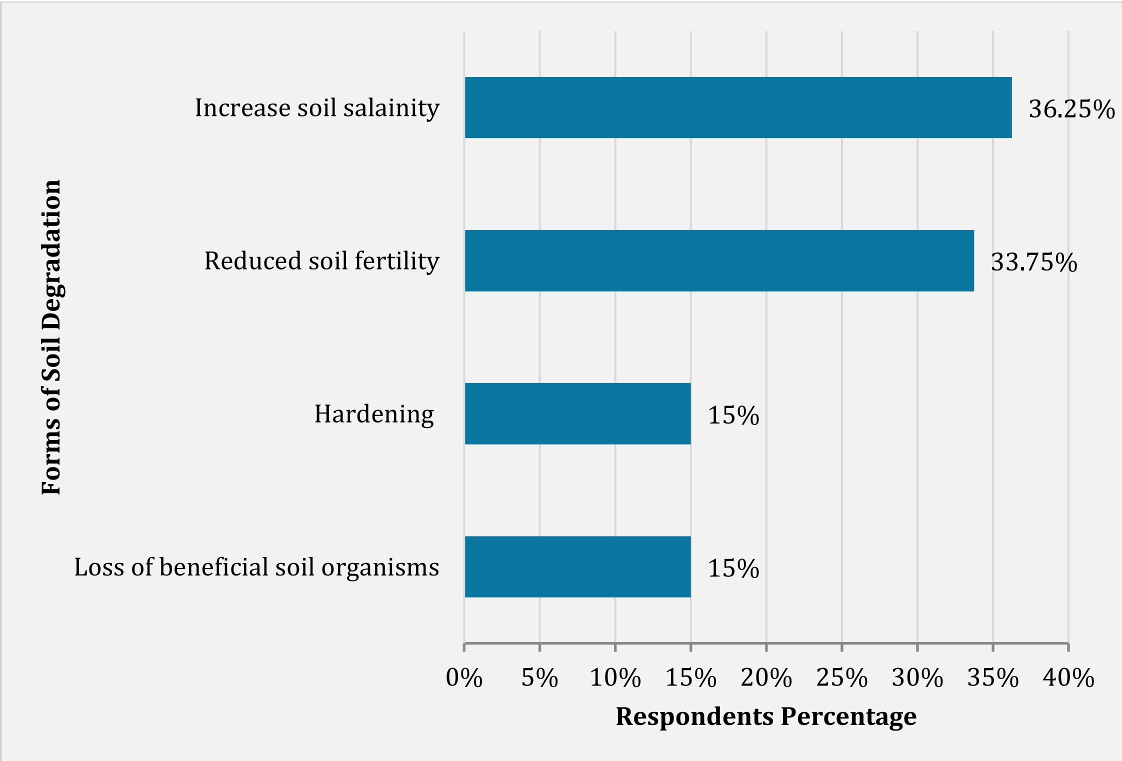

Fig. 5. Major forms of soil degradation caused by salinity intrusion in the study area

The study findings indicate that increasing soil salinity is the most significant soil-related problem in the study area. Approximately 36.25% of the respondents identified increasing soil salinity as the major cause of soil degradation, followed by reduced soil fertility, which was reported by 33.75% of the respondents. In addition, soil hardening and the loss of beneficial soil organisms were each reported by 15% of the respondents (Fig. 5). The results suggest that salinity intrusion is severely degrading soil health and reducing agricultural productivity in Baradal Union. Excessive salt accumulation in the soil negatively affects soil structure, nutrient availability, water retention capacity, and microbial activity. As a result, crop growth and overall land productivity decline significantly. Soil hardening caused by salinity reduces soil permeability and makes land preparation more difficult for cultivation. Furthermore, the decline of beneficial soil organisms adversely affects natural soil fertility and ecological balance. Similar findings regarding the impacts of salinity on soil degradation were also reported by Arslan & Demir (2013). Overall, increasing salinity is emerging as a major threat to sustainable agriculture in the study area, contributing to declining crop productivity and increasing environmental vulnerability.

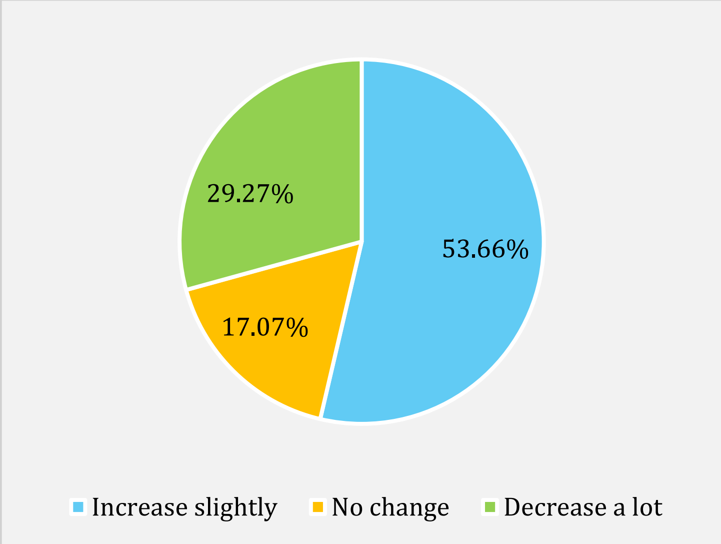

Fig. 6. Changes in crop yield compared to the last five years

The study reveals mixed trends regarding changes in crop yield over the last five years. More than half of the respondents (53.66%) reported a slight increase in crop yield, while 29.27% observed a significant decrease in yield and 17.07% reported no noticeable change (Fig. 6). The slight increase in crop production reported by many farmers may reflect the gradual adoption of various adaptation measures, including the use of chemical fertilizers, pesticides, improved irrigation practices, and salt-tolerant crop varieties. These adaptation strategies have helped some farmers maintain or moderately improve agricultural production despite increasing salinity levels. However, the study also found that these adaptation measures have substantially increased agricultural input costs. Farmers are required to invest more in fertilizers, pesticides, irrigation, and improved seeds to sustain crop productivity under saline conditions. Consequently, production costs have increased significantly, reducing overall profit margins for smallholder farmers. On the other hand, a considerable proportion of respondents reported declining crop yields due to persistent soil salinity, inadequate freshwater availability, and recurrent climate-related hazards such as waterlogging, tidal flooding, and cyclones. These environmental stresses continue to affect agricultural sustainability and food security in the study area. The findings indicate that although adaptation practices may partially reduce the adverse effects of salinity intrusion, farming systems in the area remain highly vulnerable and economically challenging.

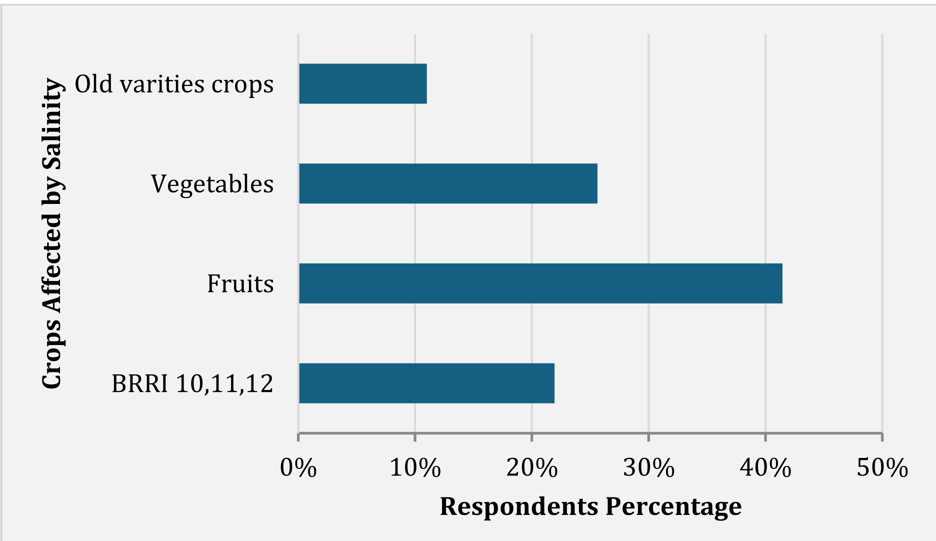

Fig. 7. Major crops affected by salinity intrusion in the study area

The study findings indicate that fruit crops are the most severely affected by salinity intrusion in the study area. Approximately 41.46% of the respondents identified fruits as the most vulnerable crop category to saline conditions (Fig. 7). Only a limited number of fruit species, such as coconut, date palm, guava, jujube, and tamarind, are able to survive and produce under saline soil conditions. Vegetable crops were identified as the second most affected category, reported by 25.61% of the respondents. Common vegetables cultivated in the area, including tomato, chili, brinjal, cucumber, and cauliflower, are highly sensitive to elevated soil and water salinity. Salinity stress negatively affects seed germination, plant growth, flowering, and overall crop productivity. Rice production is also significantly affected by salinity intrusion. Approximately 21.93% of respondents reported that commonly cultivated rice varieties, including BRRI dhan10, BRRI dhan11, and BRRI dhan12, are adversely affected because these varieties are not widely recognized as highly salt-tolerant. Increasing soil and water salinity create stress during germination, vegetative growth, and grain formation stages, resulting in lower crop yields and reduced production efficiency. The findings are consistent with the study of Negacz et al. (2021), which reported that salinity intrusion has reduced wheat production by approximately 4.42 million tons annually and contributed to the disappearance of 19 out of 40 traditional rice varieties in the coastal region of Bangladesh. Overall, the results demonstrate that salinity intrusion is significantly altering cropping patterns and reducing agricultural diversity and productivity in the study area.

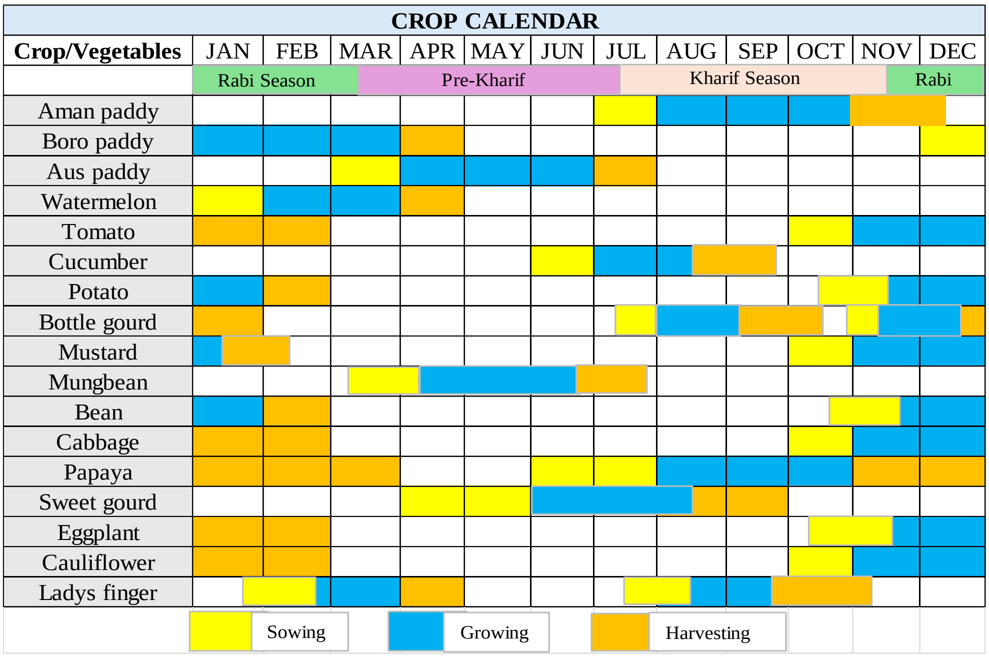

Fig. 8. Seasonal crop calendar of the study area

The crop calendar illustrates the seasonal patterns of sowing, growing, and harvesting periods of major crops cultivated in the study area (Fig. 8). In the calendar, yellow indicates the sowing period, blue represents the growing period, and golden color indicates the harvesting period. Paddy is the dominant crop cultivated in the study area. Aman rice is primarily cultivated during the Kharif season and is grown by approximately 99% of the farmers. In contrast, Boro rice in the dry season and Aus rice in the pre-Kharif season are cultivated by only about 3% of the respondents due to salinity-related constraints and limited freshwater availability. Vegetables are mainly cultivated during the Rabi season when salinity levels are relatively lower and climatic conditions are more favorable. However, during the dry season, particularly from February to May, salinity becomes more severe because of reduced freshwater flow, high evaporation rates, and limited irrigation water availability. Consequently, many crops experience difficulties in germination, growth, and yield formation during this period. Due to severe dry-season salinity, farmers often avoid cultivating salinity-sensitive crops, and a substantial portion of agricultural land remains fallow. The crop calendar also reflects local adaptation practices adopted by farmers to cope with salinity intrusion. Many farmers adjust their sowing, growing, and harvesting periods to avoid peak salinity months. In addition, short-duration crops and relatively salt-tolerant vegetation are cultivated during periods when salinity levels are comparatively lower. Overall, the findings suggest that farmers in the study area are modifying cropping patterns and agricultural practices according to seasonal salinity variations as an important adaptation strategy to sustain agricultural production under changing environmental conditions.

3.3.2 Impacts of salinity intrusion on livestock

Livestock rearing is a common livelihood practice in the study area. The survey findings indicate that approximately 96% of the respondents are involved in livestock rearing, while only 4% reported that they do not own livestock. The study found that salinity intrusion has negatively affected livestock ownership and income generation in the area. Respondents reported a significant decline in the population of sheep and goats due to increasing salinity, scarcity of fodder, and inadequate freshwater availability. In contrast, the number of cattle has remained relatively stable, with most households continuing to own approximately 4-7 cows for household income generation and agricultural purposes. Despite the continued practice of livestock rearing, farmers reported that maintaining livestock has become increasingly difficult and costly because of salinity-related environmental stresses. Reduced grazing land, fodder shortages, and water scarcity have significantly affected livestock productivity and household income.

The study identified several major challenges associated with livestock rearing under increasing salinity conditions (Fig. 9). Lack of fresh drinking water was reported as the most serious challenge by 45% of the respondents. Increasing salinity in both surface water and groundwater sources has made water unsuitable for livestock consumption. During the dry season, freshwater scarcity becomes more severe, forcing farmers to travel long distances to collect safe drinking water for their animals. Food and fodder scarcity was identified as the second major challenge, reported by 22.5% of the respondents. Salinity intrusion damages grazing land and reduces the growth of fodder crops and natural grasses. In addition, seasonal droughts, flooding, and waterlogging further limit the availability of green feed and grazing resources.

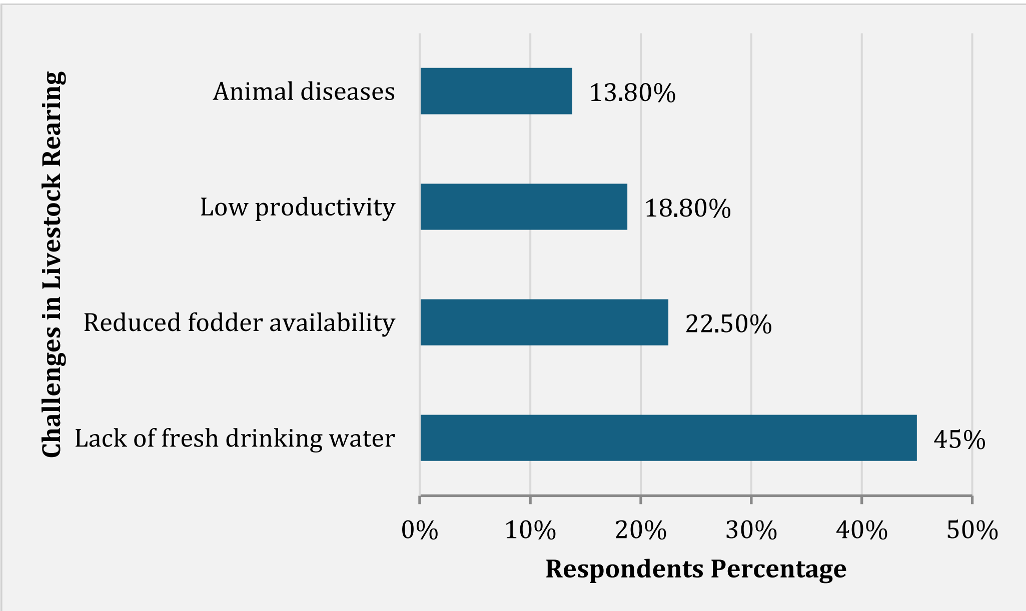

Fig. 9. Major challenges in livestock rearing due to salinity intrusion

Low livestock productivity was reported by 18.8% of the respondents. Poor nutrition, inadequate access to freshwater, and physiological stress caused by saline conditions contribute to reduced milk production, slower growth rates, and declining reproductive performance among livestock. Animal diseases were reported by 13.8% of the respondents as another important challenge. Salinity-related stress, poor feeding conditions, and lack of clean drinking water increase livestock vulnerability to diseases and health complications. Limited veterinary services and inadequate livestock management practices further intensify these problems. Overall, the findings indicate that salinity intrusion is creating substantial challenges for livestock production in the study area by reducing freshwater availability, fodder resources, livestock productivity, and household income opportunities.

3.3.3 Impacts of salinity intrusion on fish and aquaculture

The study found that only 42% of the respondents are involved in fish or shrimp farming activities. Among them, the majority practice brackish water aquaculture, particularly shrimp, crab, and tilapia farming. The increasing prevalence of brackish water aquaculture reflects farmers' adaptation to rising salinity conditions in the study area. However, excessive shrimp and brackish water farming may further aggravate environmental degradation by increasing soil and water salinity, reducing freshwater availability, and negatively affecting long-term agricultural sustainability. The intentional introduction of saline water into aquaculture ponds contributes to the spread of salinity into adjacent agricultural lands and freshwater ecosystems. The study also revealed that salinity intrusion has had a greater negative impact on native freshwater fish species such as shing, chang, koi, and other indigenous species. Increasing salinity levels in rivers, canals, ponds, and wetlands have degraded freshwater aquatic habitats and reduced the survival and reproduction of freshwater fish. Similar findings were reported by Negacz et al. (2021), who observed that the production of native freshwater fish species, including rui, katla, carp, boal, golsha tengra, koi, shing, taki, khalisha, potka, kani magur, tengra, and salbaim, is gradually declining due to increasing salinity in the coastal regions of Bangladesh. Overall, the findings suggest that salinity intrusion is gradually transforming traditional freshwater fisheries into brackish water-based aquaculture systems in the coastal region.

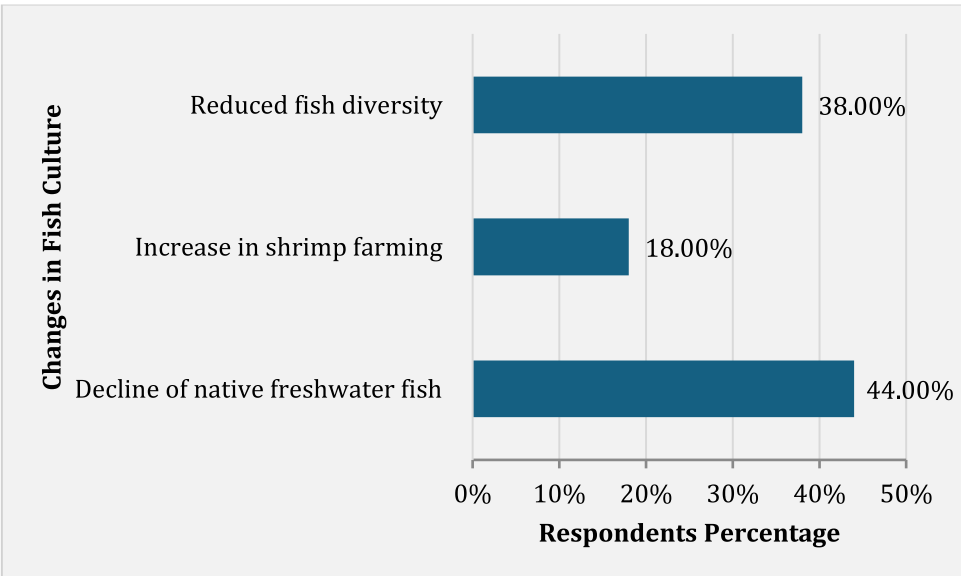

Fig. 10. Observed changes in fish culture due to salinity intrusion

The study findings indicate that salinity intrusion has substantially altered fish culture practices and aquatic biodiversity in the study area. The most significant observed change was the decline of native freshwater fish species, reported by 44% of the respondents. In addition, 38% of respondents observed a reduction in overall fish diversity in local water bodies. At the same time, 18% of the respondents reported an increase in shrimp farming, indicating a gradual shift toward brackish water aquaculture as an adaptive response to increasing salinity conditions (Fig. 10). Farmers are increasingly adopting shrimp and crab farming because these species are more tolerant to saline environments and often provide higher economic returns compared to freshwater fish culture. However, the expansion of brackish water aquaculture has also contributed to the degradation of freshwater ecosystems. Rising salinity levels are threatening indigenous fish species and reducing aquatic biodiversity by altering habitat conditions, water quality, and breeding environments. The findings suggest that salinity intrusion is not only changing aquaculture practices but also significantly affecting ecological balance, freshwater fish production, and the sustainability of traditional fisheries-based livelihoods in the study area.

3.4 Adaptation strategies

The study findings indicate that farmers in the study area have adopted a variety of adaptation strategies to reduce the adverse impacts of salinity intrusion on agriculture, livestock, and fisheries. In crop production, commonly practiced adaptation measures include the cultivation of salt-tolerant crop varieties, rainwater harvesting, changes in cropping calendars, application of chemical amendments, mulching, sorjan methods, cultivation of short-duration high-yielding variety (HYV) crops, and raised-bed cultivation techniques. In the livestock sector, most respondents prefer rearing cattle and poultry because these are comparatively manageable and economically important sources of household income and food security. In fisheries and aquaculture, farmers are increasingly shifting toward brackish water aquaculture, particularly shrimp, crab, and tilapia farming, as an adaptive response to increasing salinity conditions.

3.4.1 Adaptation strategies in crop production

The findings reveal that farmers in the study area are adopting different crop-based adaptation strategies to cope with salinity intrusion and sustain agricultural production (Fig. 11). Among these strategies, the cultivation of salt-tolerant crop varieties was identified as the most widely practiced adaptation measure. Farmers are increasingly adopting salt-tolerant rice and vegetable varieties to maintain crop productivity under saline conditions. Rainwater harvesting is another important adaptation strategy, which helps farmers store freshwater for irrigation and household use during the dry season when freshwater scarcity becomes severe. Improved drainage systems are also practiced to reduce waterlogging and remove saline water from agricultural fields. In addition, many farmers apply chemical amendments and compost to improve soil fertility and reduce the negative effects of soil salinity on crop growth.

Changing the crop calendar is another important adaptation measure. Farmers adjust sowing and harvesting periods to avoid peak salinity months and unfavorable climatic conditions. The cultivation of short-duration HYV crops allows farmers to complete crop production within shorter periods when salinity levels are relatively lower. Other adaptation strategies practiced in the study area include agroforestry, mulching, raised-bed cultivation, and limited use of groundwater for irrigation. Agroforestry and mulching help improve soil moisture retention and reduce evaporation, while raised-bed cultivation reduces direct salt accumulation around crop roots. Overall, the findings suggest that farmers are combining indigenous knowledge with modern agricultural practices to adapt to increasing salinity intrusion. However, despite these adaptation efforts, agricultural production in the study area remains highly vulnerable to climate-induced salinity and environmental hazards.

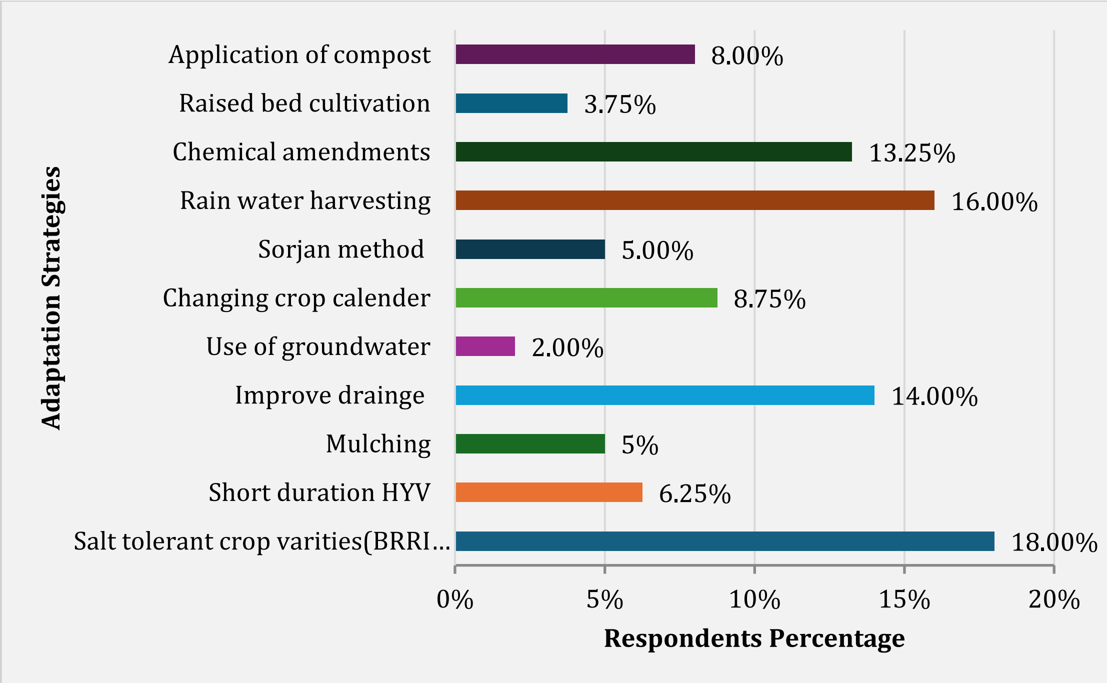

Fig. 11. Current adaptation strategies adopted in crop production in the study area

The cultivation of salt-tolerant crop varieties is the most widely practiced adaptation strategy in the study area, adopted by approximately 18% of the respondents. Farmers commonly cultivate salt-tolerant rice varieties such as BRRI dhan23, BRRI dhan40, BRRI dhan41, and BRRI dhan47 because these varieties are comparatively more resilient to saline soil conditions. Under increasing salinity stress, conventional crop varieties often experience poor seed germination, weak plant growth, and reduced productivity. In contrast, salt-tolerant varieties enable farmers to continue agricultural production under saline conditions and reduce the risk of crop failure. The adoption of these varieties has therefore become an important adaptation measure for sustaining crop production in the coastal region. Similar findings were reported by Hossain et al. (2018) and Rabbani et al. (2013), who observed that salt-tolerant crop varieties and crop diversification are widely practiced local adaptation measures against moderate salinity intrusion in coastal Bangladesh.

Rainwater harvesting is the second most widely adopted adaptation strategy, practiced by 16.25% of the respondents. This strategy is particularly important because both groundwater and river water in the study area are highly saline and often unsuitable for irrigation and household use. Farmers collect and store rainwater in ponds, mini-ponds, and other water storage systems during the monsoon season. The stored freshwater is then used for irrigation during the dry season when freshwater scarcity becomes severe. Rainwater harvesting helps maintain crop growth, improve soil moisture conditions, and reduce dependency on saline water sources. Hossain and Zaman (2018) also identified rainwater harvesting, pond sand filters, and pond excavation as effective adaptation measures for areas experiencing salinity levels ranging from 7 to 20 ppt. Local communities additionally suggested the use of khas lands for freshwater storage during the monsoon season.

Improved drainage systems are practiced by approximately 14% of the respondents. Poor drainage conditions increase waterlogging and allow saline water to remain stagnant in agricultural fields for extended periods, which intensifies soil salinity and reduces crop productivity. To address this problem, farmers improve drainage canals and remove stagnant saline water from agricultural lands. Effective drainage systems help reduce salt accumulation in the soil, improve soil conditions, and increase the suitability of land for crop cultivation.

Approximately 13.25% of the respondents reported using chemical amendments as an adaptation strategy against soil salinity. Farmers apply materials such as gypsum and lime to improve soil quality and reduce the harmful effects of salinity on crop production. These amendments help improve soil structure, reduce soil toxicity, enhance nutrient availability, and increase soil permeability. As a result, crop growth and productivity can be improved under saline conditions. Similar findings were reported by Lam et al. (2022), who noted that fertilizers and soil amendments play an important role in adapting agricultural cultivation to saline environments. Commonly used chemical fertilizers and amendments include urea, sulfate, gypsum, potash, diammonium phosphate (DAP), and triple superphosphate (TSP).

Changing the crop calendar is another important adaptation strategy, adopted by 8.75% of the respondents. Farmers adjust sowing, growing, and harvesting periods to avoid peak salinity months and periods of freshwater scarcity. By shifting cultivation to comparatively favorable periods, farmers can reduce crop damage and improve agricultural productivity. One notable indigenous adaptation practice observed in the study area is the relay mustard cultivation system. In this method, farmers sow mustard seeds into standing Aman rice fields approximately 7–10 days before harvesting the rice crop. This technique allows farmers to utilize residual soil moisture and enables mustard plants to establish immediately after paddy harvesting.

Farmers generally require about 700–800 grams of mustard seed per bigha of land. The production cost is relatively low, approximately BDT 1,500–2,000 per bigha, because the method does not require additional ploughing or extensive land preparation. At the same time, farmers can earn a profit of approximately BDT 8,000–10,000 per bigha from mustard cultivation. The relay mustard system demonstrates how local farmers are integrating indigenous agricultural knowledge with seasonal adaptation practices to cope with salinity intrusion and maximize land utilization under challenging environmental conditions.

The application of compost is practiced by approximately 8% of the respondents as an adaptation strategy to combat the adverse effects of salinity. Compost improves soil fertility by increasing soil organic matter content, enhancing nutrient availability, and improving soil structure. It also helps retain soil moisture, which is particularly important in saline environments where water availability is limited. Since many households in the study area are involved in livestock rearing, compost is readily available and represents a cost-effective and environmentally sustainable soil management option. The use of organic amendments such as compost contributes to improving soil health and maintaining agricultural productivity under saline conditions.

Approximately 6.25% of the respondents reported cultivating short-duration high-yielding variety (HYV) crops as an adaptation measure. Commonly cultivated varieties include BRRI dhan49, BRRI dhan56, and BRRI dhan57. These varieties complete their life cycles within a shorter growing period, enabling farmers to harvest crops before salinity levels become severe during the dry season. The cultivation of short-duration HYVs reduces the exposure of crops to prolonged salinity stress and helps farmers maintain agricultural production despite increasingly challenging environmental conditions.

The Sorjan method is practiced by approximately 5% of the respondents. This is an integrated farming system in which raised beds and adjacent canals are constructed simultaneously to facilitate both crop cultivation and fish production. The method is particularly suitable for coastal and waterlogged areas where salinity and seasonal flooding frequently affect agricultural activities. Raised beds are used for cultivating vegetables and other crops, while the canals serve as water reservoirs and support fish culture. This integrated approach increases land-use efficiency, diversifies income sources, and enhances resilience to environmental stresses.

Mulching is practiced by approximately 5% of the respondents as a soil and water conservation technique. In this method, the soil surface is covered with straw, crop residues, leaves, or other organic materials. Mulching reduces soil moisture loss through evaporation, conserves water, moderates soil temperature, and restricts the upward movement of salts to the soil surface. Consequently, it helps maintain favorable soil conditions for crop growth under saline environments. Farmers commonly apply mulching in the cultivation of crops such as elephant foot yam, taro, potato, and ginger, which are sensitive to moisture stress and soil salinity.

Raised-bed cultivation is practiced by approximately 3.75% of the respondents. Under this method, crops are grown on elevated planting beds to protect plant roots from saline water intrusion and prolonged waterlogging. Raised beds improve soil drainage, reduce direct salt accumulation around the root zone, and create more favorable growing conditions for vegetables and other salinity-sensitive crops. This technique has proven particularly useful in low-lying coastal areas where waterlogging and soil salinity are common constraints to agricultural production.

The use of groundwater for irrigation is the least adopted adaptation strategy, reported by only 2% of the respondents. The low adoption rate reflects the limited availability of suitable groundwater resources in the study area, as most groundwater sources are affected by high salinity levels and are therefore unsuitable for agricultural use. Consequently, farmers rely primarily on rainwater harvesting and surface water sources for irrigation. The limited use of groundwater highlights the severity of salinity intrusion and the challenges associated with freshwater availability in the coastal region. Similar findings were reported by Hossain et al. (2018), who found that, in addition to pond sand filters and rainwater harvesting systems, only a small proportion of households in the salinity-affected districts of Satkhira and Khulna used deep tube wells equipped with overhead storage tanks installed by local non-governmental organizations (NGOs). Their study reported that approximately 8% and 18% of respondents from severely and moderately water-scarce areas, respectively, relied on such groundwater-based water supply systems.

3.4.2 Types of livestock reared for salinity adaptation

The study findings indicate that farmers adopt different livestock-rearing practices as an adaptation strategy to cope with the adverse impacts of salinity intrusion. Among the various livestock species, indigenous (Deshi) cattle are the most commonly reared, accounting for 38.80% of the responses (Fig. 12). Poultry represents the second most common livestock category (19.30%), followed by ducks (15%), goats (13.8%), sheep (11.3%), and buffaloes (2%). The predominance of indigenous cattle reflects their importance as a source of household income, food security, draft power, and financial resilience. Farmers prefer indigenous cattle because they are comparatively more adaptable to local environmental conditions, require relatively low management inputs, and can tolerate climatic stresses better than some improved breeds.

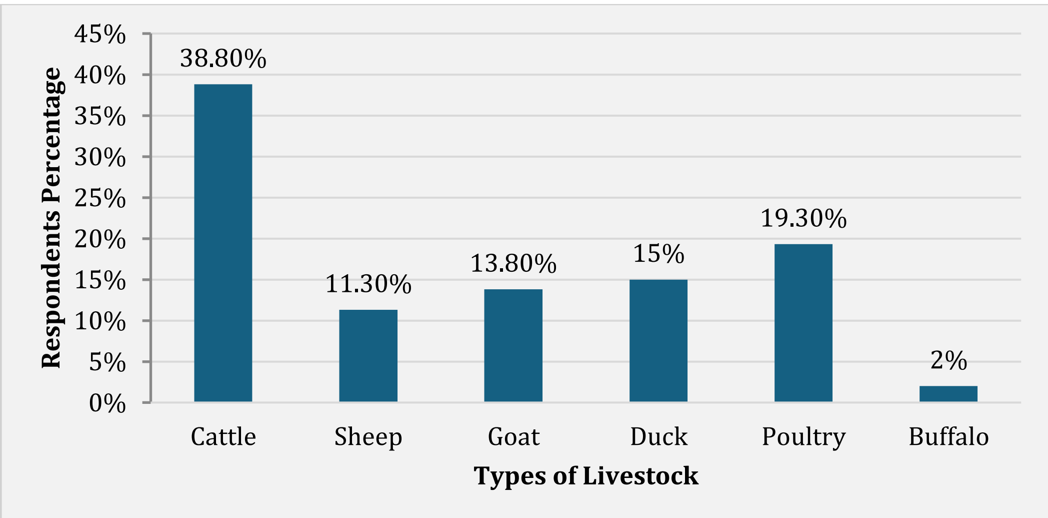

Fig. 12. Types of livestock reared as adaptation strategies to salinity intrusion

Poultry and ducks are also widely reared because they require less investment, have shorter production cycles, and provide a regular source of income and nutrition for rural households. Ducks, in particular, are well adapted to waterlogged and coastal environments and can utilize natural feed resources available in wetlands. Goats and sheep are reared on a smaller scale, primarily as supplementary income sources. However, their populations have declined in some areas due to fodder scarcity and increasing salinity-related challenges. Buffalo rearing remains limited because of higher management requirements and lower local preference. Overall, livestock diversification serves as an important adaptation strategy that helps households reduce their dependence on crop production and strengthen their resilience to salinity-induced agricultural losses.

3.4.3 Fish culture for salinity adaptation

The study reveals that farmers have increasingly adapted their aquaculture practices in response to rising salinity levels. Shrimp farming is the most common aquaculture adaptation strategy, accounting for 40.7% of the responses (Fig. 13). This is followed by carp culture (23.2%), tilapia farming (21.5%), pangasius culture (8.6%), and crab farming (6%). The dominance of shrimp farming reflects its high tolerance to saline conditions and strong market demand. Shrimp cultivation provides higher economic returns compared to many traditional freshwater fish species and has therefore become an attractive livelihood option for coastal farmers facing increasing salinity intrusion. Tilapia and certain carp species are also cultivated because of their relatively greater tolerance to varying water quality conditions and their commercial value. Pangasius farming is practiced to a lesser extent due to its specific management requirements and comparatively lower adaptability to highly saline environments. Crab farming, although practiced by a smaller proportion of farmers, is gradually gaining popularity because crabs can thrive in brackish water conditions and offer high market prices. The expansion of crab and shrimp farming demonstrates the ongoing transition from traditional freshwater aquaculture to brackish-water-based production systems in response to changing environmental conditions. These findings suggest that farmers are increasingly selecting aquaculture species based on their salinity tolerance, economic profitability, and market potential. While such adaptations help sustain household income and livelihoods, the continued expansion of brackish-water aquaculture may also contribute to further salinization of surrounding agricultural lands and freshwater ecosystems if not managed sustainably.

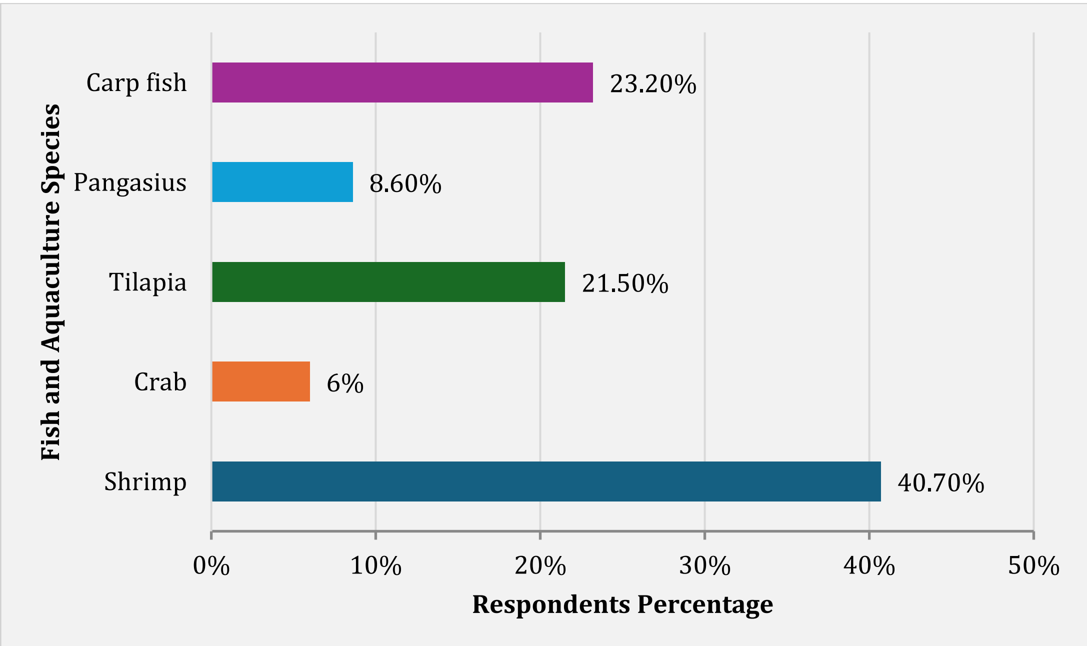

Fig. 13. Fish and aquaculture species cultured as adaptation strategies to salinity intrusion

3.4.4 Training on salinity adaptation and institutional assistance

The study findings indicate that access to salinity adaptation training remains limited in the study area. Approximately 66% of the respondents reported that they had not received any training related to salinity adaptation, while only 34% had participated in training programs. This suggests that a large proportion of farmers lack formal knowledge and technical skills necessary to effectively cope with increasing salinity intrusion. Among the institutions providing training and support, non-governmental organizations (NGOs) play the most significant role, accounting for 65% of the training initiatives. Government organizations contribute approximately 22% of the training activities, while the private sector accounts for the remaining 13%. The dominant role of NGOs highlights their importance in strengthening local adaptive capacity and promoting climate-resilient livelihood practices. Respondents reported receiving various forms of support from government agencies and NGOs, including microfinance services, cash transfers, subsidized agricultural inputs, and training programs. Among these, microfinance was identified as the most common form of assistance. Access to credit enables households to invest in agricultural adaptation measures, livestock rearing, small businesses, and other livelihood diversification activities.

Despite these interventions, most respondents expressed dissatisfaction with the level of support received. Approximately 61.5% of respondents reported that the available assistance was insufficient to meet their actual needs for adapting to salinity intrusion (Fig. 14). This finding indicates a significant gap between institutional support mechanisms and the practical requirements of vulnerable households. The results suggest that although government agencies and NGOs are contributing to adaptation efforts, greater investment in training, financial assistance, extension services, and climate-resilient infrastructure is necessary to enhance community resilience to increasing salinity intrusion.

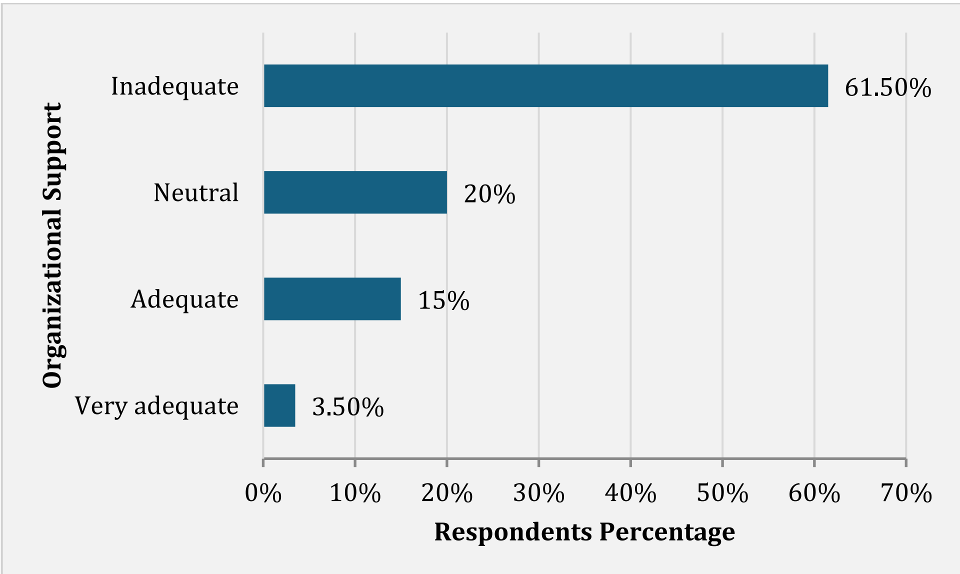

Fig. 14. Perceived adequacy of support received from government and non-governmental organizations

3.4.5 Livelihood diversification and migration patterns

Livelihood diversification has emerged as an important adaptation strategy among households affected by salinity intrusion. The study found that most respondents engage in multiple income-generating activities to reduce their dependence on agriculture and minimize livelihood risks associated with environmental changes. Common alternative livelihood activities include livestock rearing, fish catching and aquaculture, crop cultivation, wage labor, small-scale businesses, poultry farming, and other informal economic activities. These diversified livelihood strategies help households maintain income stability and improve their capacity to cope with agricultural losses caused by salinity intrusion.

The findings also reveal that temporary labor migration is a common adaptation strategy, particularly among male household members. Many individuals migrate seasonally or temporarily to nearby towns and cities in search of employment opportunities during periods when agricultural activities are limited due to salinity, water scarcity, or other climate-related constraints. Income earned through temporary migration contributes significantly to household livelihoods and supports adaptation efforts. However, permanent migration is relatively uncommon among the respondents. Most households prefer to remain in their communities despite increasing environmental challenges. Strong social ties, attachment to ancestral land, cultural identity, and dependence on local natural resources discourage permanent relocation. Instead, households tend to adopt local adaptation measures and temporary migration strategies while maintaining their residence in the study area. These findings suggest that livelihood diversification and temporary migration play a crucial role in enhancing household resilience and reducing vulnerability to the adverse impacts of salinity intrusion in coastal Bangladesh.

3.4.6 Major barriers to adaptation

The study identified several barriers that limit the effective implementation of adaptation measures against salinity intrusion in the study area (Fig. 15). Among these, the lack of knowledge and training was identified as the most significant constraint, accounting for 28% of the responses. This finding suggests that many farmers lack adequate technical knowledge, information, and practical skills to adopt and implement appropriate adaptation strategies. Limited access to agricultural extension services and climate-related training further restricts farmers' capacity to respond effectively to increasing salinity stress. Political barriers emerged as the second most important constraint, reported by 25% of the respondents. According to local communities, some influential political actors occupy government-owned (khash) canals and use them for shrimp cultivation. In addition, the management and operation of sluice gates are often influenced by local power structures. Due to their political influence and social connections, community members frequently face difficulties in challenging these practices.

As a consequence, the natural flow of water is disrupted, particularly during the monsoon season. Obstructed drainage systems contribute to waterlogging, canal and river siltation, and alterations in local hydrological processes. These conditions ultimately intensify salinity intrusion and reduce agricultural productivity. Therefore, political influence over water resources and infrastructure has become a significant institutional barrier to effective adaptation and sustainable agricultural development in the study area. Financial constraints were identified as the third major barrier, accounting for 20% of the responses. Many farmers lack sufficient financial resources to invest in adaptation measures such as salt-tolerant crop varieties, irrigation facilities, soil amendments, improved drainage systems, and alternative livelihood activities. Limited access to affordable credit further exacerbates this challenge.

Lack of access to agricultural inputs was reported by 15% of the respondents. The unavailability or high cost of essential resources, including salt-tolerant seeds, fertilizers, pesticides, and farming equipment, restricts farmers' ability to adopt effective adaptation practices. Consequently, agricultural productivity and resilience remain constrained under increasing salinity conditions. Land tenure insecurity was reported by 12% of the respondents as another important barrier. Uncertain land ownership and tenancy arrangements discourage farmers from making long-term investments in land improvement and adaptation measures. Farmers cultivating leased or shared land are often reluctant to invest in costly adaptation practices because they may not receive long-term benefits from such investments.

The findings are consistent with previous studies conducted in coastal Bangladesh. Rabbani et al. (2018) reported that approximately 77% of respondents had not received any training on climate-resilient agricultural practices, highlighting substantial gaps in adaptation support and capacity-building initiatives. Similarly, Hossain et al. (2018) found that while local communities increasingly adopted shrimp farming and polder-based management systems as adaptation measures, these interventions often contributed to unintended consequences, including riverbed siltation, prolonged waterlogging, and intensified salinization. Overall, the results indicate that adaptation to salinity intrusion is constrained not only by environmental factors but also by socio-economic, institutional, political, and governance-related challenges. Addressing these barriers through improved training programs, stronger institutional support, equitable water resource management, access to financial services, and secure land tenure arrangements is essential for enhancing the adaptive capacity and resilience of coastal farming communities.

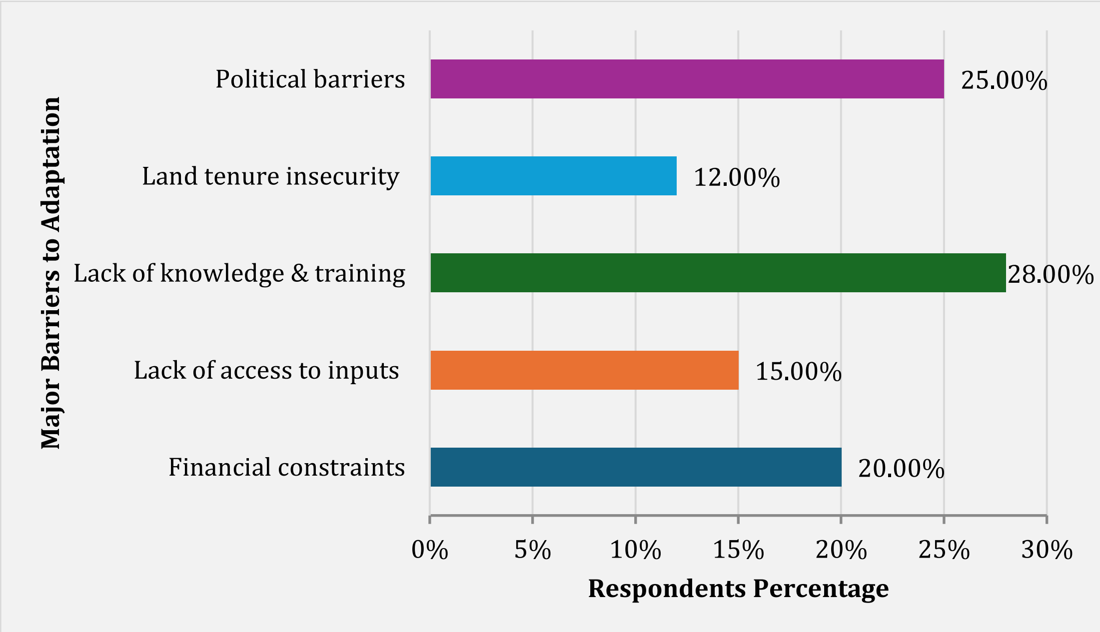

Fig. 15. Major barriers to adaptation among farming households in the study area

3.4.7 Priority needs from government and ngos for coping with salinity intrusion

Respondents were asked an open-ended question regarding the types of support they consider most important for coping with salinity intrusion. Their responses revealed five key priority needs that could strengthen local adaptive capacity and reduce vulnerability to salinity-related impacts: access to rainwater harvesting systems for domestic and agricultural use, riverbank repair and protection measures, provision of salt-tolerant crop varieties, improvement of drainage systems, and training and education on salinity adaptation measures.

These priorities reflect the urgent need for both structural and non-structural interventions to address the growing challenges associated with salinity intrusion. Respondents emphasized that improved access to freshwater is essential for sustaining agricultural production, livestock rearing, and household water security. Similarly, strengthening riverbanks and improving drainage infrastructure were considered necessary to reduce saline water intrusion, waterlogging, and land degradation. The demand for salt-tolerant crop varieties and adaptation training highlights the importance of enhancing farmers' technical capacity and access to climate-resilient agricultural technologies. Farmers indicated that practical knowledge and improved crop varieties would enable them to better cope with changing environmental conditions and maintain agricultural productivity. These findings are consistent with previous studies conducted in coastal Bangladesh. Hossain et al. (2018) recommended several adaptation pathways, including proper land-use zoning, managed aquifer recharge, and tidal river management, to address salinity-related challenges. This study emphasized that local adaptation measures are interconnected and that integrated implementation of multiple adaptation strategies is likely to produce more effective and sustainable outcomes.

Similarly, Rahman et al. (2020) highlighted the positive impacts of agricultural training on farmers' productivity and income. Using a treatment-effect model, the study found that trained farmers achieved approximately 22% higher productivity compared with non-trained farmers. Participation in training programs was influenced by factors such as age, education level, household wealth, and involvement in agricultural extension activities. These findings underscore the importance of expanding training and capacity-building programs to strengthen community resilience against salinity intrusion.

3.4.8 Implications for disaster preparedness, climate resilience, and integrated coastal management

The findings of this study have important implications for disaster preparedness and climate resilience in the coastal region of Bangladesh. Salinity intrusion is not only an environmental problem but also a slow-onset climate-induced disaster that interacts with cyclones, storm surges, tidal flooding, riverbank erosion, and reduced freshwater availability. These multiple hazards collectively threaten agricultural production, food security, freshwater resources, and rural livelihoods. Therefore, adaptation planning should adopt a multi-hazard disaster risk reduction approach rather than addressing salinity intrusion as an isolated environmental issue.

The study also demonstrates that local farmers have adopted several autonomous adaptation measures, including salt-tolerant crop varieties, rainwater harvesting, crop calendar adjustment, soil amendments, and livelihood diversification. While these practices have helped reduce vulnerability, their effectiveness remains constrained by limited institutional support, inadequate technical knowledge, financial barriers, and governance-related challenges. These findings are consistent with previous studies (e.g., Rabbani et al., 2013; Hossain et al., 2018), which reported that successful adaptation in coastal Bangladesh depends not only on technological innovations but also on strengthening extension services, institutional coordination, and community capacity-building. Compared with previous studies, this research provides a more integrated assessment by simultaneously examining the causes of salinity intrusion, its impacts on crop production, livestock, fisheries, and farmers' adaptation practices within a single coastal community. The findings indicate that although adaptation measures are increasingly practiced, they remain largely reactive and household-based, suggesting the need for stronger institutional interventions and long-term adaptation planning.

The study further highlights the importance of integrated coastal management. Sustainable management of rivers, canals, embankments, sluice gates, and freshwater resources should be coordinated across sectors to reduce salinity intrusion and improve agricultural resilience. Community participation, improved drainage systems, tidal river management, riverbank protection, and ecosystem-based approaches such as mangrove conservation should be incorporated into coastal development policies. Such integrated measures would strengthen disaster preparedness, reduce long-term climate risks, and enhance the resilience of coastal farming communities. Overall, the findings emphasize that effective adaptation to salinity intrusion requires coordinated actions involving government agencies, non-governmental organizations, researchers, and local communities. Strengthening climate-resilient agriculture, freshwater resource management, institutional governance, and disaster risk reduction strategies will be essential for achieving sustainable livelihoods in the salinity-prone coastal regions of Bangladesh.

3.5 Recommendations

Based on the findings of the study, several short-term and long-term measures are recommended to reduce the adverse impacts of salinity intrusion and enhance the resilience of farming communities in Baradal Union and other similar coastal areas of Bangladesh. These include expanding rainwater harvesting systems for both domestic consumption and agricultural irrigation to improve freshwater availability during the dry season, as well as implementing riverbank protection and rehabilitation measures to reduce riverbank erosion, prevent saline water intrusion, and protect agricultural land and settlements. It is also recommended to increase the availability and distribution of salt-tolerant crop varieties through government agricultural extension services and research institutions, and to improve drainage infrastructure by rehabilitating canals, maintaining sluice gates, and removing drainage obstructions to reduce waterlogging and salt accumulation in agricultural fields. In addition, training and awareness programs on salinity adaptation, climate-resilient agriculture, water management, and livelihood diversification should be strengthened to improve local adaptive capacity, alongside enhanced freshwater monitoring and water supply systems, particularly in areas adjacent to the Kholpetua River, where groundwater and surface water resources are severely affected by salinity. Institutional support from government agencies and NGOs should also be increased through microfinance programs, subsidized agricultural inputs, technical assistance, and community-based adaptation initiatives, while livestock adaptation measures—including the provision of safe drinking water, improved fodder production, veterinary services, and livestock health management programs—should be promoted. Furthermore, integrated water resource management practices, including tidal river management, canal restoration, and community-based water governance, should be strengthened to improve long-term water security and reduce salinity risks, and livelihood diversification opportunities should be supported through skill development, small enterprise promotion, and market access initiatives to reduce dependence on climate-sensitive agricultural activities.Implementation of these recommendations through coordinated efforts among government agencies, non-governmental organizations, research institutions, and local communities would significantly enhance resilience to salinity intrusion and contribute to sustainable agricultural development and livelihood security in coastal Bangladesh.

4. Conclusions

The coastal region of Bangladesh is highly vulnerable to salinity intrusion due to its low-lying geographical setting, proximity to the Bay of Bengal, and frequent exposure to climate-induced hazards. This study assessed the causes and impacts of salinity intrusion on crop production, livestock rearing, fisheries, and local livelihoods in Baradal Union of Assasuni Upazila, Satkhira District, and examined the adaptation strategies adopted by local communities. The findings reveal that the Kholpetua River is one of the principal drivers of salinity intrusion in the study area, as it carries saline water throughout the year. Riverbank erosion, tidal flooding, storm surges, poor drainage, and recurrent cyclonic events further exacerbate salinity levels in soil and water resources. As a result, salinity intrusion has emerged as a major environmental and socio-economic challenge affecting agricultural productivity, livestock production, fisheries, freshwater availability, and household income.

The study found that crop production is severely constrained by increasing soil salinity, declining soil fertility, soil hardening, and limited access to freshwater for irrigation. Fruit and vegetable crops were identified as the most vulnerable to salinity stress, while large areas of agricultural land remain fallow during the dry season due to unfavorable growing conditions. In the fisheries sector, increasing salinity has contributed to the decline of native freshwater fish species such as shing, chang, and koi, resulting in reduced fish diversity and changes in aquatic ecosystems. Livestock production has also been adversely affected by freshwater scarcity, fodder shortages, and increased disease prevalence. These challenges have particularly affected sheep and goat populations, leading to reduced livestock ownership and income among farming households. Despite these challenges, local communities have adopted a range of adaptation strategies to cope with salinity intrusion. In crop production, farmers are increasingly cultivating salt-tolerant crop varieties, adjusting cropping calendars, practicing rainwater harvesting, applying chemical and organic soil amendments, using mulching techniques, and adopting raised-bed cultivation methods. In the livestock sector, households predominantly rear indigenous cattle and poultry because of their economic importance and adaptability to local conditions. In aquaculture, shrimp farming has become the dominant adaptation strategy, while tilapia and crab cultivation are also expanding due to their tolerance to saline environments and favorable market demand. However, the effectiveness of these adaptation measures is constrained by several factors, including inadequate institutional support, limited access to training and technical knowledge, financial constraints, insufficient agricultural inputs, and political barriers related to water resource management.

These challenges reduce the adaptive capacity of local communities and hinder the long-term sustainability of adaptation efforts. Therefore, strengthening resilience to salinity intrusion requires integrated and long-term interventions. Priority actions should include improving freshwater management systems, expanding rainwater harvesting facilities, rehabilitating riverbanks and drainage infrastructure, promoting salt-tolerant crop varieties, enhancing agricultural extension and training services, and increasing institutional support from government agencies and non-governmental organizations. Effective collaboration among policymakers, development organizations, researchers, and local communities is essential for implementing sustainable adaptation strategies and ensuring livelihood security in coastal regions. The findings of this study provide location-specific evidence that provide valuable insights for farmers, government agencies, non-governmental organizations, policymakers, and researchers working in salinity-prone coastal areas. The results contribute to a better understanding of the impacts of salinity intrusion and offer practical guidance for designing evidence-based adaptation strategies and policy interventions aimed at enhancing agricultural sustainability and community resilience in coastal Bangladesh.

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Author Contribution

S.P.B., conceptualization, data curation, formal analysis, methodology, resources, software, validation, visualization, writing-original draft, writing-review & editing; M.F., conceptualization, formal analysis, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing-review & editing; P.R.H., conceptualization, methodology, writing-review & editing.

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The authors declare no conflict of interest.

Declaration of Generative AI Use

During the preparation of this work, the authors used ChatGPT and Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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